University of Sassari
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Via Muroni 25, I-07100 Sassari, Italy

Dissertation for the Degree of Doctor of Philosophy in Environmental Biology presented at Sassari University in 2013

XXV cycle

PELAGIC CETACEANS OFF NORTH-EASTERN SARDINIA AND IMPLICATIONS FOR CONSERVATION

PH.D. CANDIDATE: ***Dr. Luca Bittau***

DIRECTOR OF THE SCHOOL: ***Prof. Marco Curini Galletti***

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SUMMARY

[ENGLISH] The all-year-round knowledge on cetaceans off Sardinia is scarce and mostly focused on the coastal species *Tursiops truncatus* in the northern waters of the island. This work aims to increase information on pelagic cetaceans in the poor studied off-shore waters from North-Eastern Sardinian coast on the basis of surveys carried out between 2010 and 2013, using dedicated and opportunistic surveys.

First I evaluate the occurrence of pelagic cetacean species, the spatial-temporal distribution and the interactions with fixed physical variables (depth, slope and shape), non-fixed environmental variables (Sea Surface Temperature and chlorophyll *a*) which may affect their presence and distribution in the study area. The relative abundance of the cetacean species regularly inhabiting the area and the high encounter rate values, point out the significance of the Caprera Canyon for the cetaceans' conservation, in the central Tyrrhenian Sea. Therefore I analyzed the occurrence and seasonal distribution of *Balaenoptera physalus* the only Mysticete in Mediterranean Sea, in relation with oceanographic variables as Sea Surface temperature and chlorophyll *a*. The high seasonal presence of fin whale off north-eastern Sardinia reflects a yearly pattern and is linked to a mix of variables such as the bottom features, water circulations as proxy of prey availability.

Moreover, I analyzed the sightings of three social units of *Physeter macrocephalus* recorded during summer 2010 and 2013. The encounter rates of this species in the entire study period were low. Despite this I recorded three encounters with sperm whale pods that highlighted the periodic use of the Caprera Canyon by these large cetaceans. The social units were composed of several individuals such as females, calves and probably young males. Finally I present the first documented records of a free-ranging Sowerby's beaked whale (*Mesoplodon bidens*) in the Mediterranean Sea. This rare and elusive cetacean was sighted together with three Cuvier's beaked whales in a mixed species group. Scarring observed on the whale's flanks may result from interspecific interaction with males of Cuvier's beaked whales. Nevertheless, all the gathered data suggest that the mesoplodont in the Tyrrhenian Sea could be considered as a stray.

KEY WORDS: biodiversity, pelagic cetaceans, Central Tyrrhenian Sea, Sardinia, Caprera Canyon.

RIASSUNTO

[ITALIAN] Le conoscenze estese a tutto l'arco dell'anno sulla fauna a cetacei al largo delle coste della Sardegna sono scarse e si sono focalizzate fino ad ora soprattutto sulle specie costiere. Questo lavoro si propone di incrementare le conoscenze sui cetacei pelagici nelle acque *off-shore* della costa nord-orientale della Sardegna.

Inizialmente ho valutato la presenza/assenza di cetacei pelagici nell'area di studio nell'arco di tre anni, la distribuzione spazio-temporale e le interazioni con le variabili fisiche fisse (profondità, pendenza ed esposizione) e le variabili ambientali non fisse (temperatura superficiale del mare e clorofilla *a*) che possono influenzare la presenza/assenza e la distribuzione geografica. L'abbondanza relativa delle specie di cetacei che frequentano regolarmente la zona, sottolineano l'importanza del Canyon Caprera per la conservazione dei cetacei nel Mar Tirreno centrale. Successivamente ho analizzato la presenza/assenza e la distribuzione geografica stagionale di *Balaenoptera physalus* l'unico misticete regolarmente avvistato nel Mar Mediterraneo, in relazione con le variabili oceanografiche come temperatura superficiale del mare e clorofilla *a*. L'elevata presenza stagionale di balenottera comune al largo della Sardegna nord-orientale riflette un modello annuale ed è legata a un insieme di variabili fisiche e oceanografiche quali, per esempio, fattori trofici in relazione alla disponibilità di risorse alimentari. Inoltre, ho analizzato gli avvistamenti di tre 'unità sociali' (*social unit*) di *Physeter macrocephalus* avvistate durante l'estate degli anni 2010 e 2013. I tassi di avvistamento di capodoglio in tutto il periodo di studio sono stati bassi. Nonostante questo ho registrato tre incontri con gruppi sociali di questa specie che hanno evidenziato l' uso periodico del Canyon di Caprera da parte di questi grandi cetacei. Le *social unit* erano composte da diversi individui, come femmine, piccoli e probabili giovani maschi. Infine ho documentato il primo avvistamento di un mesoplodonte di Sowerby (*Mesoplodon bidens*) in ambiente libero nel Mar Mediterraneo. Il raro cetaceo è stato avvistato insieme a tre zifi in un gruppo misto. Le cicatrici osservate sul corpo del mesoplodonte possono essere attribuite a un'interazione interspecifica con maschi di zifio. Tuttavia, al momento tutti i dati raccolti suggeriscono che il mesoplodonte nel Mar Tirreno potrebbe essere considerato come un avvistamento occasionale.

PAROLE CHIAVE: biodiversità, cetacei pelagici, Mar Tirreno Centrale, Sardegna, Canyon di Caprera

INTRODUCTION

This thesis consists of three main parts dealing with presence/absence, geographic distribution and behaviour of pelagic cetacean species off the North-eastern Sardinia Island. In the First Part I evaluate the influence of environmental conditions on the occurrence of pelagic cetaceans around the Caprera Canyon area, in relation to time, space and environmental covariates. Focus on fin whales was treated separately, to deepen any temporal discontinuity of their presence in the study area and relation to environmental covariates. In the Second Part I analyze the presence of rare, cryptic and inconspicuous species as in the case of the Sowerby's beaked whale, recorded in a mixed species group and representing the first live record in the Mediterranean Sea. Finally, in the Third Part, I report the occurrence and behaviour of sperm whale social units off North-eastern Sardinia, a poor studied area for both toothed and baleen whales.

The rich and unique biodiversity of the Mediterranean Sea has led to its recognition as one of the most important biodiversity hotspots on a global scale (Medail & Quezel, 1999; Myers *et al*., 2000; IUCN, 2012). Despite its oligotrophy, a combination of different environments, sea bottoms and oceanographic features, supports high values of abundance and diversity of marine wildlife including cetaceans, which live in and migrate through the different basins.

Of the ca. eighty-seven living species of cetaceans, infraorder Cetacea (14 species of baleen whales, Mysticeti Flower, 1864 and 73 species of toothed whales, dolphins and porpoises, Odontoceti Flower, 1867) (www.marinemammalscience.org - 2013) nineteen have been recorded in the Mediterranean Sea, none of which is endemic. Eight species are common in the Western Mediterranean Sea, four are only occasional, that is not regularly present, and seven are accidental, rarely entering the Mediterranean basin.

Among the eight regular species occurring in the Western Mediterranean, seven are odontocetes: common bottlenose dolphin *Tursiops truncatus* (Montagu, 1821); striped dolphin *Stenella coeruleoalba* (Meyen, 1833); short beaked common dolphin *Delphinus delphis* Linnaeus, 1758, long-finned pilot whale *Globicephala melas* (Traill, 1809); Risso's dolphin *Grampus griseus* (G. Cuvier, 1812); Cuvier's beaked whale *Ziphius cavirostris* Cuvier, 1823; sperm whale *Physeter macrocephalus* Linnaeus, 1758, and a single species of mysticetes: the fin whale *Balaenoptera physalus* (Linnaeus, 1758).

Other two cetacean species, the rough-toothed dolphin *Steno bredanensis* (G. Cuvier in Lesson, 1828) and the false killer whale *Pseudorca crassidens* (Owen, 1846), were formerly considered visitors of the Mediterranean. At present, stable small resident populations that are not transient visitors have been tentatively recognized for both species in the Eastern Mediterranean (Levantine Basin) as a result of frequent sightings and strandings in this area (Boisseau *et al*., 2010; IUCN, 2012; Kerem *et al.*, 2012). It is clear that new, further investigations will be needed to draw a more accurate assessment on the occurrence of these two species. In the 1980s cetacean researchers were surprised to find populations of several species of whales and dolphins living in the Mediterranean Sea close to tourist/industrial hot spots along the Spanish, French and Italian coasts and the Greek Islands, even though busy shipping traffic, pollution problems and exotic marine species (Hoyt, 2005).

Despite the Western Liguria was called in Roman times *Costa Ballaenae*, the 'Coast of whales' (Orsi Relini *et al*., 1992), such ancient cultural heritage became lost for centuries, and until very recently the large whales were considered rare and accidental in the Mediterranean even by esteemed marine zoologists (Tortonese, 1965). Since the early 90s, studies on cetacean populations in the western basin revealed the importance of the Corso-Ligurian Basin as one of the pelagic areas with highest cetacean densities in the entire Mediterranean Sea (Notarbartolo di Sciara *et al*., 1993; Forcada *et al*., 1995).

The Corsican–Ligurian–Provencal basin and particularly the Ligurian Sea are probably the most productive pelagic waters of the entire Mediterranean Sea. Interaction of climatic, oceanographic and physiographic factors enables these areas to support high levels of primary productivity, and to harbour a richer cetacean fauna than neighbouring marine regions (Notarbartolo di Sciara et al., 1993).

The relevant primary productivity in the Corsican-Ligurian Basin is due to the presence of a permanent frontal system, and resulting upwelling of deep, nutrient-rich waters, unlike most of the Mediterranean pelagic waters. The large biomass of the Mediterranean euphausiid, *Meganyctiphanes norvegica* (M. Sars, 1857) together with cephalopods and fishes, supports the occurrence of eight species of cetaceans including fin, sperm, Cuvier's beaked, long-finned pilot whales, striped, Risso's, bottlenose, and shortbeaked common dolphins. The Mediterranean habitats of these pelagic cetaceans lie largely in international waters (Ardron *et al*., 2008; Notarbartolo di Sciara *et al*., 2008). The largest cetacean species occurring in the Mediterranean, the fin whale *B. Physalus,* congregate in the Ligurian Sea in high densities during summer, which is known to be the species' feeding season. Thus the fin whales summering in this area are strongly correlated with prey availability (Orsi Relini *et al.*, 1992, 1994; Relini *et al.*, 1994), moreover food availability is probably the main key factor of space use by marine mammals (e.g. Benoit-Bird & Au 2003; Friedlaender *et al*., 2006).

Towards the establishment of a Sanctuary for the protection of Mediterranean marine mammals

Based on the significant presence of cetacean species in the Corsica and Ligurian seas, France, Italy and Monaco agreed to establish in 1999 an International Sanctuary for the Protection of Mediterranean Marine Mammals also known as the "Pelagos Sanctuary", the largest Mediterranean Marine Protected Area and the world's first international high-sea MPA (Marine Protected Area). It was established as a sanctuary for marine mammals to manage the negative impacts of human activities and to protect marine mammals against all causes of disturbances and threats (Adron *et al.*, 2008; Notarbartolo di Sciara *et al*., 2008). In fact, this faunal diversity coexists with very high levels of human pressure since ancient times, resulting from various human activities causing actual and potential threats to cetacean populations.

The Pelagos Sanctuary was established on 25 November 1999, covering areas of the Mediterranean seas of France, Italy, and the Principality of Monaco (Notarbartolo di Sciara *et al.*, 2008; Hoyt, 2009).

The Sanctuary encompasses an area of 33,772 square miles (87.492 km^2) between Southeastern France, Monaco, Northwestern Italy, Northern Sardinia, and surrounding Corsica and the Tuscan Archipelago, also including a strait, the Strait of Bonifacio between the islands of Corsica and Sardinia. With a coastline of over 2,000 linear km, more than 270 km belong to the North of Sardinia coastline, where two National Parks there are: the Asinara and The La Maddalena Archipelago national Parks. In 2001, the high seas agreement was listed under the Barcelona Convention, making Pelagos a Special Protected Area of Mediterranean Importance (SPAMI) which confers the official protection of all signatory

Mediterranean countries in both national waters and on the high seas (Hoyt, 2005; Notarbartolo di Sciara *et al*., 2008). Although the Pelagos Sanctuary agreement came into force in 2002 ratified by all three member states, it came up to speed and to function as a valuable conservation tool up to 2013. However eleven years after ratification the effective conservation measures are still few. Especially within the Pelagos Sanctuary area dedicated visual and acoustic research cruises from ship-based transects grew mostly in the Corsican-Ligurian-Provençal basin, focusing more extensive studies in the Ligurian Sea than in other sectors of the Western Mediterranean (e.g. Notarbartolo di Sciara *et al*., 2003, 2008; Moulins & Wurtz, 2005; Panigada *et al*., 2005, 2008; Laran & Drouout-Dulau, 2007), reinforcing the preliminary studies carried out before the establishment of the Sanctuary (e.g. Relini *et al.,* 1992; Orsi Relini & Giordano, 1992; Notarbartolo di Sciara, 1994a; Orsi Relini *et al*., 1994; Forcada *et al.*, 1995; Forcada *et al.*, 1996; Gordon *et al.*, 2000). Despite the notable research effort only a few studies were carried out on a larger scale (e.g. Notarbartolo di Sciara *et al*., 1993).

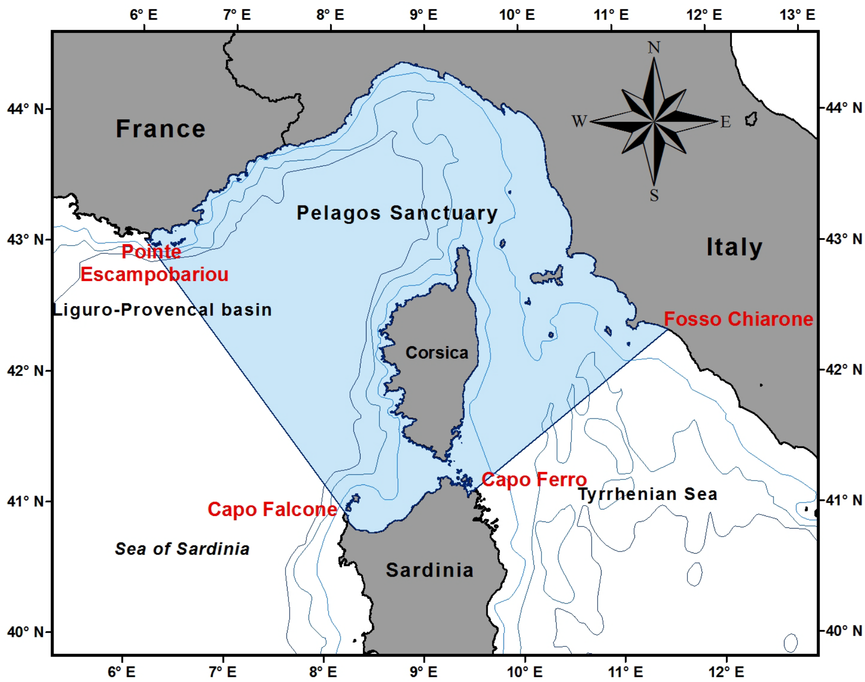

Fig. 1 The Pelagos Sanctuary area. Sardinia has more than 270 km of coastline within the area of the Sanctuary

Cetacean threats and conservation in the Mediterranean Sea

The Mediterranean cetacean subpopulations must cohabit with very high levels of human pressure. About this, the Pelagos Sanctuary area is characterized, as well as the highest density of cetaceans, by the highest risk of collision of the entire Western Mediterranean basin (Panigada *et al.*, 2006).

The coastal areas bordering on the Sanctuary are greatly populated and disseminated with urban, industrial and military settlements as well as commercial and tourist ports. These latter add a pressure load in the summer months of the tourist season, due to important tourist destinations (Notarbartolo di Sciara *et al.*, 2008).

As a consequence, a range of human activities in the Sanctuary area causes several real and possible threats to cetacean populations, such as habitat degradation, regression and destruction caused by urban, tourist, industrial, and agricultural development, also associated with pollution close to the larger ports and river mouths. High disturbance can be due to the intense maritime traffic (e.g. from passenger, cargo, fishing and pleasure vessels), particularly in summer, as well as to unregulated whale watching industry, military exercises and seismic oil and gas prospection. A growing risk of collision with vessels, also related with the increase of high-speed passenger transportation can cause mortality as well as the accidental entanglement in pelagic driftnets, which continue to be used in the area in spite of a ban on driftnetting imposed on fleets of European member states (Notarbartolo di Sciara *et al.*, 2008).

Recent studies pointed out that the Sanctuary, the Gulf of Lions and the adjacent waters are high-risk areas for fin whale collisions. In the western Mediterranean, the Pelagos Sanctuary waters are also among the busiest of the entire Mediterranean basin. As a consequence, the fatal collision mortality rate for *B. physalus* here is three times higher than for the whole western basin (Panigada *et al.,* 2006).

The 82.2% of collisions between whales and ships is within the Pelagos Sanctuary boundaries, 6.7% in the Tyrrhenian Sea, and 11.1% in the Alboran Sea/Balearic basin and the Sardinian Sea (Panigada *et al.*, 2006). The presence in the North-eastern Sardinia of two busiest Tyrrhenian commercial ports (Olbia and Golfo Aranci) and several tourist harbours generates an intense commercial, cargo and recreational maritime traffic that intensify in the summer, due to the high tourist appeal of the Sardinia and Corsica islands and their archipelagos, making this area one of the busiest of the entire Western Mediterranean. The intensity of maritime traffic carries the risk of collisions with large cetaceans or may cause abandoning of habitat as a result of disruption caused by human activities.

Pollution can cause severe threat to the health of marine ecosystems and cetaceans in particular, as they represent 'top predator' affected by bioaccumulation and biomagnification of toxic elements. For example, striped dolphins in the Pelagos Sanctuary are subject to greater toxicological stress than other Mediterranean cetacean populations. Particular concerns arise from the evidence that 50% of the striped dolphins from the Pelagos Sanctuary were classified in the high toxicological hazard group (Fossi *et al.,* 2013). Aguilar *et al.* (2002) and Marsili *et al.* (2004) detected ecotoxicological gender differences: 70.6% of females striped dolphins were classified in the low toxicological risk group and 32% and 44% of males were classified in the moderate and high groups, respectively, confirming that male cetaceans are subject to higher toxicological risk.

Fossi *et al*. (2013) clearly highlighted the effectiveness of MPAs describing the first evidence of toxicological stress in cetaceans living in the only Mediterranean pelagic MPA of the Mediterranean Sea: the Pelagos Sanctuary. Protecting Pelagos Sanctuary's marine biodiversity requires active management to prevent, control or eradicate environmental threats. This should include developing and delivering programs and activities that efficiently and effectively use available resources to achieve desired environmental outcomes. However, in the 13 years since its establishment Pelagos has partially failed to fulfill its goal of significantly improving the conservation status of the area's cetacean populations (Fossi *et al.*, 2013).

Out of the Pelagos, an increasingly 'tight' boundary for the cetacean conservation in the Mediterranean Sea, recently Italy established an Ecological Protection Zone (EPZ) in its Tyrrhenian, Ligurian and Sardinian waters (D.P.R. 209/2011). This EPZ follows and joins the adjacent French EPZ, declared in 2004, allowing Italy to extend Italian (and EU) regulations to much larger areas under its sovereignty and enforcing the measures so far, applicable only in Italian territorial waters. Among the primary objectives of the new established EPZ, there is the protection of marine biodiversity and ecosystems with a specific reference to marine mammals. The first significant consequence for cetacean conservation is that most marine waters of the Pelagos Sanctuary now lie within the jurisdiction of either France or Italy, extending their jurisdiction beyond their strict territorial waters as provided by UNCLOS - the

United Nations Convention on the Law of the Sea (Hoyt, 2005). This will greatly facilitate the implementation of management measures in the Sanctuary, which are so important for many of the region's cetacean populations, removing a psychological barrier that until now has prevented from considering Pelagos a "real" MPA (www.ciesm.org; www.accobams.org).

Many cetacean species, including sperm, beaked, other toothed whales and large baleen whales spend part or even most of their life cycles in pelagic waters, off the continental shelves and far from the coasts. Large areas of their critical habitats may be in the 50% of the world ocean classed as international waters, or high seas, outside the limits declared by most countries under the UNCLOS Convention (Hoyt, 2009). In such areas, where no single state or authority has the power to establish MPAs, adopt management schemes, or enforce compliance, new strategies must be designed to protect and manage high seas habitats (Thiel & Koslow, 2001; Hoyt, 2009).

In this study, I highlighted how research on marine mammals in areas outside the already established Marine Protected Areas, often poor or unknown, are critical for the conservation and management of cetacean populations in the Mediterranean Sea.

Fig. 2 A fin whale enjuried from a medium-size propeller, photographed in summer 2011, during t**he field work** carried out for this PhD thesis. Fatal ship strikes are the higher threat for large cetaceans.

Cetacean subpopulations in the Mediterranean Sea and conservation

The knowledge of pelagic cetaceans' eco-ethology at the Mediterranean sub-population level is scarce and at present both short- and long-distance movements of individuals/groups are poorly known within the entire basin, and among sub-basins. Although the IUCN (International Union for the Conservation of Nature) Red List assessment of Mediterranean resident cetacean species classifies the conservation status as 'Data Deficient' for three sub-populations in the basin (*Z. cavirostris*, *G. griseus*, and *G. melas*) it is a general opinion that Mediterranean cetacean populations are at risk.

Despite eight cetacean species are considered as 'regular' in the Mediterranean Sea and their IUCN classification criteria varies from *Least Concern* to *Vulnerable*, the poor knowledge on the Mediterranean cetacean populations size led to lack of absolute abundance estimates and the impossibility of define the certain conservation status.

S. coeruleoalba is the most abundant cetacean throughout Mediterranean offshore waters (Aguilar, 2000) with an estimated summer population size of 20,000–30,000 individuals (Forcada *et al.*, 1995) within the area of the Corsican–Ligurian–Provencal basin. Fin whale and striped dolphin are even the two most abundant cetaceans in the Pelagos Sanctuary area and represent, respectively, 20% and 60% of all historical (1986–1989) summer-time cetacean sightings (Notarbartolo di Sciara, 1994). Presently, the striped dolphin in the Mediterranean Sea is classed as 'Vulnerable', under the IUCN criteria (Reeves & Notarbartolo di Sciara 2006; Notarbartolo di Sciara & Birkun, 2010) (Tab. 1). In the past, many striped dolphins were hunted for their meat, which was used as bait for shrimp traps and long lines. It was recently reported that in Italy striped dolphin meat trade continues illegally, despite the legal risks to sell meat of protected animals such as cetaceans, either by-catched or intentionally killed.

The striped dolphin is primarily threatened by habitat degradation caused by agricultural pesticides and antifoulants, water pollution and commercial fisheries (Aguilar & Gaspari, 2012 in www.iucnredlist.org). A disease outbreak in 1990–1992, caused by a morbillivirus, devastated a large proportion of the population, causing many deaths (IUCN, 2012). Starting from January 2013, preliminary studies on an unusual frequency of striped dolphin strandings along the Italian coasts of the Tyrrhenian Sea suggested an infectious agent. Now it is clear that the dramatic outbreak that occurred in the Tyrrhenian Sea striped dolphin population from January to April 2013 was again due to *Dolphin Morbillivirus* (DMV) which caused at least four epidemics in the Western Mediterranean during the last 20–25 years. These epidemics may dramatically impact the health and conservation of striped dolphins living in this area (Di Guardo & Mazzariol, 2013). Lethal cases of DMV infection has recently affected even two individuals of fin whale stranded along the Tyrrhenian coast of Italy (Di Guardo & Mazzariol, 2013).

Regarding *B. Physalus*, about 3,500 individuals are recorded in the western Mediterranean (Forcada *et al*., 1995) and a large proportion of these gather in the Corsican–Ligurian–Provencal basin in summer to feed on krill (Forcada *et al*., 1996), although they can be observed in this area all the year round (Notarbartolo di Sciara *et al*., 2003). Recently the estimate of the fin whale in the western Mediterranean needs to be revised downward, due to the presence of occasional immigrant whales from the Eastern North Atlantic Ocean into the Western Mediterranean (Castellote *et al.*, 2011). Currently, the fin whale is classed as 'Vulnerable' at the Mediterranean basin level (Tab. 1). The biggest threats to fin whales are disturbance by ship, including the increasing use of high-speed ferries, recreational vessels and by seismic airguns. The high-speed ferries are not yet sufficiently investigated. For example, the latest passenger ships connecting Sardinia to the Italian mainland, can reach speeds close to 30 knots, crossing the Pelagos Sanctuary area and the study area that I investigated in this study. Human-induced mortality of fin whale is due to vessel collisions and by-catch in fishing gear (Panigada *et al*., 2006). Panigada *et al*. (2006) made a review of the known collision events that affected fin whales: many whales have been brought into the port on the ship's bow and several occurred in Sardinia (Olbia, Golfo Aranci and Porto Torres).

Fossi & Marsili (2003) and Fossi *et al*. (2004a, 2012) described high levels of contamination by organochlorines, trace elements and DDT metabolite values in Mediterranean fin whales and suggested that their estrogenic and anti-androgenic effects may negatively influence the population.

The six other cetacean species are a regular component of the Pelagos Sanctuary cetacean fauna (Notarbartolo di Sciara *et al*., 2008). Deep-diving squid-eating odontocetes such as sperm whales, long-finned pilot whales and Risso's dolphins, occur both offshore and continental slope waters (Di Meglio *et al.*, 1999; Gordon *et al*., 2000; Bearzi *et al.*, 2010). Cuvier's beaked whales show habitat preference for continental slopes (Cañadas *et al.*, 2002;

Moulins *et al.,* 2007). The now rare and endangered short-beaked common dolphins prefer both coastal and offshore waters mostly in the southern sector of the Pelagos Sanctuary (Bearzi *et al.,* 2003). Bottlenose dolphins frequent mainly coastal habitats as the shelf areas surrounding Corsica, northern Sardinia, the Tuscan Archipelago and continental France (Bearzi *et al.*, 2009; Gnone *et al.*, 2011).

Despite being the most common species of dolphin in coastal habitat, there is no overall estimate of the Mediterranean population of *T. truncatus*. Little information exists on the geographic range, especially in the Levantine and Southern Mediterranean basins. The total Mediterranean population may be in the low 10,000s, based on observed densities in surveyed areas (Bearzi *et al.*, 2008). Further subpopulation structure exists and may require future assessments at a finer geographical scale (Bearzi *et al.*, 2012 in www.iucnredlist.org). An overall decline in the population seems likely, however, as in those regions where regular monitoring takes place, there has been a stable decrease in the areas where they are observed as well as reductions in their range and abundance (possibly by more than 30% since 1940) (IUCN, 2012).

The northern Adriatic Sea is the only Mediterranean area with quantitative historical information that can be used to infer population trends over time scales of more than two decades. There, common bottlenose dolphin numbers are considered to have declined by at least 50% over the last 50 years, initially as a consequence of deliberate killing by the fishing industry, followed by reduced food availability caused by overfishing and environmental degradation (Bearzi *et al.*, 2004; IUCN, 2012).

Intentional killing still continue, although less than in the past, as evidenced by episodes of bottlenose dolphins injured, killed or hit with harpoon for underwater fishing in August, 2013 both in Croatia (Olib island, the dolphin survived) and Sardinia (Archipelago of La Maddalena, the dolphin died due to the wound) (Fig. 1). In both areas studies on dolphins are regularly but recently performed while professional and sport fishing represent a long tradition. Coexistence between bottlenose dolphins and fisheries is still difficult, as evidenced by these few, known episodes.

Fig. 3 August 2013: a) Bottlenose dolphin harpooned and survived near the island of Olib in the Vir Sea (Croatia) (www.blue-world.org); b) bottlenose dolphin harpooned with a long Tahitian spear close to Razzoli Island, Archipelago di La Maddalena (Italy) (www.lamaddalenapark.it). The latter dolphin died due to the wound. Both cases have occurred within or in the vicinity of Marine Protected Areas.

For some other areas of the northern Mediterranean (e.g. in Italy and southern France) the available information is less precise but suggests similar decreasing trends (Blanco & González 1992; Borrell *et al*., 2007). Off southern Spain, where this species has been studied intensively, abundance estimates have shown variability but no trend since the early 1990s (Cañadas *et al.*, 2006).

Mediterranean common bottlenose dolphins are, at present, classed as 'Vulnerable' according to the IUCN Red List criteria (Bearzi *et al*., 2012 in www.iucnredlist.org). Since 2006, the year of this proposed classification, was based primarily on suspected population declines caused by (i) direct kills and extermination campaigns conducted until at least the early 1960s in portions of the basin and (ii) recent and ongoing incidental mortality in fishing gear (generally known as 'by-catch') (Bearzi *et al.*, 2008). The major threats that currently put the survival of the species at risk are the competition with commercial fisheries, by-catch in driftnets and water pollution causing the accumulation of toxins in their bodies from chemical pollution (Bearzi *et al.*, 2008; IUCN, 2012).

D.delphis, once a very common Mediterranean species, has declined by more than 50% in the past 30–45 years. Literature and osteological collections unambiguously confirm that common dolphins were widespread and abundant in large areas of the Mediterranean Sea until the late 1960s, and that their decline occurred relatively quickly (Bearzi *et al*. 2003). However, there is very limited information on population size and trends for this species and there is no basin-wide estimate of abundance for Common Dolphins at Mediterranean Sea level. The species is today relatively abundant in the Alboran Sea, off western Sardinia, in the Sicily Channel around Malta, in the eastern Ionian Sea, in the Aegean Sea, and off Israel

(Levantine basin); whereas it has apparently vanished from many areas including the Adriatic Sea, Balearic Sea, Provençal basin and Ligurian Sea and is scarce for the central Tyrrhenian Sea (Notarbartolo di Sciara *et al.*, 1993; IUCN, 2012). An estimate of 14,736 (CV=0.38; 95% CI=6,923) derived from line-transect ship surveys of the Alboràn Sea (1991-1992) with a density of 0.16 dolphins/km², but the low number of sightings not allowed estimates for this species elsewhere in the western Mediterranean (Forcada & Hammond, 1998).

As with many cetacean species, little is known about their presence in the waters along the North African coast. The species is currently listed as 'Endangered' in IUCN 2013 Red List (Bearzi, 2003 in www.iucnredlist.org).

The decline in numbers of Common Dolphins in the Mediterranean could be a consequence of prey depletion by commercial fisheries, by-catch in gillnets (drift gillnets), habitat degradation, noise pollution, environmental changes and high loads of pollutants, including accumulation of PCBs and heavy metals, which are thought to cause immune suppression, reproductive impairment and ultimately death (Bearzi, 2003 in www.iucnredlist.org).

No estimate of *P. macrocephalus* population size exists for the Mediterranean Sea. The total number of Mediterranean sperm whales in the whole Mediterranean basin amounts to only a few hundred individuals (Notarbartolo di Sciara *et al*., 2012, in www.iucnredlist.org). However, at least until the 1950s, there is evidence that sperm whales were once common in some Mediterranean areas, such as the Strait of Messina and the Aeolian Islands (coast of Sicily) where they could be seen in large groups of as many as 30 individuals, while nowadays such sightings are rare (IUCN, 2012).

Recently, the sperm whale classification was changed in 'Endangered', under the IUCN criteria (Reeves & Notarbartolo di Sciara, 2006; Notarbartolo di Sciara & Birkun, 2010). Over the last decade a considerable decline in the number of individuals in the region was pointed out by increasingly frequent reports of annual strandings (stranded, floating dead or entangled individuals) from France and Italy. Entanglement in fishing gear (especially swordfish drift gillnets and tuna driftnets), vessel strikes and disturbance by intense boat and ship traffic are the primary causes of the sperm whale endangered conservation status.

	FAMILY	SCIENTIFIC NAME	ITALIAN COMMON NAME	IUCN RED LIST CATEGORY AND CRITERIA						RELEVANT INTERNATIONAL AGREEMENTS FOR THE PROTECTION OF WILDLIFE IN THE MEDITERRANEAN AND BLACK SEAS**
				Global		**Mediterranean**		Black Sea		
				Category	Criteria	Category	Criteria	Category	Criteria	
PINNIPED	Phocidae	**Monachus monachus*	foca monaca	CR	A2abc; C2a(i); E	CR	A2abc; C2a(i); E			HD: II-IV / CMS: I-II/ BCCEW: II/ BARCOM: II / CITES: I
CETACEANS	Balaenopteridae	*Balaenoptera physalus*	balenottera comune	EN	A1d	VU	C2a(ii)			HD: IV / CMS: I-II / BCCEW: II / BARCOM: II / CITES: I
	Delphinidae	*Delphinus delphis*	delfino comune	LC		EN	A2abc			HD: IV / CMS: I-II / BCCEW: II / BARCOM: II / CITES: II
		**Delphinus delphis ponticus*	delfino comune del Mar Nero	VU	A2cde			VU	A2cde	HD: IV / CMS: II / BCCEW: II / BARCOM: II / CITES: II
		Globicephala melas	globicefalo	DD		DD				HD: IV / BCCEW: II / BARCOM: II / CITES: II
		Grampus griseus	grampo	LC		DD				HD: IV / CMS: II / BCCEW: II / BARCOM: II / CITES: II
		Stenella coeruleoalba	stenella striata	LC		VU	A2bcde			HD: IV / CMS: II / BCCEW: II / BARCOM: II / CITES: II
		Tursiops truncatus	tursiope	LC		VU	A2cde			HD: II-IV / CMS: II / BCCEW: II / BARCOM: II / CITES: II
		**Tursiops truncatus ponticus*	tursiope del Mar Nero	EN	A2cde			EN	A2cde	HD: II-IV / CMS: II / BCCEW: II / BARCOM: II / CITES: I-II
	Phocoenidae	**Phocoena phocoena relicta*	focena	EN	A1d+4cde			EN	A1d+4cde	HD: II-IV / CMS: II / BCCEW: II / BARCOM: II / CITES: II
	Physeteridae	*Physeter macrocephalus*	capodoglio	VU	A1d	EN	C2a(ii)			HD: IV / CMS: I-II / BCCEW: II-III / BARCOM: II / CITES: I
	Ziphiidae	*Ziphius cavirostris*	zifio	LC		DD	A2abc; C2a(i); E			HD: IV / BCCEW: II / BARCOM: II / CITES: I

Tab. 1 IUCN (International Union for Conservation of Nature) Conservation status and international agreements, concerning marine mammals of the Mediterranean and Black Seas. The IUCN Red List Criteria: EX: Extinct, EW: Extinct in the Wild, CR: Critically Endangered, EN: Endangered, VU: Vulnerable, NT: Near Threatened, LC: Least Concern, DD: Data Deficient, NE: Not Evaluated. Abbreviations **HD**: European Union Habitats Directive; **CMS**: Convention on the Conservation of Migratory species of Wild animals (Bonn Convention); **BCCEW**: Convention on the Conservation of European Wildlife and Natural Habitats (Bern Convention); **BARCOM**: Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean (Barcelona Convention); **CITES**: Convention on International Trade in Endangered Species of Wild Fauna and Flora (IUCN, 2012). * Species not evaluated at regional level, but whose regional category coincides with the global one (endemic species); ** Roman numerals indicate the Annexes/Appendices where the species are listed.

Study area: the central Tyrrhenian Sea

During the late 1980s the first research expeditions focusing on cetaceans in the Mediterranean revealed sighting rates of all species in western Ligurian and Corsican seas as four times the mean for the adjacent Tyrrhenian waters (sighting frequencies for all cetacean species combined: 27.05 vs. 7.01 sightings/h*100) (Notarbartolo di Sciara *et al*., 1993). The apparent low frequency of the Tyrrhenian Sea was thought due to disturbance by fishing activities such as pelagic driftnet as well as disturbance by intense maritime traffic, and contaminant load (Notarbartolo di Sciara *et al.,* 1993).

Despite this, the recently new discovered hot spot areas representing favourable habitats for rare and elusive species as the Cuvier's beaked whale, such as the Ligurian and just the Tyrrhenian Sea (e.g. Gannier, 2011; Holcer *et al*., 2012) create new interrogative about the chronic lack of information, preventing a full assessment of the consistency of populations and conservation status of cetaceans in the Mediterranean Sea. A three-year cetacean monitoring of cetaceans presence repeated during 17 years along a fixed line transect from ferries in the Central Tyrrhenian Sea confirmed the existence of high density areas of cetaceans, especially of fin whale, whose sightings grew by 300% (Marini *et al*., 1997; Arcangeli *et al*., 2012; Bittau et al., 2013).

The many studies focused on the Pelagos Sanctuary area also reinforced the early belief of the poor abundance of cetaceans in the surrounding areas. However, the discovery of such favorable habitats helped to point out the potential existence of other areas in the Mediterranean Sea in need of further studies, to enhance their real significance for the conservation of cetaceans.

In this study, for the first time I describe the importance of the Caprera Canyon area, off North-eastern Sardinia, as a high density area for cetacean species, and the relations of its physiographic features on cetacean distribution. Studies at a medium-small scale, along both the continental shelf and slope off north-eastern Sardinia can provide key data for managing and conservation of pelagic cetaceans in a proposed open sea SPAMI area (the Central Tyrrhenian Sea).

Physiographic and oceanographic features of the Central Tyrrhenian Sea and the Bonifacio Strait

The Tyrrhenian Sea is the deepest of the Western basins (3,620 m), although the volume (about 328,000 Km^3) does not differ significantly from the other major regional basins of the Western Mediterranean Sea (Astraldi & Gasparini, 1994).

The basin extends its western border along the North-South coastline of Sardinia and Corsica, interrupted only by the Strait of Bonifacio. The latter is a narrow channel wide around 6.5 miles, further narrowing to 4 miles (7 km) among the smaller closer islands of the Italian (La Maddalena) and French (Lavezzi) archipelagos.

Though affected by interesting physical processes, the smaller opening of the Bonifacio Strait is not considered to significantly contribute to the general Tyrrhenian basin circulation due to its limited cross-sections (Astraldi & Gasparini, 1994).

The physiography of the Tyrrhenian basin is very complex and the central part hosts a number of submerged structures such as systems of canyons and seamounts. The Caprera Canyon, just above the latitude of the Bonifacio Strait (41°18’N) extends approximately from 41°10’N to 41°25’N and from 09°39’E to 10°23’E, representing the main sea bottom morphological features eastward between Sardinia and Corsica islands. The 1,000 m isobath of the Caprera Canyon lies *ca*. 24 nautical miles (*ca*. 44 Km) from the nearest ground point on the Sardinian coast.

The entire canyon system is a turbiditic system, flanked eastward by the Etruschi Seamount, and westward by the 25 km north-eastern Sardinian continental shelf, narrowing southward, and partially confined by a 20 km wide continental slope with an average dip of around 2° (Dalla Valle, 2007). In the upper slope, it consists of two tributaries canyon, *ca*. 15 km in lenght joining to form a single, ca. 1 km wide canyon at depth of 1,000 m lasting for a further 9 Km of length until 1,600 m of depth. Initially, the Caprera Canyon is oriented North-Eastward, later turns 65° South East, towards the Olbia basin (a fan valley) for about 20 km with a steep scarps on the external side (300 m in height) due to the presence of the Etruschi Seamounts ridge (Gamberi & Marani, 2004; Gamberi & Dalla Valle, 2009; Dalla Valle & Gamberi, 2010). The presence of canyons may affect the circulation of water masses and oceanographic variables. It is known that upwelling associated with canyons may enhance local primary productivity, with positive effects extending up the food chain to include birds and cetaceans (Waterhouse *et al.* 2009; Würtz, 2012). Canyons represent cetacean feeding grounds, commonly located at the heads of the submarine feature (Hooker *et al*., 1999) so that the cetacean fidelity to these sites may be used to design MPAs (Hooker *et al.*, 1999).

A recent interest focused on the role of submarine canyons in the exchanges between the deep ocean and continental shelf, as well as in the functioning of the benthic and pelagic ecosystem (Würtz, 2012), led to highlight the importance of conservation and protection of these deep sea habitats.

Almost 518 large submarine canyons have been identified in the Mediterranean Sea (Harris & Whiteway, 2011) and they were considered as key structures for its ecosystem functioning. Submarine canyons were defined as "steep-walled, sinuous valleys with V-shaped cross sections, axes sloping outward as continuously as river-cut land canyons and reliefs comparable to even the largest of land canyons" (Shepard, 1963, 1981).

The oceanography of the Tyrrhenian Sea at mesoscale level is characterized by a main cyclonic circulation (the 'Tyrrhenian Gyre') along its limit, while in the inner sector occur several gyre structures. The circulation in the Western-central sector of the basin presents two main gyres, namely a cyclonic cell with a variable shape and size depending on the season, mostly located to the east of the Bonifacio Strait and a southernmost anticyclonic gyre adjacent of the first, off the Eastern coast of Sardinia (Small *et al.*, 2012). These gyres are usually considered wind-driven (Artale *et al.*, 1994; Nair *et al.*, 1994), but recent studies revealed that topography may play an important role (Budillon *et al.*, 2009; Vetrano *et al.*, 2010). This specific wind field, mainly the West and Mistral winds, blow reinforced by the 'Venturi effect' through the Bonifacio Strait, inducing two large counter-rotating vortices and generating a filament of cold water just off the Northeastern Sardinian coast (Bignami *et al.*, 2008). This largest, Northern structure caused by the wind jet stream blowing all year round eastward through the Bonifacio Strait, is called the "Bonifacio Gyre" and appears as a quasi-permanent cyclonic circulation (Moen, 1984; Vetrano *et al.*, 2010).

The resulting northernmost cyclonic gyre carries a clear upwelling of colder waters with nutrients and increase in Chlorophyll concentration. These hydrographic conditions resulting in an upwelling in the northern area, have a divergence of water mass, and downwelling in the south, with adjacent relative convergence. In the central Tyrrhenian Sea, relationships with early spring primary production and the thermal front were observed and this front, related to local upwelling east of Bonifacio, produces strong surface thermal gradients (Littaye *et al.*, 2004).

After the recent availability of novel analytic tools and satellite data, it was also possible to evaluate the effects of physiographic and oceanographic features on the distribution of cetaceans, such as depth, slope, Sea Surface Temperature and Chlorophyll-*a* concentrations (e.g. Panigada *et al.*, 2005, 2008; Laran and Drouout-Dulau, 2007; Moulins *et al.*, 2007; Azzelino *et al.*, 2008, 2012; Laran and Gannier, 2008; Druon *et al.*, 2012).

Whale watching as platform of opportunity for cetacean data collection

Data on the geographic distribution and habitat utilization of pelagic marine mammals are difficult to collect and yet such information is basic for many conservation and management purposes.

The cost of dedicated research activities using chartered vessels often prohibits regular surveys. In fact, they provide information limited to the time and space of a transect which is often surveyed only once within a specific area. Also monitoring with fixed line transect from ferries are valuable methods. Ferries allow long term, repetitive surveys along a fixed transect which can be conducted regularly throughout progressive years (Kiszka *et al.*, 2007) and covering long distance, with the disadvantage of the absence of any control of ship direction and that visual surveys carried out by ferries cannot assure the correct identification of small cetaceans, at medium-large distance from the ship. Furthermore, no photo-identification data can be collect using ferries platforms.

Amongst the wide range of platforms that can offer possibilities to gather data at relatively low cost, commercial whale watching activities can provide valuable opportunities for research. Whale watching vessels are likely to have high sighting rates and allow close observation of the target species. These vessels cross large areas of sea often on a routine basis as part of their activities in good sea-weather conditions, primarily to minimize costs and increase the probability of sighting.

Data from platforms of opportunity such as whale watching are unlikely to be useful in estimating absolute densities or abundance of cetaceans within an area (Leaper *et al.*, 1997). The impossibility of controlling over where the vessel goes making it not feasible to sample wide areas. In addition, rather than following tracklines, the vessels randomly search for whales, often returning to areas where whales are known to be or where whales are reported by other whale watching vessels and finally, the whale watch activities adhere to a set schedule, limiting the timetable of research operations (Koslovsky, 2008).

Despite this, the opportunity to collect large data samples over relatively long time periods are a feasible alternative for gathering data on the abundance and distribution (Koslovsky, 2008). They may enable a relative index of abundance of marine mammals to be estimated with careful collection and analysis of the gathered data (Leaper *et al.*, 1997; Evans & Hammond, 2004). Furthermore, the whale watching data could supply detailed information on habitat use of cetaceans in a specific area (Hauser *et al.*, 2006) and photo-identification are among the easiest data to collect.

However, it is necessary to be able to identify the factors that affect the probability of detection of cetaceans at sea and the analyses should be conducted taking into account viewing conditions such as sea state (Leaper *et al.*, 1997). The need for testing data quality from platforms of opportunity, as well as acknowledgment of data limitations and biases before such research is pursued and these should be tested on a regular basis, if long-term use of whale watching platforms of opportunity is planned (Hauser *et al.*, 2006).

For this reason, platform of opportunity, such as whale watching vessels, can be and are increasingly used for opportunistic cetacean surveys, representing a more affordable approach to distribution studies on cetaceans (Hauser *et al.*, 2006).

For this Doctoral Thesis, I evaluate the use of platform of opportunity during 2010, carrying out a pilot study to test, modify and adapt the survey protocol to the effort conditions of the study area, due to the particular weather conditions of the Bonifacio Strait and the characteristics of the whale watching trip, in time and space. This approach, widely used in other areas of Mediterranean Sea, allowed for the first time in Sardinia to conduct a study on pelagic cetaceans by optimizing resources and reducing the costs of research.

Estimating the abundance of rare species (i.e. small population size), elusive animals, and animals that are abundant overall but occur over vast areas at low densities is a everlasting difficult problem (Thompson, 2004). Often the presence of rare species cannot be estimated with conventional design-based methods, especially when the surveys are intended to maximize encounter rates and to estimate abundance.

The goal of Chapter 1 deals with the presence/absence and the distribution of pelagic cetaceans such as the Cuvier's beaked whale, the most cryptic and elusive species inhabiting the Mediterranean Sea, through the use of data obtained from opportunistic surveys.

On the other hand, Chapter 3 describes the encounter with a very rare Sowerby’s beaked whale, occurred during one of the several opportunistic survey carried out for this thesis and give new impetus to research on the ecology of cetacean species both rare and regularly present off the coast of Sardinia.

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FIRST PART

Temporally and spatially changes in cetaceans distribution off north-eastern Sardinian coast

Chapter 1

Occurrence, distribution and encounter rates of pelagic cetaceans around the Caprera Canyon (North-Eastern Sardinia, Western Mediterranean Sea)

Occurrence, distribution and encounter rates of pelagic cetaceans around the Caprera Canyon (North-Eastern Sardinia, Western Mediterranean Sea)

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ABSTRACT

The Caprera Canyon, the largest submarine canyon system off the coast of Northeastern Sardinia, Western central Tyrrhenian Sea, is currently though to have a high density marine pelagic fauna. Little is known however about values of species richness, temporal and spatial distribution of cetaceans in this area. Visual surveys were carried out on dedicated vessels and whale watching platforms of opportunity, collecting data during 70 one-day survey (January 2011-July 2013). The research aims to verify whether any changes occurred in the pattern of cetacean occurrence and distribution over the 3 year study period around the Caprera Canyon, which is assumed to be a high density area of cetaceans as well within the Central Tyrrhenian Sea. Encounter rates were calculated, based on 'on-effort' Km travelled. Seven cetacean species were recorded, including, in order of decreasing frequency: striped dolphin, fin whale, Cuvier's beaked whale, common bottlenose dolphin, sperm whale, Risso's dolphin, short beaked common dolphin and Sowerby's beaked whale. Encounter rates of striped dolphins were the highest, suggesting a regular occurrence followed by fin whales. A robust modelling approach accounting for autocorrelation in the data was used to model the probability of whale presence across the study area as a function of environmental variables and to evaluate which environmental factors were associated with the observed dynamics at different spatial and temporal scales. The temporal and spatial pattern of cetacean distribution displayed not significant seasonal differences for striped dolphin and Cuvier's beaked whale with the first occurring throughout the year, and fin whale observed from early spring until fall. The data suggest seasonality for sperm whale and Risso's dolphin, although both are few records. This three year study increases our understanding of habitat determinants of species distribution in an area with high density of cetaceans just beyond the south-eastern boundary of the Pelagos Sanctuary, close to Sardinian and Corsican Marine Protected Areas. The results have the potential to be applied to conservation and management in a key Tyrrhenian area, proposed to become a potential SPAMI in the Mediterranean open seas.

Keywords: Cetaceans, Sardinia, Central Tyrrhenian Sea, Caprera Canyon, statistical modelling,

INTRODUCTION

During the first years after the establishment of the Mediterranean Pelagos Sanctuary, the need for cetacean conservation led to the concentration of resources and efforts in this area, neglecting the search of other possible areas of high cetacean density in the Mediterranean basin. The beginning of extensive research highlighted however the existence of a few areas where cetaceans may occur in high density, with seasonal congregations of fin whales (Arcangeli et al., 2012; Marini et al., 1997; Bittau et al., 2013b) and favourable habitats for rare and cryptic species such as the Central Tyrrhenian Sea and Adriatic Sea for the Cuvier's beaked whale (Ziphius cavirostris) (e.g. Gannier, 2011; Holcer et al., 2012).

A three-year monitoring of cetacean presence in the Central Tyrrhenian Sea repeated after 17 years using passengers ferries along a fixed line transect confirmed the existence of high density areas of cetaceans, especially of fin whale, whose sightings increased by 300% after 17 years (Marini et al., 1997; Arcangeli et al., 2012).

Offshore populations of cetaceans occurring in waters surrounding Sardinia have been poorly studied (Lauriano and Notarbartolo di Sciara, 1996; Lauriano et al., 2003b) in comparison with investigations focused on coastal populations of Tursiops truncatus, especially in the northern sector of the island (see for example Lauriano et al., 2003a; Lauriano et al., 2004; Díaz López et al., 2005; Díaz López, 2006; Díaz López and Mariño, 2011; Díaz López, 2012).

The Tyrrhenian Sea is a semi-enclosed basin, representing the deepest, most isolated basin in the western Mediterranean Sea (Artale, 1994). It extends its western border along the North-South line of the coasts of Sardinia and Corsica, interrupted only by the Strait of Bonifacio, between the two islands. The western sector of the Central Tyrrhenian Sea is an high primary productivity area of pelagic waters, important for feeding of endemic and other seabird species of conservation concern and a nursery area for several species of cartilaginous and bony fish, further supporting marine mammal species (Notarbartolo di Sciara and Agardy, 2010).

The physiography of the Tyrrhenian basin is very complex and the central part hosts a number of submerged structures such as systems of canyons and seamounts (Astraldi and

Gasparini, 1994). The Caprera Canyon represents the main bottom-sea morphological features eastward between Sardinia and Corsica islands.

Although not yet fully understood the Tyrrhenian Sea circulation at mesoscale level is characterized by a main cyclonic circulation (‘Tyrrhenian Gyre’) along its limit while several gyre structures occur in the inner sector. The circulation in the Western-central sector of the basin presents two main gyres, namely a cyclonic cell with a variable shape and size depending on the season, mostly located to the east of the Strait of Bonifacio and a southernmost anticyclonic gyre adjacent of the first off the Eastern coast of Sardinia (Artale et al., 1994; Small et al., 2012).

These gyres are usually considered wind-driven (Artale et al., 1994; Nair et al., 1994), but recent studies revealed the key role of topography (Budillon et al., 2009; Vetrano et al., 2010) i.e. the presence on canyons may affect the circulation of water masses and oceanographic variables. It is known that upwelling associated with canyons may enhance local primary productivity, with positive effects extending up the food chain to include birds and cetaceans (Waterhouse et al., 2009; Würtz, 2012). Canyons may become cetacean feeding grounds, commonly located at the heads of the submarine feature so that the cetacean fidelity to these sites may be used to design Marine Protected Areas (Hooker et al., 1999).

Platforms of opportunity such as whale-watching vessels are often used worldwide to support low cost sustainable research on cetaceans. The use of whale-watching vessels as sighting platforms became an important tool to gather data in a cost effective method, providing long-term wide coverage also in North western Mediterranean, after the Pelagos Sanctuary establishment (Azzelino et al., 2008; Airoldi et al., 1999, Moulins et al., 2007, 2008).

These platforms increase the potential to perform replicas, but with no control over where the vessel goes, thus limiting abundance estimation (see Evans and Hammond, 2004). Nevertheless, whale watching data may supply detailed information on habitat use of cetaceans in a specific area allowing such data to be accurate enough to be useful for describing cetacean distribution (Hauser et al., 2006).

Seasonal high density of pelagic cetaceans off the Northeastern coast of Sardinia and the occasional presence of fin whale in coastal waters are supposed to be linked to longitudinal/latitudinal movements along both sides of Sardinia and Corsica islands (Bittau and Manconi, 2011; Bittau et al., 2013).

Some recent predictive analyses made trough habitat models outlines areas of higher biodiversity such as the continental slope areas along the Sardinian coasts outside the Sanctuary borders such as the Southeastern area (Northern Tyrrhenian Sea) (Azzelino et al., 2012). Cetacean–habitat modelling is now a potentially powerful instrument for predicting the cetacean distributions and understanding the ecological reasons that lead to these distributions (Redfern et al., 2006). Spatial modelling is increasingly being used as an alternative to conventional design based line transect sampling to estimate cetacean abundance on the relationship of animals observed to environmental factors and allowing the use of both ‘platforms of opportunity’ and conventional platforms (Gomez de Segura, 2007).

In this study we model the cetacean probability of distribution using data collected both from opportunistic and systematic surveys with environmental covariates.

The aims of this study were: 1) to investigate the occurrence and diversity of cetacean species in the Caprera Canyon area (central Tyrrhenian Sea); 2) to determine any temporal differences in the species occurrence; 3) to model the spatial probability of cetacean occurrence across the study area as a function of depth, slope and aspect of sea bottom.

This work aimed to increase the all-year-round knowledge and datasets on pelagic cetaceans off Sardinia and provide new information in a poor investigated area, designated to become a Specially Protected Area of Mediterranean Importance (SPAMI).

The Central Tyrrhenian Sea was first identified as a marine area of conservation significance or concern, known as Ecologically or Biologically Significant Area (EBSA) and then proposed as an Open Sea SPAMI under the protocol on Special Protected Areas and Biological Diversity, according to the Barcelona Convention (Notarbartolo di Sciara and Agardy, 2010; UNEP, 2010).

Later, to facilitate the implementation of conservation measures in Mediterranean open sea habitats, ‘key areas’ for many of the region’s cetacean populations, Italy established in 2011 an Ecological Protection Zone (EPZ) in its Tyrrhenian Sea, Ligurian and Sea of Sardinia waters, extending their jurisdiction beyond their strict territorial waters (D.P.R. 209/2011). Most marine waters of the Pelagos Sanctuary now lie within the jurisdiction of either France or Italy as well as the pelagic waters of the Central Tyrrhenian Sea within the study area is located and adjacent to the Sanctuary.

Westward, between Sardinia and Corsica islands, the Bonifacio Strait is the only strait lying within the pelagos sanctuary. It was designated in 2011 as “Particularly Sensitive Sea Area” (PSSA), an area that needs special protection through action by IMO (International Maritime Organization), resolution A.982(24). Finally, the waters surrounding the southern part of Corsica and North-eastern part of Sardinia islands hosts several French, Italian and international Marine Protected Areas, such as the National Park of La Maddalena (Italy) and the Natural Reserve of the Straits of Bonifacio (France) both gathered by the International Marine Park of the Strait of Bonifacio (PMIBB) all of them inscribed within the larger MPA, the international Pelagos Sanctuary for Marine Mammals.

MATERIALS AND METHODS

Study area

The study area of ca. 2300 km^2 within the Central Tyrrhenian Sea ranges from the Eastern Corsican-Sardinian coast to longitude 10° E and between 41° to 41°40' N latitude East of the Bonifacio strait, just beyond the south-eastern border of the Pelagos Sanctuary (Figure 1). The depth range of the study area ranges from the coastline to 1400m.

The physiography of this area is very complex, resembling that of the entire central Tyrrhenian Sea basin, including the continental shelf and slope, canyons and seamounts. The major canyon systems are the Caprera and Mortorio canyons (Gamberi and Marani, 2004b).

A wide shelf is present along much of the North-eastern Sardinian, East of Bonifacio and the Archipelago of La Maddalena. In the northern area the shelf reaches a width of ca. 20 km breaking into a slope, gentler to the north (average dip of around 2°) and steeper towards the south. The North-Eastern Sardinia slope is incised by some canyon systems and bounded seaward by the Etruschi and further south the Baronie seamounts (Dalla Valle, 2007).

The Caprera Canyon, just above the latitude of the Strait of Bonifacio (41°18’N) extends approximately from 41°10’N to 41°25’N and from 09°39’E to 10°23E, representing the main bottom-sea morphological feature eastward between Sardinia and Corsica islands. The 1000 m isobath of the Caprera Canyon lies ca. 24 nautical miles (ca. 44 Km) from the nearest ground point on the coast of Sardinia. It consists of two meandering tributaries canyons incised in the continental upper slope that join in a single, 2.5 km wide canyon, at a depth of ca. 1000 m in the lower slope (Gamberi and Marani, 2004b).

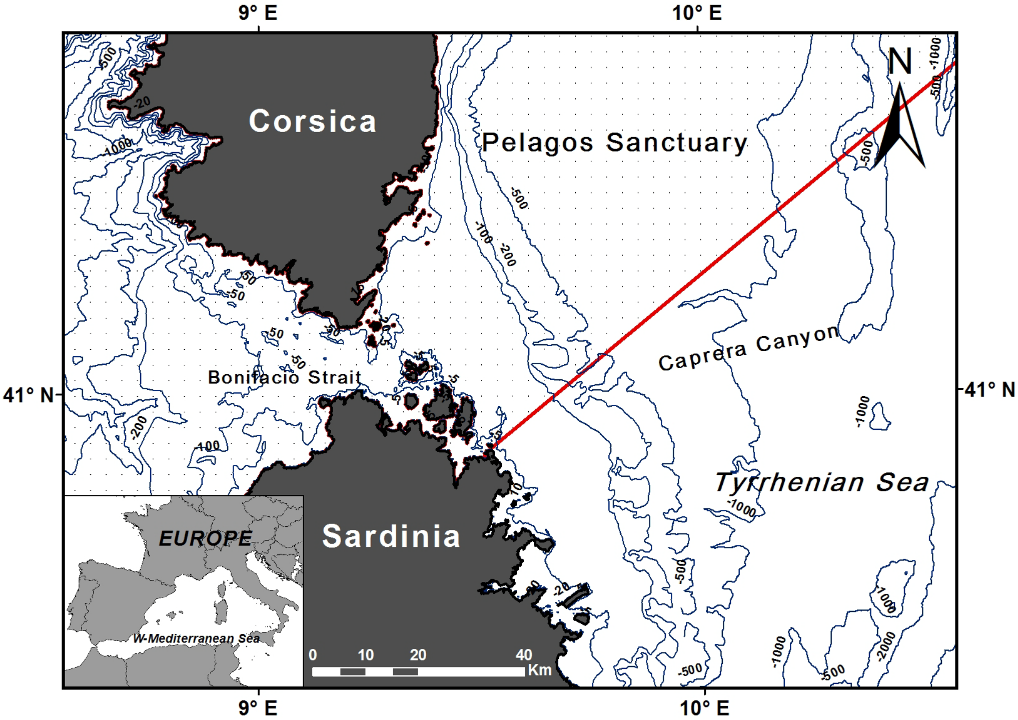

Fig. 1 Study area of pelagic cetaceans and bathymetry of the Caprera Canyon, off North-eastern Sardinia.

In terms of water circulation, the central Tyrrhenian Sea is characterized by the 'Tyrrhenian Gyre' a main, larger cyclonic circulation while in the inner sector occur several gyre structures. The circulation in the Western-central sector of the basin presents two main gyres: a cyclonic cell the "Bonifacio Gyre", with a variable shape and size depending on the season, mostly located to the east of the Bonifacio Strait, and a southernmost anticyclonic gyre adjacent of the first, off the Eastern coast of Sardinia (Small *et al.*, 2012). These gyres are usually considered wind-driven (Artale *et al.*, 1994; Nair *et al.*, 1994), but recent studies revealed that topography may play a local key role (Budillon *et al.*, 2009; Vetrano *et al.*, 2010). The specific wind field, mainly the West and Mistral winds, blows reinforced by the 'Venturi effect' through the Strait of Bonifacio, inducing the two large counter-rotating vortices and generating a filament of cold water just off the Northeastern Sardinian coast (Bignami *et al.*, 2008). The largest, Northern structure caused by the Bonifacio Strait wind jet stream appears as a quasi-permanent cyclonic circulation (Vetrano *et al.*, 2010; Moen, 1984) that produces eastward an upwelling of deep, cold water and creates water front affecting the study area.

Distribution of effort

Visual surveys were conducted from 2011 to 2013 by the Department of Science for Nature and Environmental Resources of the Sassari University (DIPNET), *ca.* 15-40 nautical miles off the Northeastern coast of Sardinia. Sampling effort was widely distributed mainly across the major axis of the Caprera Canyon area (see effort data, Table 1) which was the core of the investigated area in 'on-effort' mode. Transects during opportunistic surveys did not follow a systematic design with random probability sampling, but the resulting routes cross depth contours almost perpendicular, covering as much as the possible habitats, from the continental shelf to deep sea.

A total of 70 one-day surveys were carried out, 54 of which were opportunistic and 16 additional systematic surveys, covering around 2,300 km^2 in 'on-effort' conditions. The latter surveys were designed and carried out by using the same boats and field protocol during the three years, in order to better cover in space and in time areas not enough investigated by opportunistic surveys. Even though being undertaken mostly opportunistic survey, we at least randomized the choice of the starting point of the 'on-effort' tracks.

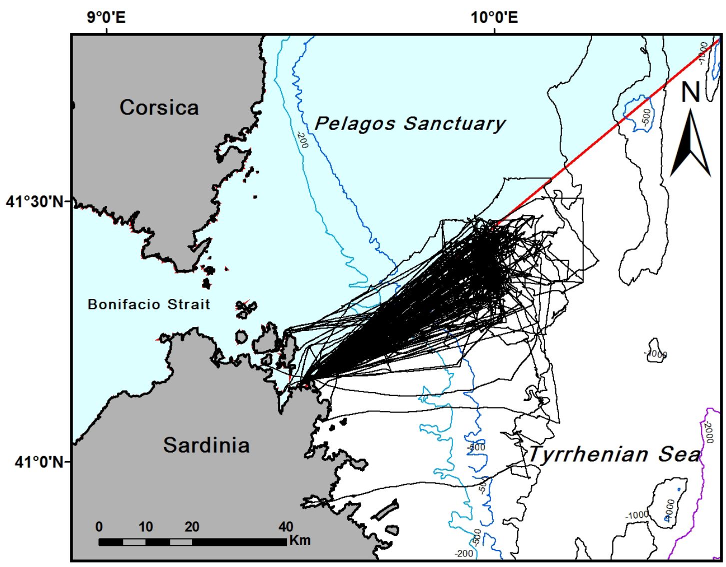

Fig. 2 Effort distribution within North-eastern Sardinia study area. Depth contours (200 m, 500 m, 1000 m, 2000 m) and survey tracks are shown. The red line indicates the South-eastern boundary of the Pelagos Sanctuary.

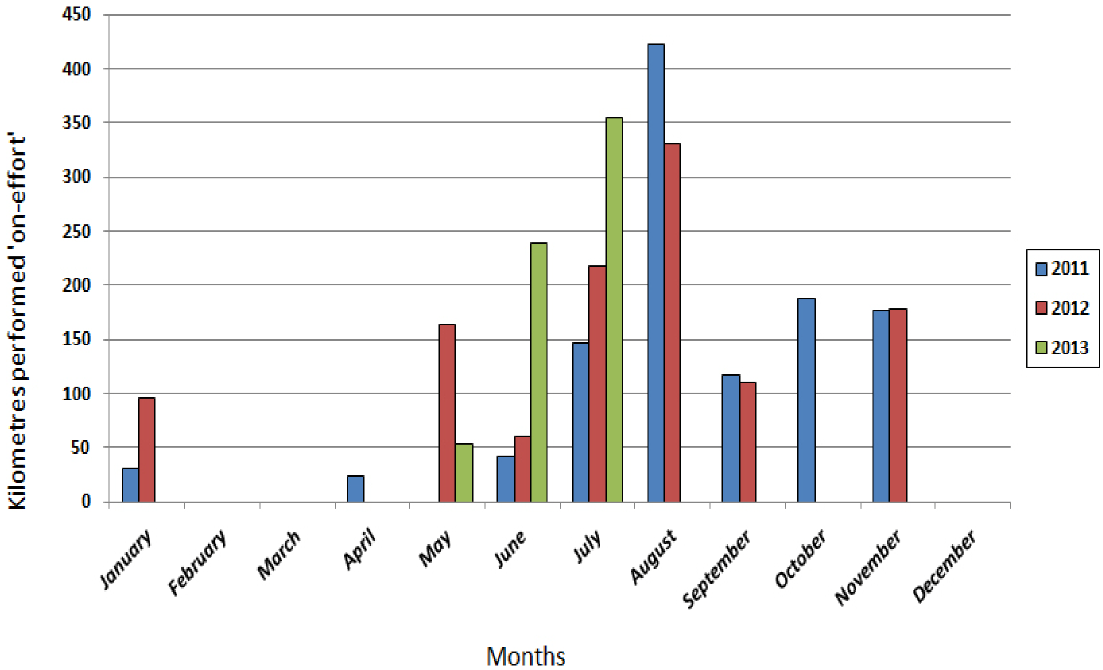

Fig. 3 Variation of observation effort (Km) according to years and months, from 2011 to 2013. Summer and autumn are the most surveyed seasons.

Fields methods

Survey methods remained relatively constant throughout the 3-year study period. Two boats were used: the 11 m power catamaran Orso Cat with 6 m sighting tower and the 16 m motor boat 'Over Winds', equipped with a flying bridge. The observation height on both boats from the flying bridge deck was approximately 6 m above the sea surface level. The primary team consisted at least of three trained observers. Port and starboard observers were on the upper deck of the boat, searching both through unaided eyes and 7x50 Nikon handheld binoculars with compass (typically from 10° on the opposite side of the bow to 90° on their side) and one centre trained observer searching 360° around by unaided eyes and occasional scanning by 7x50 handheld binoculars. The centre observer in the Orso Cat boat was in the tower, which is mounted onto the boat roof, while on the flying bridge of the Over Winds. One of the two observers was also responsible for recording search effort and sightings data. Survey effort (time and space) was quantified by recording every 5" the boat's position using a handheld Global Positioning System (GPS) Garmin E-Trex 20.

The vessels surveyed at 8-13 knots during daylight hours in 'on-effort' condition, according to survey protocol. The 'on-effort' conditions were the following: all observers in the correct position for visual search and sea-weather in 'favourable conditions' (daytime, Beaufort ≤3, sea state ≤ 2 Douglas, visibility ≥ 4 Km, swell high less than ca. 0.5 m).

Searching 'on-effort' start and end times were determined by slowing down or increasing the speed of the boat at the a) start/end time of the survey, b) start and end times of a sighting, c) the worsening of weather conditions (when the sea and visibility conditions did not respect the 'favourable conditions') or d) when opportunistic, the whale watching boat was stopped for and re-started up.

After a positive detection of cetaceans the boat was directed towards the animal(s) to obtain certain species identity, group size estimates and reliable position of the school, moving near to the dive position even if the animals dived deep, before the boat approach (modified from Barlow *et al.*, 2001).

Immediately after a sighting (and before turning the boat), we measured the bearing angle to the animal (or group) with compass binoculars and the distance using a measuring stick always held from the same position (the boat roof).

During the approach to animal(s), we kept the boat within a safe distance and often drifting, engine in neutral, in order to limit the disturbance to the animals and at the same time to observe behaviour. Animals were always approached, adapting the vessel speed and heading according to the ACCOBAMS' guidelines (Carlson, 2009; www.accobams.org). 'On-effort' condition was resumed when, at the end of a sighting, the vessel rejoined the trackline following the tangent to the direction that had been left due to a detection.

Sighting data were: i) sighting position of the primary sightings, ii) time of start/end of the sighting, iii) species identification, iv) group size (minimum, maximum and best estimate), v) behaviour of the animal/s, vi) position of the boat, and vii) photo-identification data (not analyzed in this paper). Only definite species identifications were considered in this study. Thanks to the photo-identification field work carried out in conjunction with the present study, all the schools identified at species level were considered reliable and used for the analysis.

Groups were defined as individuals having the same activity and being in close proximity to each other. We defined a ''sighting'' as a group of animals of the same species seen at the same time showing similar behavioural characteristics, coordinated surfacing and diving patterns i.e. within approximately 500 m for striped dolphin and 1 km for fin whales (modified from Azzelino *et al*., 2008). Group sizes used to provide mean, standard deviation, and range values were best estimates recorded at sea. The sightings made during ‘off-effort’ conditions were considered only for presence data and were not used in the computation of encounter rate analyses. Differences in group size between season and year were tested with a non-parametric Kruskal–Wallis test. Considerations about sightings and group size of sperm whale were made each time, with caution depending on the behavioural pattern observed and due to the lack of acoustic survey.

The environmental variables were recorded every 60 minutes or more frequently if changes in conditions occurred, were: wind direction (degrees), sea condition (Beaufort and Douglas scale for wind and sea state), swell height, cloud cover (%), precipitation and visibility (Km). Collected effort data were: GPS boat coordinates every 5”-10” during all survey tracks. All data were collected on prepared data sheets and logged into an Excel database after each survey (modified from Kiszka *et al.*, 2007).

Additionally, photo-identification data were gathered and analyzed in separate paper. On return to the port, all the tracks and sightings data were downloaded from the GPS to a laptop computer using Garmin Software MapSource.

Following, all the data were prepared to enter into ESRI ArcView 9.3 Geographic Information System (GIS) Geodatabase with Excel software (Microsoft). The depth, slope and aspect covariates at all initial cetacean sighting positions were extracted by overlaying point location data on an 150 m resolution bathymetric raster surface in ArcGIS Version 9.3 (ESRI).

Wind exceeding Beaufort 3 can affect the detection of small cetaceans (Hiby & Hammond, 1989; Buckland *et al*., 1993; Hammond *et al*., 1995) and also the overall cetacean detection probability may be biased downwards in poorer conditions. Hence, for the processing of encounter rates, only sighting data collected in ‘favourable conditions’ and in ‘on-effort’ modality were included in the analysis.

Group sizes used to provide mean, standard deviation, and range values were best estimates recorded at sea. The sightings made during ‘off-effort’ conditions were considered only for presence and cetacean diversity data and were not used in the computation of encounter rate analyses. Differences in group size of season vs. year were tested with a non-parametric Kruskal–Wallis test.

DATA ANALYSIS METHODS

The analytical approach of the sightings dataset in the study area includes: (1) an analysis of the interannual variability of the cetacean densities, defined as encounter rate (ER) used as relative abundance measure (referring to schools encountered/100Km); (2) an analysis of the seasonal variability of the cetacean ER and diversity; (3) a comparison at the species level of the relations with physiographic variables such as depth, slope and aspect.

As for the interannual variability of cetacean densities a Chi-square test of independence for given probabilities was used to assess whether the temporal pattern of frequency of all species sightings and the frequency of sightings for each species changed significantly in the different years, during the study period. The expected frequencies were fixed in proportion to the amount of kilometres “on effort” travelled in each year.

The seasonal variability of the cetacean Encounter Rate (ER) and diversity: in order to obtain relative abundance estimate, the ER values were calculated as the number of encounters with distinct groups per 100 kilometres travelled in ‘on-effort’ conditions (ER = n/L*100 Kms) (Ferguson *et al.,* 2006). The data from tracklines and sightings ‘off-effort’ were excluded from the ER counts.

To perform a comparative analysis versus other western Mediterranean areas previously investigated (see Gannier, 2001) the diversity values of cetacean community was estimated on the basis of species richness (S), the Shannon–Weaver (H’) and the Simpson (D’) diversity indices (Shannon, 1948; Simpson, 1949; Krebs, 1994). The Shannon–Weaver (H’) was calculated as:

$$H' = - \Sigma (N_i/N_t) \text{ Log}_2 (N_i/N_t)$$

where, N_i is the number of observed individuals belonging to the species *i* and N_t is the total number of observed cetaceans in the study area during the survey period.

We used also the Simpson’s index, given by the following equation:

$$D' = 1 - \frac{1}{N(N-1)} \sum_{j-1}^{S} n_j(n_{j-}1)$$

where *N* is the total number of individuals in the sampled community, *S* is the total number of types described, and n_j is the number of individuals belonging to the jth species. The cetacean richness, the Shannon-Weaver Index and the Simpson Index were calculated for the whole study area respect to whole surveys and seasons of the study period.

MCMCglmm (generalized linear mixed models - GLMM with a Bayesian Markov chain Monte Carlo - MCMC approach implemented in the R package "MCMCglmm"; Hadfield, 2010) were used to search for seasonal trends in:

a) The cetacean relative abundance in the study area. The ERs of the whole cetacean community and of the most common species (striped dolphin, fin whale and Cuvier's beaked whale) were added to four different models as dependent variables. The season was a factorial variable with four levels (winter: 1/12 - 28/2; spring 1/3 - 31/5; summer 1/6 - 31/8; autumn 1/9 - 30/11) and was added to the models as fixed effect; the year of survey (2011-2013) was fitted as random effect. All the models are based on 70 observations from 2950 km of 'on-effort' navigation. MCMC Gaussian models were run for 13000 iterations with a burn-in period of 3000.

b) The cetacean biodiversity in the study area. The species richness and the Shannon's and Simpson's diversity indices were added to three different models as dependent variables. The season was a factorial variable with four levels (winter: 1/12 - 28/2; spring 1/3 - 31/5; summer 1/6 – 31/8; autumn 1/9 - 30/11) and was added to the models as fixed effect; the year of survey (2011-2013) was fitted as random effect. All the models are based on 70 observations from 2950 km of 'on-effort' navigation. MCMC Gaussian models were run for 13000 iterations with a burn-in period of 3000.

The level of non-independence between successive samples in the chain was checked for all models with the *autocorr* function of MCMCglmm, while the convergence of the chains was checked by visual inspection. Reported credible intervals (CI) are the 95% highest posterior density intervals. The MCMC mean posterior estimates of the dependent variables with their credibility intervals are reported. Interspecific comparison of the sighting locations properties: the physiographical variaables at each sighting point (including both 'on' and 'off-effort' sightings) were obtained with cartographic software GIS ArcMap 9.3 (ESRI), while the group size was estimated directly in the field. To test if there are any differences in these covariates for the different species inhabiting the study area, the data collected at each sighting point were compared with a Kruskal–Wallis (KW) test. A series of Wilcoxon-Mann-

Whitney (WMW) tests were used as post hoc tests to check which pairs of species showed different covariate values. All the statistical analyses were performed using R version 2.12.1 (R development core team, 2010). Following Pirotta *et al.* (2011, 2013) further approach with a Generalized Additive Model (GAM) framework was used to model the relationships between fin whale presence/absence at each GPS fix and the covariates described (Hastie & Tibshirani 1990; Wood, 2006). An autocorrelation function (ACF) plot was used to visualize the level of autocorrelation in the GAM residuals, and Generalized Estimating Equations (GEEs; Liang & Zeger 1986) were then used to explicitly model this observed autocorrelation (see also Dormann *et al.,* 2007; Pirotta *et al*., 2011; Bailey *et al*., 2013). Results is still in progress, in order to better explore the relationships between the different variables taken together and to investigate whether this combination can be considered as a proxy of any spatial and temporal pattern.

Physiographical features

Three features were measured and used as static covariates for describing the physiography of the study area: depth, slope, and aspect. Depth data was derived from the Italy CNR-Ismar bathymetric data (GRID resolution 200m) and was expressed as a negative value in metres. Slope gradient (hereafter 'slope') was defined as the maximum rate of change in depth in a given grid cell and expressed as percent slope. Slope was computed using GIS software (ESRI ArcMap 9.3). Slope aspect (hereafter 'aspect') was defined as the compass orientation of the slope, ranging from 0 to + 359° with respect to true north. In addition ecological variables, the group size, was employed in the analysis.

Tab. 1 Environmental and ecological covariates treated in the analysis.

Covariate	Unit	Spatial scale	Temporal scale
Depth	m.	200x200m	-
Slope	%	200x200m	-
Aspect	°	200x200m	-
group size	n	-	sighting

Our analysis aimed to determine for all species the depth of each sighting (coordinates) for each individual, and the depth of any points along the survey tracks. We therefore performed an extraction of the depth corresponding to coordinates of the total sightings and of the positions without any observation. A Geographic Information System (GIS) of the study area was constructed using Environmental Systems Research Institute (ESRI) ArcView 9.3 software where the overall sightings and effort were mapped. ESRI Arcview 9.3 was used to divide the study area into a 374 grid cells, each measuring 5x5Km (2.7x2.7 nautical miles), and also to integrate sighting data into a set of environmental-physiographic characteristics, such as depth, slope and aspect. The occurrence of different species in relation to depth and gradient were examined and compared between species. Finally we tested even the temporal variability in group size of any cetacean sightings from both 'on-effort' and 'off-effort' observations.

RESULTS

Cetacean *presence/absence*

During three year of surveys (2011-2013), 9644 Km were travelled in the study area (Fig. 1) spending a total of 70 days at sea. Only 2950 Km were performed in 'on-effort' conditions (see details in Tab. 1). Total sightings of cetaceans ('on-' + 'off-effort' encounters) were 419, with an estimate of ca. 4703 counted individuals. A total of 324 sightings were made in 'on-effort' condition, with an estimate of ca. 3758 individuals encountered. Seven cetacean species were observed, in order of decreasing observed abundance: striped dolphin, *Stenella coeruleoalba* (Meyen, 1833); fin whale, *Balaenoptera physalus* (Linnaeus, 1758); Cuvier's beaked whale *Ziphius cavirostris* Cuvier, 1823; common bottlenose dolphin, *Tursiops truncatus* (Montagu, 1821); sperm whale, *Physeter macrocephalus* Linnaeus, 1758; Risso's dolphin, *Grampus griseus* (G. Cuvier, 1812); short beaked common dolphin, *Delphinus delphis* Linnaeus 1758; and a single sighting of the very rare Sowerby's beaked whale *Mesoplodon bidens* (Sowerby, 1804) (Tab. 2). The latter was the first sighting ever of a free-ranging Sowerby's beaked whale in the entire Mediterranean basin, however considered as a vagrant into the basin (Bittau *et al.*, 2013; see present thesis). Striped dolphin and fin whale were the most frequently encountered species (Tab. 2).

Sightings of Risso's dolphin (*G. griseus*) were rare and the encounter rate was the lower. Several sightings of calves and newborn occurred in all the seven encountered cetacean species. Foetal folds were observed, mostly during August, in all the four small-size cetacean species occurring off north-eastern Sardinia, namely Risso's, bottlenose, striped and short-beaked common dolphin and Cuvier's beaked whale. During a survey on 17 August 2013 a birth of a striped dolphin was observed. Short beaked common dolphin was sighted within the study area only two times, both in 2013, but data were not included in the present analysis. Finally, long finned pilot whale *Globicephala melas* (Traill, 1809) was not sighted, during this study.

Tab. 2a Research effort and encounters with cetaceans 2011-2013, off North-eastern Sardinia. Study period, number of days worked, total number of Km surveyed, research effort, referred to the study area.

Year	First date	Last date	No. of days worked	Searching effort (Km)	Tot.Km performed	overall sightings	'on-effort' sightings
2011	16 Jan.	27 Nov.	28	1147.03	3774.66	161	135
2012	18 Jan.	24 Nov.	25	1155.68	3634.08	168	132
2013	16 Mar.	26 Sep.	17	647.57	2235.15	90	57
Total			**70**	**2950.27**	**9643.89**	**419**	**324**

Tab. 2 Encounters with cetaceans species, relative frequencies and total amount of specimens sighted, and school size, relative to 'on-effort' and 'off-effort' encounters during the entire study period (2011-2013) off North-eastern Sardinia.

	overall sightings			'on-effort' sightings		
species	Frequency	%	Specimens	Frequency	%	Specimens
S. coeruleoalba	243	58.00	4259	192	59.26	3455
B. physalus	87	20.76	142	76	23.46	127
Z. cavirostris	45	10.74	92	42	12.96	87
T. truncatus	32	7.64	140	3	1.85	27
P. macrocephalus	7	1.67	28	6	1.23	41
G. griseus	4	0.95	41	4	0.93	20
D. delphis	0		0	0	0	0
M.bidens	1	0.24	1	1	0.31	1
	419	**100**	**4703**	**324**	**100**	**3758**

Interannual variability of cetacean abundance

The abundance of pelagic cetaceans off North-eastern coast of Sardinia from 2011 to 2013, seems to show a gradually decrease of the encounter rate (ER) values of striped dolphin and the increase of those of sperm and Cuvier's beaked whale (Fig. 4). However, the duration of the study period was not sufficient to determine an annual trend and further investigations are needed to explore this aspect. Furthermore, sightings of Risso's dolphin were rare, with only four encounters during 2011 and 2012.

As can be seen from the graphs (Figs 4-5) the encounter rate values of striped dolphin is inversely proportional to the school size, during the study period. The opposite occurred for sperm whale and bottlenose dolphin. It should be noted, however, that the latter was an occasional species during the surveys, given that the slope and to a lesser extent the lower continental shelf were mainly investigated habitats. Since we did not perform any acoustics survey, the encounter rate values of sperm whale should be treated with caution and may be underestimated.

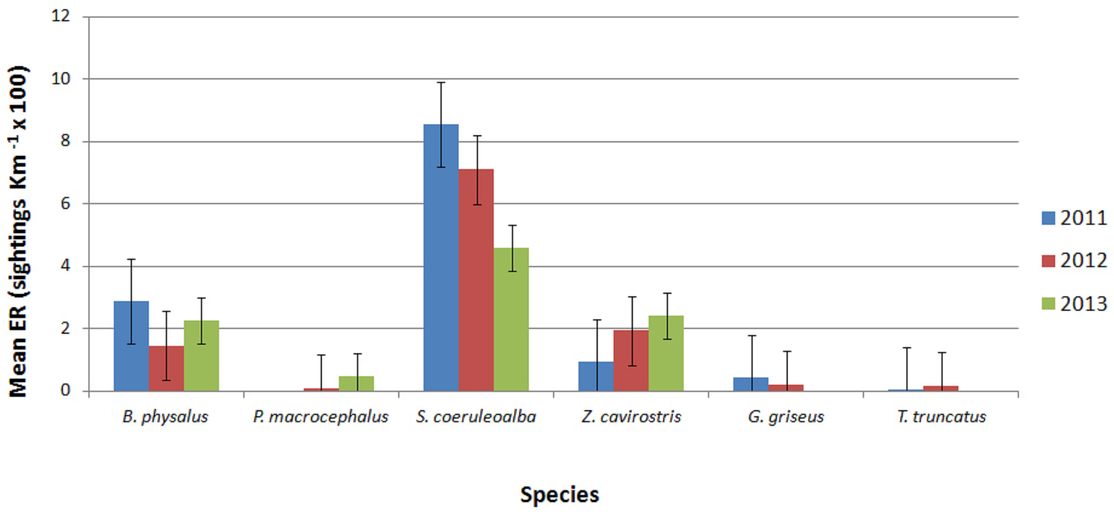

Fig. 4 Mean encounter rate (ER) values of cetacean species off North-eastern Sardinia, recorded 'on-effort' during the study period (2011-2013) ± SE. Number of sightings were: striped dolphin n=192; fin whale n=76; Cuvier's beaked whale n=42; sperm whale n=6; Risso's dolphin n=4; common bottlenose dolphin n=3.

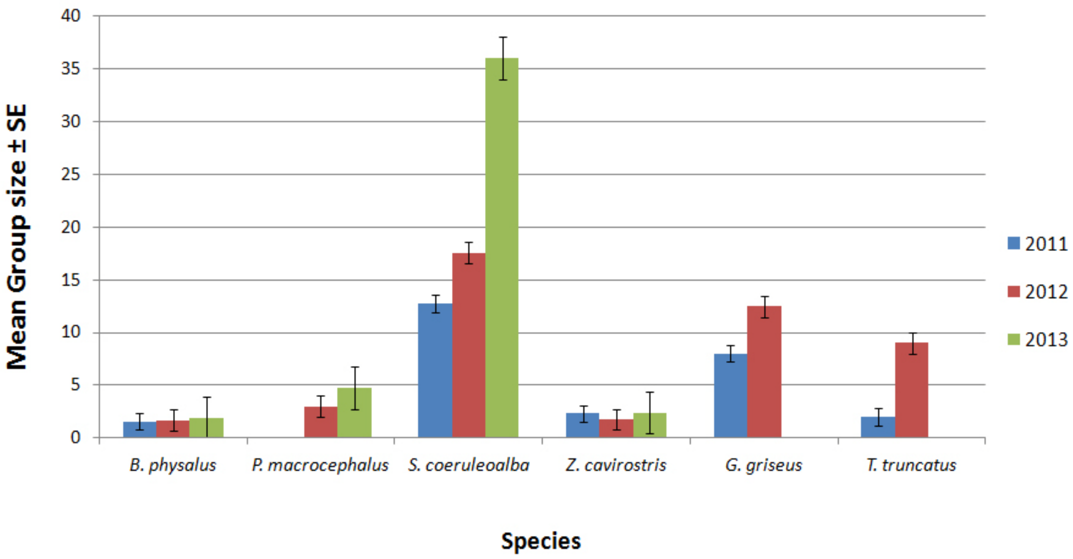

Fig. 5 Mean group size ± SE of sighted cetaceans species off North-eastern Sardinia during the study period, relative to 'on-effort' encounters (n=324).

To test the interannual variability, we used a Chi-square test in rder to determine whether the abundance of the most frequently sighted cetacean species (striped dolphin, fin whale and Cuvier's beaked whale) was significantly higher in a year rather than in another. The encounter rate (ER) of striped dolphin was not significantly different between 2011 and 2012 (χ^2 = 0.0023, df = 1, P = 0.9614; ER_{sc2011}=7.24 *vers*us ER_{sc2012}=7.18), while in 2011 (χ^2 = 10.269, df = 1, P = 0.00135) and in 2012 (χ^2 = 10.0416, df = 1, P = 0.00153) the ER was significantly higher than in 2013 (ER_{sc2013}=4.02).

Fin whale in 2011 showed significantly higher ER than in 2012 (χ2 =5.3621, df = 1, P = 0.02058), but not significantly different than in 2013 (χ2 = 1.938, df = 1, p-value = 0.1639). Finally, in 2012 the ER of fin whale was not significantly different than in 2013 (χ2 = 1.938, df = 1, p-value = 0.1639). The abundance of Cuvier's beaked whale in 2011 showed an ER significantly lower than that in 2012 (χ2 = 4.7102, df = 1, p-value = 0.02998) while not significantly different than in 2013 (χ2 =2.972, df = 1, p-value = 0.08472). In 2012, the Cuvier's beaked whale did not show a significantly different ER than in 2013 (χ2 = 0.0716, df = 1, p-value = 0.789).

Seasonal variability of cetacean abundance

To investigate the effect of seasonality, we analysed the seasonal cetacean distribution using a subset of the seasonal dataset, as the graphical analysis of the only four seasons not allowed us to find any pattern.

Therefore, we explored the data with the time variable of the year's week, to have the best seasonal detail and to graphically better represent any trend in the data description. We found a low seasonality in the relative abundance of cetacean records (see overlap of the boxplot in Fig. 7a) but even the difficulty of seeing any clear seasonal trend (Fig. 7b).

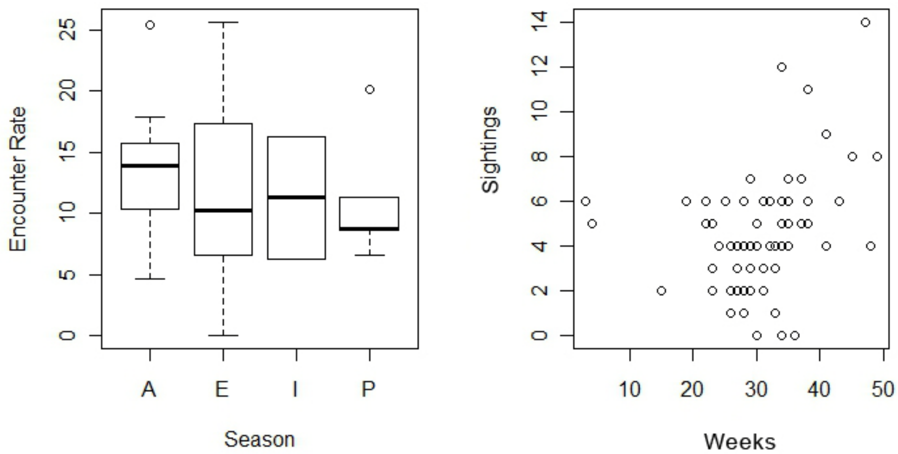

Fig. 7 a) Box plot with the variation in the cetaceans ER off North-eastern Sardinia in different seasons during the entire study period (2011-2013); b) scatter plot showing the number of sightings compared to 56 weeks.

By analyzing the data by species, we did not see any seasonal dynamics (see Figs 9-10), probably due to the lack of data during the winter period. For striped dolphin and Cuvier's beaked whale seasonality is most likely absent.

Furthermore, it is realistic to affirm that the middle months (May to September) are more favorable for the presence of Risso's dolphin and sperm whale in the Caprera Canyon area.

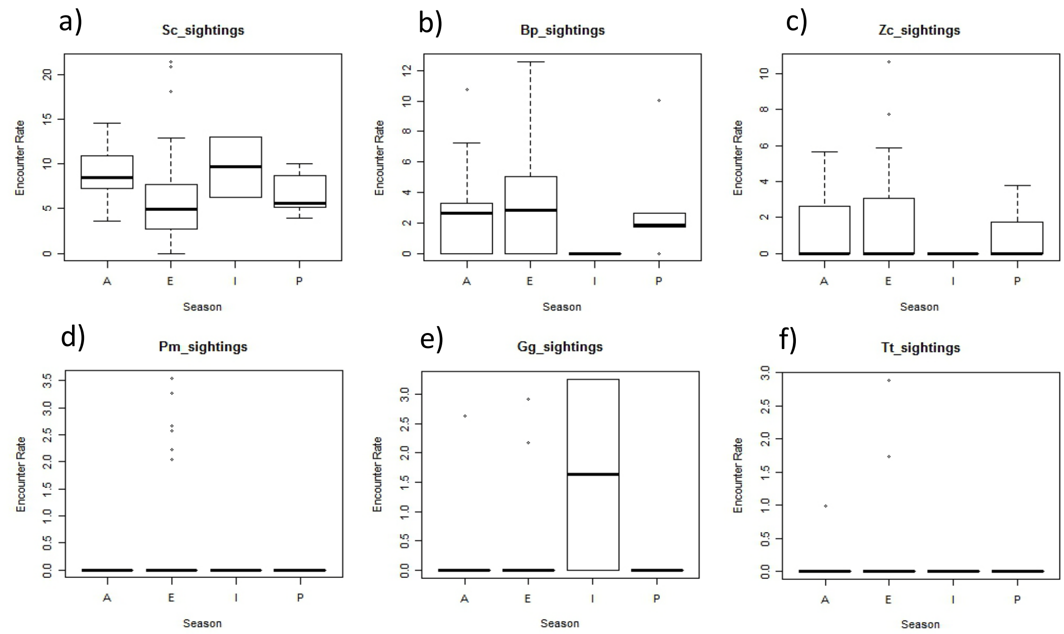

Fig. 8 Box plots of seasonal cetacean species ER in pelagic waters off north-eastern Sardinia, during 2011-2013. a) striped dolphin (Sc, n=192); b) fin whale (Bp, n=76); c) Cuvier's beaked whale (Zc, n=42); d) sperm whale (Pm, n=6); e) Risso's dolphin (Gg, n=4); f) common bottlenose dolphin (Tt, n=3).

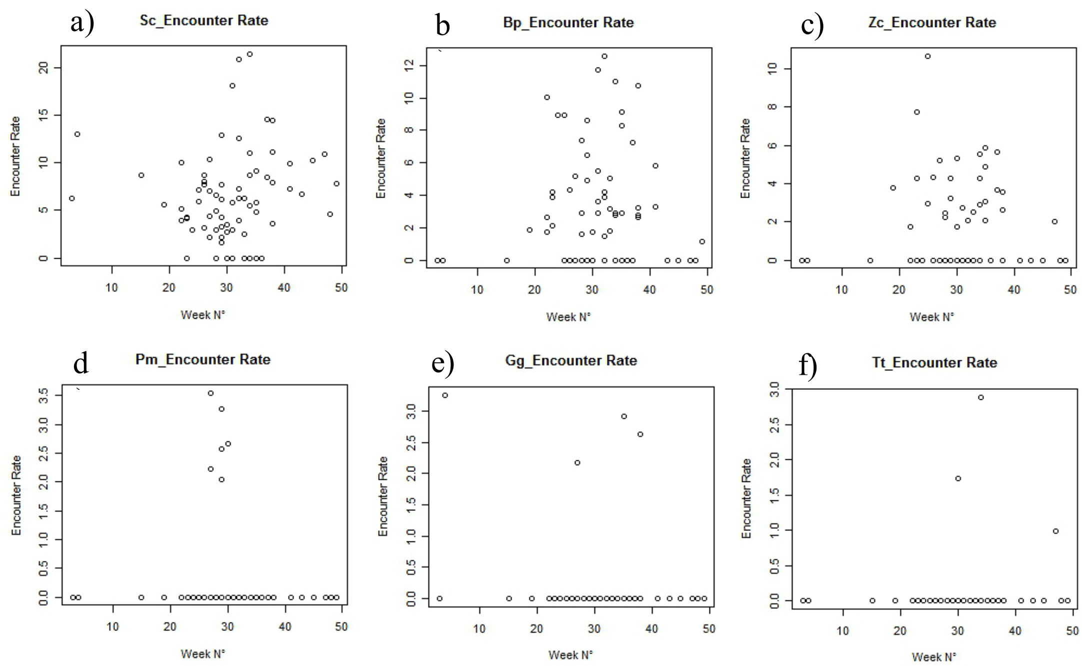

Fig. 9 Scatter plots of ER seasonal variation for each cetacean species, divided by weeks starting on January 1, 2011 (56 weeks) for: a) striped dolphin (Sc, n=192); b) fin whale (Bp, n=76); c) Cuvier's beaked whale (Zc, n=42); d) sperm whale (Pm, n=6); e) Risso's dolphin (Gg, n=4), and f) common bottlenose dolphin (Tt, n=3) in pelagic waters off north-eastern Sardinia, during 2011-2013.

Comparison of the encounter rate values from different regions

The overall cetacean encounter rate during the study period in the Caprera Canyon area is high (ER_{cet}=10.98, SD ± 1.62, SE ± 0.94) when compared to literature data (see Tab. 3). Azzelino *et al.* (2012) and Moulins *et al*. (2008) even presented ER resulting from opportunistic survey by whale watching.

However, it should be noted that our ER values should be treated with caution due to the small study area and due to mostly opportunistic surveys. The developed protocol, providing observations also towards the rear sector, probably increased the ERs, compared to a standard practice.

Furthermore, we interrupted the survey effort whenever one school was detected and thus probably induced a positive bias on the ERs due to the need to stop the boat waiting for the re-surfacing of spotted cetaceans, thus keeping the boat within the high-density area.

Therefore, the positive bias may be due to the small size of the area where research effort was distributed, with a few Kilometres on the continental shelf travelled 'on-effort' and mostly performed near or inside the Caprera Canyon. Finally, the high values of the ER suggest that the area is particularly interesting for cetacean frequency and diversity.

The high relative abundance fuel the hypothesis that the Caprera Canyon area could be a 'hot spot' (Bittau & Manconi, 2011; Bittau *et al*., 2012, 2013a, 2013b), defined as locations where the cetaceans occurred at significantly greater frequencies than expected (Moulins *et al*. 2008).

This would be worthy of further investigation all year round. Mean group sizes observed during this study were also higher than have been reported from other sources (Tab. 3).

Tab. 3 Comparison of the encounter rate values of pelagic cetaceans between different regions of the Western Mediterranean Sea: Ligurian Sea, Sardinian Sea and Central-Western Tyrrhenian Sea (Caprera Canyon), as obtained from the literature.

Species	N-E Sardinia (Caprera Canyon) 70 days, n=323 (present study)	W-Ligurian Sea, 2000 days, n=2935 (Azzellino *et al.* 2012)	W-Ligurian Sea, 318 days, n=1350 (Moulins *et al.* 2008)	N-W Sardinia- (Asinara), 107 days, n=94 (Lauriano *et al.* 2003b)
S. coeruleoalba	6.51	2.62	2.96	0.80
P. macrocephalus	0.20	0.15	0.10	0.15
B. physalus	2.58	0.82	0.74	0.98
Z. cavirostris	1.42	0.03	0.47	-
G. griseus	0.14	0.02	0.02	0.09
D. delphis	-	0.01	0.03	0.12
G. melas	-	0.03	0.03	-
T. truncatus	0.10	0.04	0.04	0.68
Tot.	**ER_{cet}=10.98**	**ER_{cet}=3.85**	**ER_{cet}=4.56**	**ER_{cet}= 2.89**

Cetacean diversity

First we assessed the diversity of the cetacean community in the Caprera Canyon area trough the Shannon-Weaver (H') and the Simpson indices of diversity (Shannon, 1948; Simpson, 1949; Krebs, 1994). Species richness (S), which is the number of species present in an area, is considered to be an unsuitable measure of diversity on its own, because it fails to take into account whether each species is rare or common (Kiszka, 2010). However, we decided to determine species richness of North eastern Sardinia to assess richness level throughout the study area, following the hypothesis that the Caprera Canyon might be a 'hot spot' of cetaceans (Bittau & Manconi, 2011, 2013ab).

For the whole study area and entire period, we calculate a Shannon-Weaver index of diversity as H' = 1.206 (mean H' = 0.36, SD = 0.32, SE = 0.04). This index is similar to higher H' obtained by Gannier (2005) in the northern Tyrrhenian Sea (H' = 1.42) whereas moderate H' were recorded from the southern Tyrrhenian Sea (H' = 0.79) and the Ionian Sea (H' = 0.97). It is difficult however, to compare study areas directly, because the number of species recorded is also linked to the spatial and temporal distribution of sampling effort, according to Kiszka (2010).

The Simpson diversity index we obtained was D' = 2.518 (mean D' = 1.32, SD = 0.47, SE = 0.06). We then assess species richness as 2.46 (mean S = 2.46, SD = 1.03, SE = 0.12) that means at least 2.5 encountered species for each performed survey. We initially found that the variability of cetacean diversity is higher in summer than in other seasons, this could simply be due to a higher sampling effort or to a real change in diversity.

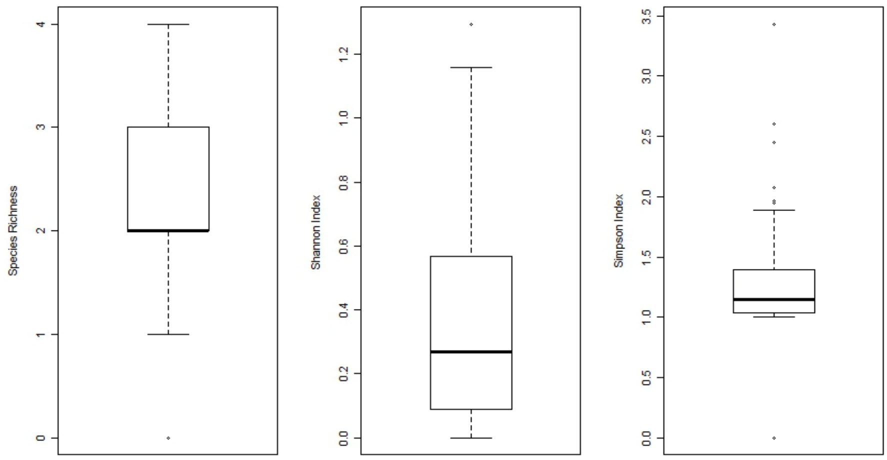

Fig. 10 Variability of cetacean species richness and diversity (Shannon-Weaver and Simpson indices) tested in the whole surveys, from 2011 to 2013 off north-eastern Sardinia.

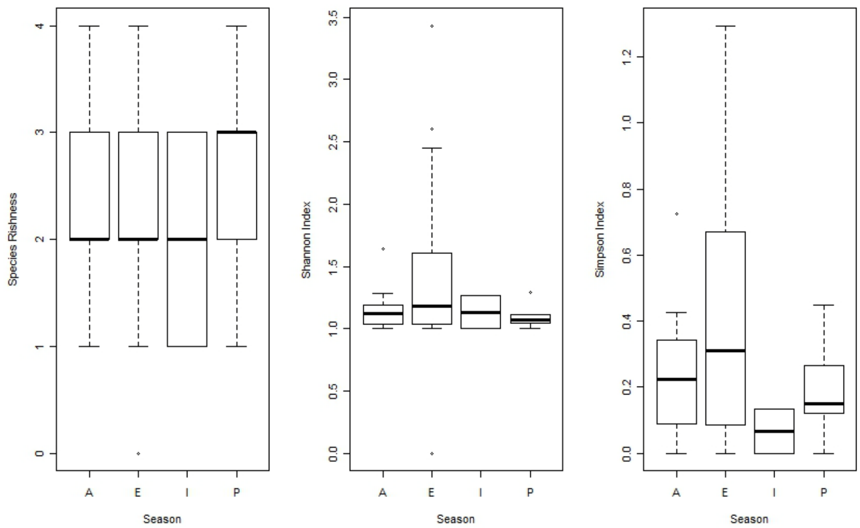

Fig. 11 Seasonal variability of species richness and diversity indices of Shannon-Weaver and Simpson calculated in the whole dataset of surveys during the study period (2011-2013) off north-eastern Sardinia.

Spatial distribution

The spatial distribution of species differs within the study area. As expected, by comparing the presence-absence data striped and bottlenose dolphin show clearly distribution pattern in Northeastern Sardinia waters. Striped dolphin occurs in more offshore waters than bottlenose dolphin, which is primarily restricted to continental shelf of Sardinia (Fig. 6a).

Cuvier's beaked whale and Risso's dolphin showed a distribution pattern more related with steep slope and with the Caprera Canyon system (Fig. 6b). The fin whale occurred both in shallow and deep waters while sperm whale showed a clear preference both for the slope and the steep areas of the Caprera Canyon (Fig. 6c). During the study period, several incidental sightings of fin whales (not detailed in this paper) occurred very close to the Sardinia coast occasionally entering small bays and harbours, and within the Strait of Bonifacio (DIPNET, unpublished data) according to Notarbartolo di Sciara *et al.* (2003).

Tab.4 Mean (± SD) of main covariates; depth, slop, aspect and school size for cetacean sightings, off north-eastern Sardinia.

Species	Depth (m)	Slope (%)	Aspect (°)	School size (n)
Z. cavirostris	871.16 (99.68)	7.64 (6.46)	164.65 (111.48)	2.0 (0.93)
S. coeruleoalba	793.40 (155.00)	7.26 (7.04)	147.50 (106.40)	17.5 (15.28)
G. griseus	769.00 (64.07)	3.86 (2.88)	181.30 (129.77)	10.3 (4.86)
P. macrocephalus	757.05 (92.52)	6.72 (6.62)	212.22 (139.17)	4.0 (4.51)
B. physalus	757.02 (256.05)	6.58 (7.18)	153.71 (111.59)	1.6 (0.82)
T. truncatus	81.37 (93.79)	1.43 (1.59)	134.92 (104.30)	4.5 (3.50)

Species	Depth range (m)	Slope range (%)	Aspect range (°)	School size range (n)
Z. cavirostris	673-1248	0.36-23	6.98-355.37	1-4
S. coeruleoalba	336-1229	0.2-32.94	4.71-358.58	1-80
G. griseus	685-820	1.01-7.32	11.31-325.54	3-13
P. macrocephalus	606-840	0.71-17.46	43-355.37	1-11
B. physalus	91-1292	0.95-33.34	7.09-355.91	1-5
T. truncatus	20-534	0.02-5.94	0.43-345.63	1-15

Bottom depth relative to the entire cetacean species dataset at initial sighting positions ('on-' and 'off-effort' sightings) ranged from 1292 to 91 m (mean = 743 m, SD = ± 253, SE = ± 12, n = 419) (Tab.4).

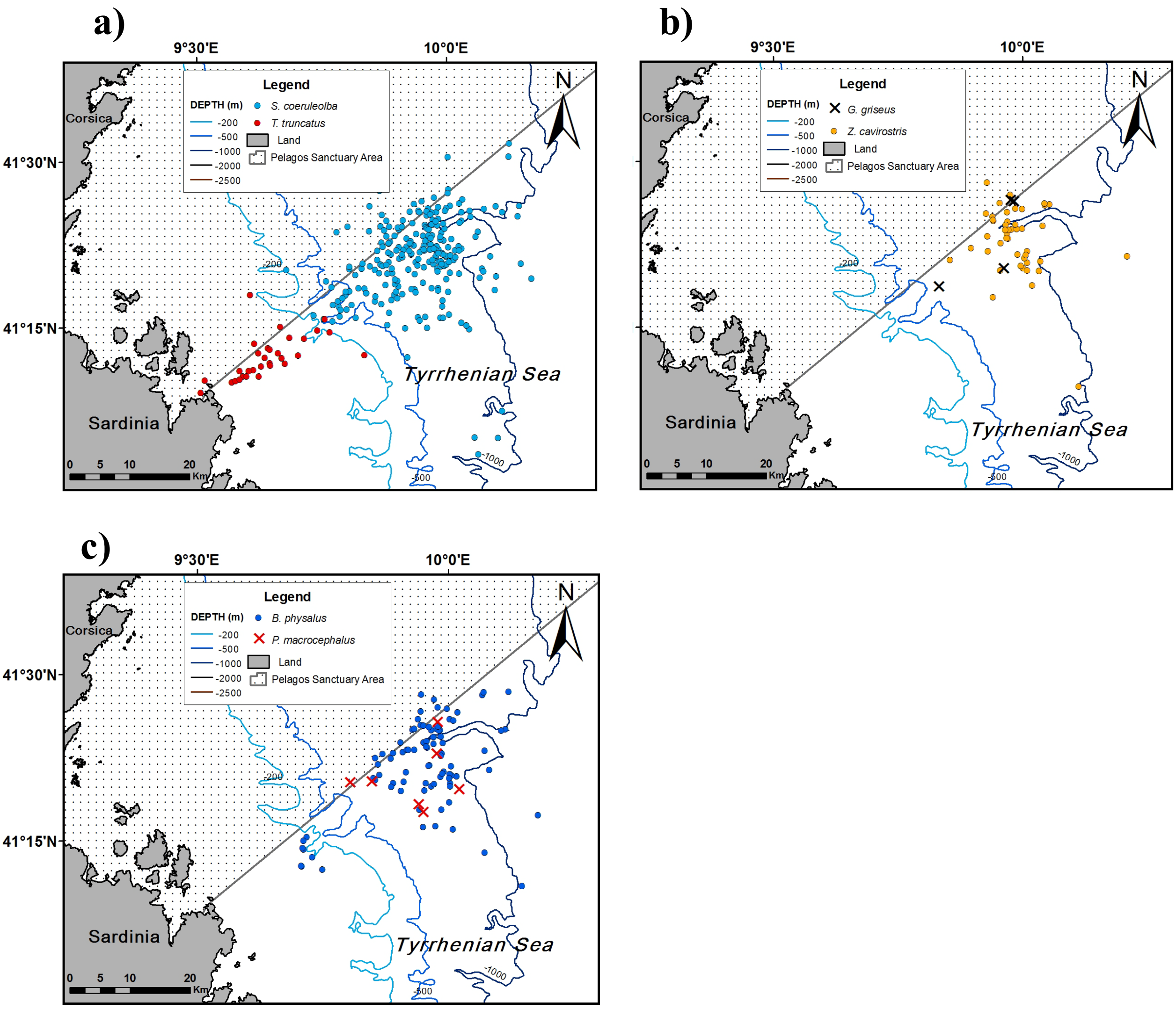

Fig. 6 Distribution of striped and bottlenose dolphin (a); Risso's dolphins and Cuvier's beaked whale (b); fin and sperm whale (c) over the study area during the entire period (2011-2013). Most of the sightings were out of the Pelagos Sanctuary South-eastern border.

Distribution of cetaceans in relation to physiographical features

Cuvier's beaked whale. This species in the Caprera Canyon area showed preference for the deepest water (ranging from 673-1248m, mean=871.16, SD=99.68, SE=14.86) and steeper sea floor (0.36-23%, mean=7.64, SD=6.46, SE=0.96) with the highest values of mean depth and slope between cetacean species encountered (see Tab. 4). In the Pelagos Sanctuary area Moulins *et al.* (2007) highlighted that the number of Cuvier's beaked whale sightings (n=247) was higher between 756 and 1389 m of depth and more frequent (34 %) where the sea floor slope was between 3.1 and 5.1 %. Finally, Gannier (2011) focused that the mean depth of 22 sightings was 1124.41 m (SD=298.94, SE=63.74) in an area ca. 40 Km north of the Caprera Canyon from 2007 to 2008.

Risso's dolphin. This species had the smallest range of depth (685-820m, mean depth=769m, SD=64.07, SE=32.03) and even slope (range 1.01-7.73%, mean=3.86, SD=2.88, SE=1.44). In the central Mediterranean Sea, Notarbartolo di Sciara *et al.* (1993) described the highest encounter rates of Risso's dolphin (n=12) in areas 1000 m deep (range 750-2500 m, mean 958 m, SD=531, SE=153). Praca & Gannier (2008) modelled the distribution of Risso's dolphins in the North-western Mediterranean, arguing that the its main habitat was restricted to the upper part of the continental slope at a mean depth of 638 m and 6.291 % of slope with an ecological niche differentiation between this species and the sperm whale and pilot whale.

Striped dolphin. This species showed a high depth range from 336 to 1230m (mean depth=769, SD=155 SE=9.94) due to their known widespread occurrence in many habitats and even a wide slope range (0.20-32.94 %, mean=7.26, SD=7.04, SE=0.45). Notarbartolo di Sciara *et al.* (1993) pointed out for striped dolphin in the Central Mediterranean Sea a mean depth of 1490 m (range 25-2500m, SD=836, SE=93) while Arcangeli *et al.* (2012) compared the mean depth and slope of striped dolphin in the central Tyrrhenian Sea (close to our study area) relative to two periods: 1990s and 2000s (respectively: depth 1021 m, SD=24 *vs.* 1041 m, SD=29; slope: 4.03%, SD=0.21 *vs.* 4.05%, SD=0.24). Striped dolphin was the species with the greatest mean group size MGS=17.5 (Tab. 4).

Fin whale. The largest species, had the highest values of depth range (91-1292 m, mean 757.02 m, SD=256.05, SE=27.14) and of sea floor slope range spanning from 0.10 to

33.34 % (mean 6.58, SD=7.18, SE=0.96). Arcangeli *et al.* (2012) found that in the central Tyrrhenian Sea mean depth and slope of fin whale in 1900s and 2000s were relatively similar. Mean depth ranged from 1012 m (SD=49) in 1990s to 1066 m (SD=36) in 2000s; slope range was 4.03 % (SD=0.21) in 1990s to 4.05 % (SD=0.24) in 2000s. The fin whale depth distribution we found off North-eastern Sardinia was bimodal, with 90.8 % of sightings occurring in deeper and 9.2 % (n=8) in shallower waters, less than 200 m of depth, over the wide continental shelf.

The latter were all encounters with young individuals (group size ranging: 1-2). Moreover, the fin whale is primarily observed in deep offshore waters, although its occurrence over the continental shelf is not unusual (Notarbartolo di Sciara *et al.,* 2003; Aissi *et al.*, 2008) due to feeding on small fishes as observed by Beaubrun *et al*. (1999) near the coast in the Gulf of Lions, or even on the euphausiid *Nyctiphanes couchi*, as described by Canese *et al*. (2006) in the waters surrounding the Lampedusa island, at a depth less than 100 m. In our study area, the mean group size was 1.6 with a peak on June, 2013 with 5 individuals.

Sperm whale. Around the Caprera Canyon sperm whale sightings (n=7) showed a smaller depth range (600-840 m) than those of the fin whale (mean=757 m, SD=92.52, SE=34.97) but with a higher slope range (0.71-17.46 %, mean=6.72, SD=6.62, SE=2.50). Probably this range was lowered by the presence, within the overall sightings, of two different observations of social units with group size >10 individuals, sighted in summer 2013 in mean depth of 745 m and a slope of 2.59%. In the Central Mediterranean Sea, Notarbartolo di Sciara *et al.* (1993) found sperm whale (n=12) at mean depth of 1433 m (range: 450-2500 m, SD=845, SE= 244). According to Praca & Gannier (2008) the characteristics of the suitable area of this species were: mean depth of 1748 m, and mean slope of 3.67%. Regarding the slope Cañadas *et al.* (2002) showed that sperm whales in the Alboran Sea did not show any preference for a slope gradient.

Analysis of physiographical and ecological covariates

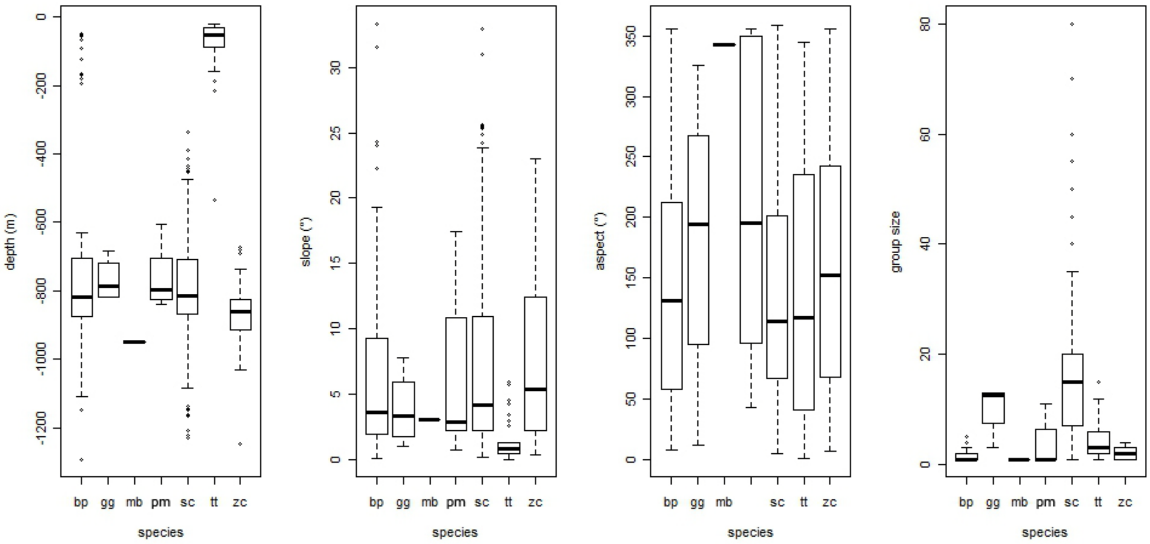

Fig. 12 Comparison between the distributions of the covariates (depth, slope, aspect, and group size) of the cetacean species encountered off north-eastern Sardinia..

To test if any differences in cetacean species distribution with respect to depth, slope and aspect and if group size is significantly different among species, we applied a Kruskal Wallis test (KW, non-parametric ANOVA).

When significant results occurred, we have implemented a series of tests (WMW, Wilcoxon-Mann-Whitney rank sum) as a 'post hoc' to test between pairs of species any different covariate values.

When we analyzed separately the different covariates, the variables that showed significant values were depth (KW χ^2 = 103.50, df = 6, p-value < 0.0001), slope (KW χ^2 = 51.6305, df = 6, p-value = 2.213) and group size (KW χ^2 = 244.5732, df = 6, p-value < 2.200).

However, there is no significant difference in aspect variable for the different cetacean species. Tabs 5-7 show the post hoc tests for multiple comparison of the distributions of the main covariates associated with sightings.

Tab. 5 Depth

	bp	gg	pm	sc	tt
bp	-				
gg	W=133.5 p=0.40	-			
pm	W=230.5 p=0.25	W=14 p=1	-		
sc	W=10555 p=0.74	W=588.5 p=0.47	W=1028 p=0.35	-	
tt	W=86, P<0.0001	W=0 P<0.01	W=0 p<0.0001	W=16 p<0.0001	-
zc	W=2605 p<0.01	W=153 p<0.05	W=268.5 p<0.01	W=7365 p<0.001	W=1485 p<0.0001

Tab. 6 Slope

	bp	gg	pm	sc	tt
bp	-				
gg	W=200 p=0.68	-			
pm	W=308.5 p=0.97	W=13 p=0.93	-		
sc	W=9869 p=0.22	W=375 p=0.43	W=789 p=0.74	-	
tt	W=2487, P<0.0001	W=109 P<0.05	W=193 p<0.001	W=7005 p<0.0001	-
zc	W=1729.5 p=0.20	W=63 p=0.32	W=143 p=0.70	W=5173.5 p=0.57	W=181 p<0.0001

Tab. 7 Group size

	bp	gg	pm	sc	tt
bp	-				
gg	W=7 P<0.001	-			
pm	W=269 p=0.51	W=25.5 P<0.05	-		
sc	W=841.5 p<0.0001	W=363 p=0.38	W=234.5, p<0.01	-	
tt	W=540.5, P<0.0001	W=110 P<0.05	W=82.5 P=0.23	W=6813 p<0.0001	-
zc	W=1496 p<0.01	W=171.5 p<0.01	W=156.5 p=0.98	W=10336..5 p<0.0001	W=1097 p<0.001

SEASONAL MODELLING

Modelling seasonal cetacean distribution and diversity

To explore the effect of seasonality, we modelled the seasonal cetacean distribution with GLMM, using a subset of the seasonal dataset, as the graphical analysis of the only four seasons (Fig.7) not allowed us to find any pattern. Therefore, we explored the data with the time variable of the year's week, to have a best seasonal detail and to graphically better represent any trend in the data description.

Statistical analysis did not allow us finding any significant seasonal pattern for the cetacean species encountered in the study area, off North-eastern Sardinia.

Modelling with GLMM the seasonal analysis of all the cetacean species dataset, it is evident that during the study period, there were no significant statistical differences between the different seasons (Tab. 8), with very similar post-mean values and a high overlap of the credible intervals (CI) of the seasonal ER posterior estimates.

We modelled the analysis only on the most sighted pelagic species: striped dolphin, fin whale and Cuvier's beaked whale. Models are based on 324 'on-effort' cetacean sightings records (the entire dataset).

Furthermore, wodelling the cetacean diversity indices, we tested this result with a MCMCglmm model to assess if seasonal variability of species richness and Shannon and Simpson diversity indices varied by season.

Year was fitted as additive random term, to account for repeated measurements and avoid pseudoreplication and diversity indices values and season was fitted as interacting fixed effects. The results (Tab. 9) showed that none of the seasons has significantly different values of species richness and diversity.

Seasonal analysis of fin whale dataset

Similarly to the entire dataset analysis, the fin whale data do not show that abundance differs significantly between seasons.

This may partly be due to the lack of data during winter and spring, but there is no difference even for those well-sampled seasons (e.g. summer-autumn), suggesting that fin whales at least long time stay within the study area.

However, as the graphical analysis of ER suggests, this cannot be considered as a definitive result.

In fact, the decrease in ER during autumn seasons in 2011 and 2012 (Fig. 4) and the model results (Tab. 8) may be explained with a gradual movement of whales away from the area during the early winter season, when prey availability and ecological need affect the whale movement across the Mediterranean Sea.

We can consider the possibility of nomadic behavior rather than actual seasonal migrations (aggregation-dispersion scheme according to Notarbartolo di Sciara *et al.*, 2003). To test this hypothesis new winter and spring surveys are necessary to implement the annual dataset.

Seasonal analysis of striped dolphin and Cuvier's beaked whale dataset

Modelling the striped dolphin and Cuvier's beaked whale seasonality, we would be more confident in indicating an absence of seasonality for both species and considering them almost sedentary within the Caprera Canyon area, even due to overlapping intervals of abundance (see also Figs 10a and 10c, where is impossible to draw a trend line).

Although there is a clear sub-sampling relative to the winter months, we can state, with a good approximation, that there are no visible seasonal trends for Cuvier's beaked whale and striped dolphin (Fig. 9), therefore, it is evident that striped dolphin and Cuvier's beaked whale occur throughout the year in the Caprera Canyon area, off North-eastern Sardinia. However, further winter surveys would be necessary to confirm these results.

Tab. 8 Posterior estimates and credible intervals of GLMMs for cetacean Encounter Rate, with year (2011-2013) as random effect and season (Spring, Summer, Autumn, Winter,) as fixed effect. Data was collected in North Sardinia (Italy), from 2011 to 2013. Models are based on 70 surveys from 2950 km of navigation for line transect monitoring. *NS*: non significant MCMC probability value.

Total sightings

Factor		Post.mean	Lower-95% CI	Upper-95% CI	pMCMC
(Intercept)		13.485	9.643	17.060	$p < 0.001$
Season					*NS*
	Spring	10.775	4.971	16.286	
	Summer	11.415	9.235	13.304	
	Autumn	13.360	9.654	17.375	
	Winter	11.321	2.373	21.396	

B. physalus

Factor		Post.mean	Lower-95% CI	Upper-95% CI	pMCMC
(Intercept)		2.700	0.555	4.721	$p < 0.001$
Season					*NS*
	Spring	3.414	0.250	6.440	
	Summer	3.340	1.931	4.309	
	Autumn	2.870	0.750	4.725	
	Winter	0.085	-4.841	5.172	

S coeruleoala

Factor		Post.mean	Lower-95% CI	Upper-95% CI	pMCMC
(Intercept)		9.017	6.171	11.461	$p < 0.001$
Season					*NS*
	Spring	6.680	2.526	10.739	
	Summer	5.780	4.215	7.378	
	Autumn	9.011	6.473	11.674	
	Winter	9.835	3.278	16.186	

Z. cavirostris

Factor		Post.mean	Lower-95% CI	Upper-95% CI	pMCMC
(Intercept)		1.358	0.132	2.5949	$p < 0.001$
Season					*NS*
	Spring	1.107	-1.103	3.064	
	Summer	1.817	1.092	2.514	
	Autumn	1.388	-0.097	2.602	
	Winter	0.088	-3.380	3.499	

Tab. 9 Seasonal analysis of diversity and species richness. Posterior estimates and credible intervals of GLMMs for cetacean richness and diversity, with year (2011-2013) as random effect and season (Spring, Summer, Autumn, Winter,) as fixed effect. Data was collected in North Sardinia (Italy), from 2011 to 2013. Models are based on 70 observations from 2950 km of navigation for line transect monitoring.
NS: non significant MCMC probability value.

Species richness					
Factor		**Post.mean l-95% CI**	**Lower-95% CI**	**Upper-95% CI**	**pMCMC**
(Intercept)		2.2214	1.531	2.836	*p* < 0.001
Season					*NS*
	Spring	2.592	4.971	3.4292	
	Summer	2.460	2.177	2.7643	
	Autumn	2.220	1.675	2.8439	
	Winter	1.983	0.540	3.4041	
Shannon index					
(Intercept)		0.242	0.048	0.406	*P* < 0.001
Season					*NS*
	Spring	0.200	-0.070	0.527	
	Summer	0.400	0.320	0.498	
	Autumn	0.246	0.063	0.435	
	Winter	0.072	-0.354	0.505	
Simpson index					
(Intercept)		1.159	0.874	1.407	*P* < 0.001
Season					*NS*
	Spring	1.097	0.680	1.5485	
	Summer	1.372	1.229	1.4883	
	Autumn	1.162	0.899	1.4231	
	Winter	1.130	0.543	1.819	

DISCUSSION

The presence off Northeastern Sardinia of small, close-spaced canyons with steep slope and seamounts together with a water mass circulation inducing persistent upwelling may enhance the productivity, affecting cetacean species distribution in both direct and indirect ways (see Croll, *et al.*, 2005). The Caprera Canyon is characterised by high values of species richness, diversity and relative abundance of cetaceans than the adjacent shelf waters, with seven species out of the eight regularly occurring species in the Western Mediterranean Sea. This high abundance may be relate the Caprera Canyon area to an 'hot spot' of cetacean (Bittau & Manconi, 2011, 2013ab) identified as location where the cetacean species occurred at a significantly greater frequency than expected according to Moulins *et al.* (2008).

In this study, the use of both opportunistic platforms and systematic surveys with dedicated platforms allow us to assess first, relevant information about the occurrence, distribution and relative abundance of cetaceans off North eastern Sardinia, in the Caprera Canyon area. Platforms of opportunity, such as whale watching vessels, are valuable tools of monitoring cetaceans and can be used on a long-term basis. In this study, they enabled access to offshore areas off Sardinia for a very low cost. However, limitations and biases in spatial and temporal coverage are due to this kind of platforms. Nevertheless, the protocols used in this study enabled surveying to be completed through several habitat types (shelf, shelf edge, and canyon systems) thanks to good cooperation with the whale watching companies to define both protocols and guide lines. The collected data enabled us to investigate how cetaceans distribute in relation to different habitats, particularly for depth, slope and aspect. Moreover encounter rates and group size data help to provide an accurate picture of the temporal distribution of the seven recorded species, with the use of effort-related data, in relation to the main habitat types.

Most species were sighted mainly within the continental slope habitat. The striped dolphin was the commonest and most widespread species, being present all year-round in the Caprera Canyon area and over the continental slope off North eastern Sardinia, as typical habitat. Group size of this species varied considerably during the study period, with larger groups sighted during summertime and even increasing throughout the years. Despite this we recorded, at the same time, a decrease of the striped dolphins' encounter rate (Fig. 4). This may have occurred as a result of the atypical mortality events occurred along the Tyrrhenian Sea Italian coastline during the winter 2012-2013 (>100 carcasses collected from January to April 2013 (unpublished data, Italian Ministry of Environment). However, due to ongoing studies, this hypothesis needs further evidence to be verified, as well as the analysis of more stranding data and further large-scale survey at the entire Tyrrhenian basin level. The 50 % of the examined striped dolphin carcasses were positive to *Dolphin Morbillivirus* and 65 % was affected by a common bacterium *(Photobacterium damselae* subsp*. damselae*) with hemolytic and necrotic findings (Di Guardo & Mazzariol, 2013). *Dolphin Morbillivirus* has caused at least four epidemics in the Western Mediterranean during the last 20–25 years, dramatically impacting the health and conservation of striped dolphins living in this area (Di Guardo & Mazzariol, 2013). The data we collected can be useful to increase local knowledge on striped dolphin in the central Tyrrhenian Sea.

The fin whale is the second most frequently recorded species, with a bimodal distribution, particularly concentrated in deepwater, over the continental slope and the Caprera Canyon and even, to a lesser extent, over the continental shelf in shallower water. This species showed a yearly and seasonally variability in occurrence and distribution, probably reflecting its ecological traits and highly mobile pattern. Higher occurrence was detected in 2011 and 2013 with a decrease in 2012. No sightings of fin whales are reported in deep water of the study area during wintertime because of the occurrence of a lack of sampling due to weather constraints that affected the surveys, but several incidental sightings occurred in very shallow waters in late winter.

The Cuvier's beaked whale showed a preference for the deepest waters and steepest sea bottom floor, especially the Caprera Canyon area. This species did not have a significant seasonal occurrence. During summertime it was sighted several times with calves.

The sperm whale has largely offshore distribution, centred upon the continental slope where water depths exceed 500 m. Sperm whales were mainly summer visitors to the Caprera Canyon, occurring during July and three times observed in social units with more than ten individual, with females, calves and young males.

The Risso's dolphin showed the most variable inter-annual distribution and was the least common species with the lowest relative abundance occurring exclusively in slope areas.

The common bottlenose dolphin showed a low occurrence, as was expected considering the habitat features that have been surveyed. The species was distributed above the continental shelf, with rare detection on the shelf-break. The recorded seasonal pattern of distribution is most likely due to noise disturbance in the summer for the high presence of boats in the coastal area, forcing the animals to look for areas acoustically less noisy at the edge of their habitat range, as well as for a flexible adaptation in relation to the seasonal change in prey availability.

The short beaked common dolphin was seen in the study area only two times, in August and September 2013, but the data were not analyzed in the present paper. Another species (one individual) was encountered on a single occasion in the Caprera Canyon area is the Sowerby's beaked whale (*Mesoplodon bidens*). This is the first, ever documented

Mediterranean record of a free ranging *M. bidens* (Sowerby, 1804) (Bittau *et al.*, present thesis).

As for the potential role of the study area as cetacean nursery we focus on the records over the three years of study of newborn calves with foetal folds observed for bottlenose, striped, Risso's, short beaked common dolphin and Cuvier's beaked whale. Calves have been observed several times in all the encountered cetacean species.

The use of responsible whale watching platforms allows us to collect data for unambiguous species identification and group composition. Carrying out systematic survey enabled us to collect data even in areas not covered by the opportunistic routes. Therefore, we were able to record sightings of fin whales in shallow waters, above the continental shelf.

The cetacean ER values, together with the presence of newborns of all species and records of cryptic species (e.g. beaked whales) point out the special conservation interest of the study area supporting the proposal of an open sea SPAMI in the Tyrrhenian Sea.

Significant differences among the species were found regarding environmental variables such as depth, slope, aspect and group size. General Linearized Model (GLMM) showed (not significantly) that distribution of fin whales is related to depth, probably due to the shallow water encounters. In contrast, the probability to detect odontocetes is significantly proportional to the depth and is related with the Caprera Canyon slope values. Temporally, only the relation for odontocetes is significant, with an increased probability to be detected over the years, with a peak (not significant) in July.

Despite the positive biased ER the area off North-east Sardinia appears to have a high density of cetaceans, compared to other areas in the western Mediterranean Sea. Diversity indices showed significant high values, compared with those of other Tyrrhenianareas investigated by Gannier (northern and sounthern Tyrrhenian Sea). Although the Corsica and Ligurian seaa are characterised by the most productive pelagic waters of the entire Mediterranean harbouring a richer cetacean fauna, our study points out that even small-scale survey are needed to highlight other areas of high density of cetaceans, and to investigate the presence of rare or inconspicuous species such as Cuvier's beaked whales. The regularly presence and relative abundance of cryptic species such as Cuvier's beaked whale, observed with calves and newborn, suggests that the Caprera Canyon may even be an important feeding and breeding area for this Mediterranean beaked whale.

For relatively low cost, the integration of datasets from platform of opportunity and dedicated vessels may offer potential for identification of areas of relative high density that help to plan more efficient strategies of conservation management. Nevertheless, further systematic studies covering a larger temporal and spatial range need to be developed off North-eastern Sardinia, because several new records have been documented (Sassari University, unpublished data) from incidental sightings. Finally, new investigations should be required as mark-recapture methods via photo-identification studies, in order to provide further information on movements, site fidelity and population parameters (as in Hammond, 1986, 1990).

CONCLUSION

Before this study, little was known about the species richness and distribution of pelagic cetaceans off North-eastern coast of Sardinia, particularly in the Caprera Canyon. Although all presently recorded species have been reported previously for central Tyrrhenian waters, the present study is a small scale study focused in a suggested ‘hotspot’ of cetaceans (Bittau & Manconi, 2011) defined as location where the cetaceans occurred at significantly greater frequencies than expected (Moulins *et al*., 2008).

The monitoring of three consecutive years of the Caprera Canyon area allowed collecting important information about the presence and distributions of cetaceans, within the Central Tyrrhenian Sea. Species occurrence, diversity and relative abundance indices have little variability in the study area that we investigated. Overall, the high diversity of cetacean recorded off North-eastern Sardinia seems to be related to both the diversity of habitat types occurring there and the presence of a high productivity area together with a canyon system. The high diversity of species combined with the high level of encounter rate underline the importance of the Caprera Canyon area to cetaceans, just a little outside the Pelagos Sanctuary boundary.

Our results provide significant, descriptive information that is critical for conservation and management efforts off North-eastern Sardinia, within a proposed open sea SPAMI area, the central Tyrrhenian Sea (UNEP, 2010). Human activities, especially maritime traffic, fishing pressure, and pollution are growing off North-eastern Sardinia due to the presence of near important neighbouring ports. Further effort is needed to assess the spatial and temporal interactions between maritime human activities and cetaceans around this probable 'hot spot' for cetaceans, but certain 'hot spot' for several human impacts. We suggest that a year-round Marine Protected Area is necessary for the Caprera Canyon as a core area within the proposed central Tyrrhenian Sea open sea SPAMI (UNEP, 2010).

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Chapter 2

Seasonal occurrence and distribution of fin whale (*Balaenoptera physalus*) and oceanographic variables off eastern Bonifacio Strait (Central Tyrrhenian Sea)

Seasonal occurrence and distribution of fin whale (*Balaenoptera physalus*) and oceanographic variables off eastern Bonifacio Strait (Central Tyrrhenian Sea)

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ABSTRACT

The seasonal and inter-annual distribution of Mediterranean fin whales (*Balaenoptera physalus*) during 2011-2013 off the North-Eastern coast of Sardinia is investigated in relation to physiographic and oceanographic variables. The waters off N-E Sardinia are a particularly productive area of the central Tyrrhenian Sea, adjacent to the Pelagos Sanctuary for the Conservation of Mediterranean Marine Mammals. The hydrographic conditions results in the northern sector in an upwelling, with high primary productivity, and downwelling in the adjacent southern, with relative convergence and low productivity. During the study period, opportunistic and systematic surveys were performed. Survey effort amounted to 9643 km with 70 days spent at sea, recording 87 overall sightings of fin whales. Mean yearly whale encounter rates showed significant differences between 2011 and 2012-13 years. The highest encounter rate and largest Mean Group Size (MGS) were during the summer seasons (mean summer ER=2.97; SD=0.72; mean MGS=1.73, SD=0.17). The MGS during the entire study period was 1.64 (SD±0.82, range = 1-5). For the three years of data examined here, physiographic covariate (depth, slope, and aspect) and satellite-derived sea-surface chlorophyll content (chl *a*) and Sea-Surface Temperature (SST) were used preliminarly to perform a qualitative approach. A robust modelling approach accounting for autocorrelation in the data was used to model the probability of whale presence across the study area as a function of environmental variables and to evaluate which environmental factors were associated with the observed dynamics at different spatial and temporal scales. Sightings occurred in areas with lower SST and higher spring productivity, indicating that fin whales generally preferred the deep, nutrient-rich water masses of the study area, but also showed that, over the time, the probability to sight whales decreased (not significantly). The abundance of fin whale North-east of Sardinia, both in shallow and deep waters, points out the special interest of the study area for conservation and may support the proposal to create an open sea SPAMI in the Tyrrhenian Sea in accordance with RAC/SPA and Biodiversity Protocol.

Key words: fin whale, remote sensing, Sardinia, Caprera Canyon, incidental sightings.

INTRODUCTION

Fin whale *Balaenoptera physalus* (Linnaeus, 1758) is the only representative of the Superfamily Mysticeti regularly found in Mediterranean Sea. Until 70s fin whale was generally considered to be a summer immigrant into the Mediterranean Sea from the neighbour Atlantic Ocean (Duguy & Vallon, 1976; Paulus, 1966). It is now thought that the Mediterranean fin whale population is part of a distinct resident population on the basis of genetic evidence from those in the North Atlantic (Bérubé *et al.*, 1998).

Currently there are three major gaps in knowledge about Mediterranean fin whales, namely 1) the lacks of a reliable abundance estimate of the resident population in the Mediterranean, 2) their movement patterns in the Mediterranean, and 3) their feeding and breeding behaviour in the region (Notarbartolo di Sciara *et al.*, 2003).

In 1991, line-transect surveys resulted in estimates of 3,583 fin whales (S.E. 967. 95% C.I. 2.130-6,027) over a large area of the Western Mediterranean (Forcada *et al.*, 1996) and 901 (S.E. 196.1.95% C.I. 591-1.374) in the Corsican-Ligurian-Provençal Basin in 1992 (Forcada *et al.*, 1995). Further line-transect survey effort in the same area resulted in density estimate of 0.015 individuals km^{-2} by Gannier (1997). The results from Castellote *et al*. (2011) may lead to re-evaluation downward for the population size estimate of the Mediterranean fin whales in the North-West of the basin due to the presence of occasional immigrant whales from the Eastern North Atlantic Ocean into the Western Mediterranean.

Recently the relationship between Mediterranean and North Atlantic fin whales was highlighted by Castellote *et al.* (2011), suggesting that the North-eastern North Atlantic fin whale distribution extends into the southwest Mediterranean basin, with spatial and temporal overlap between the relative two subpopulations. The distribution range of Mediterranean fin whales could be smaller than previously defined and the two subpopulations may be using the same Mediterranean niche and likely competing for the same resources.

The latest studies on stable isotopes confirm that some Atlantic fin whale individuals do penetrate into the Mediterranean Sea up to the northernmost latitudes of the region and that the subpopulation borders are not as strict as previously thought (Giménez *et al.*, 2013).

Furthermore, the fin whale habitat is widely variable across the currently known Mediterranean range (Notarbartolo di Sciara *et al.*, 2003). Due to the high inter-annual variability of potential habitat, fin whales may be likely to follow seasonal patterns of recurrent favourable habitats covering large distances searching for food or calving/breeding areas with an important ability for spotting productive areas at the scale from 10s to 100s of kilometres (Druon *et al.*, 2012). Moreover, a satellite tracking of 8 tagged Mediterranean individuals in 2008 highlighted that during winter, fin whale show a clear tendency to remain north of the Balearic Islands, reflecting a regional fidelity to the North-western Mediterranean (Cotté, 2009).

The protection of fin Mediterranean whales and all marine mammals against every cause of disruption and threats originating from human activities has been tried with the establishment of the Pelagos Sanctuary. It covers a more or less triangular area (ca. 87,000 km²) whose apex is in the sea between Capo Falcone (North-western Sardinia) and Capo Ferro (North-eastern Sardinia) and the base in continental Europe from the French Riviera to Tuscany. This area is believed to be the main Mediterranean feeding ground for fin whales thanks to the oceanographic features supporting high levels of prey biomass (Notarbartolo di Sciara *et al.*, 1993, 2008; Gannier, 2002). After its establishment, the majority of research efforts have focused on the northern part of the Pelagos Sanctuary, mainly focusing on the Ligurian-Provencal basin with little effort on the southern part.

In the Pelagos Sanctuary area bathymetric features were considered the most valuable predictors for fin whale while Sea Surface Temperature values were indicators of whale presence due to a tendency to prefer colder waters (21–24 °C) (Panigada *et al.*, 2008).

In spite of the semi-enclosed Mediterranean basin has long been considered oligotrophic with low levels of nutrients and productivity the recent availability (late 90s) of satellite-derived data from Sea-viewing Wide Field-of-view Sensor (SeaWiFS) imagery has revealed the existence of several areas with intermediate to high productivity (high chlorophyll-*a* values) scattered in the Aegean and Adriatic seas, off the coasts of Spain and France, and in the Tyrrhenian Sea (Artale *et al.*, 1994; Notarbartolo di Sciara *et al*., 2008). In this scenario local upwelling east of Bonifacio produces strong surface thermal gradients (Littaye *et al*., 2004).

In the Central and Western area of the Pelagos the distribution and the habitat preference of fine whale was found mainly associated with pelagic areas at depths of 2000 m or higher (Gannier, 1995) and the probability of detecting fin whales is proportional to depth and slope (Notarbartolo di Sciara *et al*., 2003). Long term monitoring trough ferry transects in the central Tyrrhenian Sea, found that fin whales have strongly increased (+300%, $P<0.001$) over two decades with a drastic difference in spatial and temporal distribution and habitat preference (Arcangeli *et al*., 2012).

Regarding moving patterns, Marini *et al*. (1997) suggested that Mediterranean fin whales migrate seasonally from northern feeding grounds in the Ligurian Sea to southern breeding areas near the North African continental shelf. If Mediterranean fin whales is known to gather during summer in highly productive areas to feed, their winter distribution is still unknown (Notarbartolo di Sciara *et al.*, 2003).

The migratory movements to and from the Ligurian Sea are related with the distribution of highest primary productivity and food availability of the Ligurian-Provencal basin throughout the Mediterranean basin (Notarbartolo di Sciara *et al.*, 1993).

As the other cetacean species, there is a strong link between the habitat choice, distribution of fin whale and the prey availability (Orsi Relini *et al.*, 1992a; Relini *et al.*, 1994). Fin whale feed typically of Northern krill, the Euphausiid, *Meganyctiphanes norvegica* (M. Sars, 1857) (Viale, 1985; Orsi Relini & Giordano, 1992b; Notarbartolo di Sciara *et al*., 2003). As for the relathionships among trophic role and seasonal behaviour Recently in the Sicily Channel, (late winter) feeding aggregations of fin whales have also been observed and fin whale were engaged in surface feeding activity on the other Euphausiid species, *Nyctiphanes couchi* (Bell, 1853) living in Mediterranean Sea (Canese *et al*. 2006). Finally Mediterranean fin whales may feed on small mesopelagic fishes such as sardines or anchovies, as the whales occupy the same mean trophic level as these fish species (Bentaleb *et al.*, 2011).

Occurrence of fin whales off North-East Sardinia also involves shallow waters, crossing Marine Protected Areas and further north the International Marine Park of the Strait of Bonifacio (Bittau *et al.*, 2013). Fin whales are known to occur also in shallow waters, e.g. the continental shelf off the northeastern coast of the United States and Canada (Hain *et al.*, 1992) due to surface feeding activity. In the Mediterranean Sea, the shelf waters of the Sicily Channel and around Lampedusa Island hosts fin whales in late winter, engaged in surface feeding activity (Canese *et al*., 2006). In February 2010 and 2011, surface feeding activity has been observed in North-eastern Sardinian coastal waters, with depth less than 100 m (Magnone *et al*., 2011). Fin whales are also known occasionally to enter ports, bays and narrow channels. Some individuals may migrate crossing the straits such as the Strait of Gibraltar (Cotté *et al*., 2009; Castellote *et al.*, 2011) and preliminary results showed similar pattern within the Strait of Bonifacio (Arcangeli *et al.*, 2013; Bittau *et al.*, 2013).

The fin whale summer distribution in the northwestern Mediterranean Sea seems to be correlated with spring primary production including a time lag of a few weeks, but gradually become more correlated with short-term processes such as production peaks linked to thermal fronts.

Current conservation status

Currently, the IUCN Red List category of the Mediterranean fin whale subpopulation is classified as ‘Vulnerable’ (Panigada and Notarbartolo di Sciara, IUCN 2012). The species is listed in Appendix I of Convention on Migratory Species, in Appendix II of the Bern Convention, in Appendix I of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) and in Annex 2 of the Protocol on Specially Protected Areas and the Biological Diversity in the Mediterranean of the Barcelona Convention. For the present at least, Mediterranean fin whales are protected by the International Whaling.

In this study, we carried out an interdisciplinary investigation focusing on the seasonal and inter-annual occurrence and distribution of a large predator, the Mediterranean fin whale, to understand spatial and temporal patterns in a high primary productivity area that is thought to be a high density area of cetaceans, within the central Tyrrhenian Sea, off North-eastern Sardinia (Italy). We used the combination of three year sighting data with physiographic and remote sensing oceanographic data, to model fin whale densities according to oceanographic parameters.

Physiographic and oceanographic features of the Central Tyrrhenian Sea and the Bonifacio Strait

The Tyrrhenian Sea is the deepest of the Western basins (3,620 m) although the volume (ca. 328,000 Km^3) does not differ significantly from the other major regional basins of the Western Mediterranean Sea (Astraldi & Gasparini, 1994).

The basin extends its western border along the North-South coastline of Sardinia and Corsica, interrupted only by the Strait of Bonifacio. The latter is a narrow channel ca. 6.5 miles, further narrowing to 4 miles among the smaller closer islands of the La Maddalena and Lavezzi archipelagos in the International Marine Park of The Strait of Bonifacio.

Though affected by interesting physical processes, the smaller opening of the Bonifacio Strait is not considered to significantly contribute to the general Tyrrhenian basin circulation due to its limited cross-sections (Astraldi & Gasparini, 1994).

The physiography of the Tyrrhenian basin is very complex and the central part hosts a number of submerged structures such as systems of canyons and seamounts. The Caprera Canyon, just above the latitude of the Bonifacio Strait (41°18’N) extends approximately from 41°10’N to 41°25’N and from 09°39’E to 10°23’E, representing the main sea bottom morphological features eastward between Sardinia and Corsica islands. The 1,000 m isobath of the Caprera Canyon lies *ca*. 24 nautical miles (*ca*. 44 Km) from the nearest ground point on the Sardinian coast.

The entire canyon system is a turbiditic system, flanked eastward by the Etruschi Seamount, and westward by the 25 km north-eastern Sardinian continental shelf, narrowing southward, and partially confined by a 20 km wide continental slope with an average dip of around 2° (Dalla Valle, 2007).

In the upper slope, it consists of two tributaries canyon, *ca*. 15 km in lenght joining to form a single, ca. 1 km wide canyon at depth of 1,000 m lasting for a further 9 Km of length until 1,600 m of depth. Initially, the Caprera Canyon is oriented North-Eastward, later turns 65° South East, towards the Olbia basin (a fan valley) for about 20 km with a steep scarps on the external side (300 m in height) due to the presence of the Etruschi Seamounts ridge (Gamberi & Marani, 2004; Gamberi & Dalla Valle, 2009; Dalla Valle & Gamberi, 2010).

The presence of canyons may affect the circulation of water masses and oceanographic variables. It is known that upwelling associated with canyons may enhance local primary productivity, with positive effects extending up the food chain to include birds and cetaceans (Waterhouse *et al.* 2009; Würtz, 2012). Canyons represent cetacean feeding grounds, commonly located at the heads of the submarine feature (Hooker *et al*., 1999) so that the cetacean fidelity to these sites may be used to design MPAs (Hooker *et al.*, 1999).

A recent interest focused on the role of submarine canyons in the exchanges between the deep ocean and continental shelf, as well as in the functioning of the benthic and pelagic ecosystem (Würtz, 2012), led to highlight the importance of conservation and protection of these deep sea habitats.

Almost 518 large submarine canyons have been identified in the Mediterranean Sea (Harris & Whiteway, 2011) and they were considered as key structures for its ecosystem functioning. Submarine canyons were defined as “steep-walled, sinuous valleys with V-shaped cross sections, axes sloping outward as continuously as river-cut land canyons and reliefs comparable to even the largest of land canyons” (Shepard, 1963, 1981).

The oceanography of the Tyrrhenian Sea at mesoscale level is characterized by a main cyclonic circulation (the ‘Tyrrhenian Gyre’) along its limit, while in the inner sector occur several gyre structures. The circulation in the Western-central sector of the basin presents two main gyres, namely a cyclonic cell with a variable shape and size depending on the season, mostly located to the east of the Bonifacio Strait and a southernmost anticyclonic gyre adjacent of the first, off the Eastern coast of Sardinia (Small *et al.*, 2012).

These gyres are usually considered wind-driven (Artale *et al.*, 1994; Nair *et al.*, 1994), but recent studies revealed that topography may play an important role (Budillon *et al.*, 2009; Vetrano *et al.*, 2010). This specific wind field, mainly the West and Mistral winds, blow reinforced by the ‘Venturi effect’ through the Bonifacio Strait, inducing two large counter-rotating vortices and generating a filament of cold water just off the Northeastern Sardinian coast (Bignami *et al.*, 2008). This largest, Northern structure caused by the wind jet stream blowing all year round eastward through the Bonifacio Strait, is called the "Bonifacio Gyre" and appears as a quasi-permanent cyclonic circulation (Moen, 1984; Vetrano *et al.*, 2010).

The resulting northernmost cyclonic gyre carries a clear upwelling of colder waters with nutrients and increase in Chlorophyll concentration. These hydrographic conditions resulting in an upwelling in the northern area have a divergence of water mass and downwelling in the south, with adjacent relative convergence. In the central Tyrrhenian Sea, relationships with early spring primary production and the thermal front were observed and this front, related to local upwelling east of Bonifacio, produces strong surface thermal gradients (Littaye *et al.*, 2004).

After the recent availability of novel analytic tools and satellite data, it was also possible to evaluate the effects of physiographic and oceanographic features on the distribution of cetaceans, such as depth, slope, Sea Surface Temperature and Chlorophyll-*a* concentrations (e.g. Panigada *et al.*, 2005, 2008; Laran and Drouout-Dulau, 2007; Moulins *et al.*, 2007; Azzelino *et al.*, 2008, 2012; Laran and Gannier, 2008; Druon *et al.*, 2012).

MATERIALS AND METHODS

Fields methods

Survey methods remained relatively constant throughout this 3-year study period. Two vessels were used: the 11 m power catamaran 'Orso Cat' and the 16 m motor boat 'Over Winds'. On both vessels, the observation height from the flying bridge deck was approximately 6m above the sea surface. The primary team consisted at least of three trained observers: two, port and starboard were on the upper deck of the boat searching both through unaided eyes and 7x50 Nikon handheld binoculars with compass (typically from 10° on the opposite side of the bow to 90° on their side) and one centre trained observer searching 360° around by unaided eyes and occasional scanning by 7x50 handheld binoculars.

The centre observer in the Orso Cat boat was in 6 m sighting tower mounted onto the boat roof, while a flying bridge ca. 6 m above the sea surface was used in the monohull boat. One of the two observers on the main deck was also responsible for recording search effort and sightings data. Survey effort in time and space was quantified by recording every 5" the boat's position using a handheld Global Positioning System (GPS) Garmin E-Trex 20.

The vessels surveyed at 8-13 knots during daylight hours in 'on-effort' condition, according to survey protocol. The 'on-effort' conditions were based on two main points a) all observers in the correct position for visual search and b) sea-weather in 'favourable conditions' (daytime, Beaufort ≤3, sea state ≤ 2 Douglas, visibility ≥ 4 Km, swell high less than ca. 0.5 m).

Searching 'on-effort' start and end times were determined by slowing down or increasing the speed of the boat at i) the start/end time of the survey, ii) the start and end times of a sighting, iii) the worsening of weather conditions (when the sea and visibility conditions did not respect the 'favourable conditions') or iv) when, if opportunistic, the whale watching boat was stopped for and re-started up after a break.

After a positive detection of fin whales the boat was directed towards the animal(s) to obtain certain species identity, group size estimates and reliable position of the school, moving near to the dive position even if the animals dived deep, before the boat approach (modified from Barlow *et al.*, 2001). Immediately after making a sighting (and before turning the ship), we measured the bearing angle to each animal (or group) with compass binoculars and the distance using a measuring stick always held from the same position (the boat roof, ca. 3m high). During the approach, we kept the boat within a safe distance and often drifting, engine in neutral, in order to limit the disturbance to the animals and at the same time to observe and collect data on behaviour.

Animals were always approached, adapting the vessel speed and heading according to the ACCOBAMS' guidelines (Carlson, 2009; www.accobams.org). 'On-effort' condition was resumed when, at the end of a sighting, the vessel rejoined the trackline following the tangent to the direction that had been left due to a detection.

Sighting data were: sighting position of the primary sightings, time of start/end of the sighting, species identification, group size (minimum, maximum and best estimate), behaviour of the animal/s, position of the ship, and photo-identification data (not analyzed in this paper). Only definite species identifications were considered in this study. Thanks to the photo-Identification field work carried out in the framework of the present study, all the whales identified at species level were considered reliable and used for the analysis.

Groups were defined as individuals having the same activity and being in close proximity to each. We defined a ''sighting'' as a individual or group of fin whales seen at the same time showing similar behavioural traits, coordinate surfacing and diving patterns within approximately 1 km, according to what observed in the Ligurian Sea (modified from Azzelino *et al.*, 2008).

The sea and visibility conditiond were recorded every 60 minutes or more frequently if changes in conditions occurred. They were: wind direction (degrees), sea condition (Beaufort and Douglas scale for wind and sea state), swell height, cloud cover (%), precipitation and visibility (Km). Collected effort data were: GPS boat coordinates every 5"-10" during all survey tracks.

All field data collected on a data sheet format were logged into an Excel database after each survey (modified from Kiszka *et al.*, 2007). Additionally, photo-identification data were gathered and analyzed in a separate format. On return to the port, all the tracks and sightings data were downloaded from the GPS to a laptop computer using Garmin Software MapSource. Following, all the data were prepared to enter into ESRI ArcView 9.3 Geographic Information System (GIS) Geodatabase with Excel software (Microsoft). The depth, slope and aspect covariates at all initial fin whale sighting positions were extracted by overlaying point location data on a 150 m resolution bathymetric raster surface in ArcGIS Version 9.3 (ESRI).

Wind exceeding Beaufort 3 can affect the detection of small cetaceans (Hiby & Hammond, 1989; Buckland *et al.*, 1993; Hammond *et al.*, 1995) and also the overall cetacean detection probability may be biased downwards in poorer conditions. Fin whale sighting are less affected from this drawback and it is also possible to perform visual search of fin whale until Beaufort 4. Despite this, for the processing of encounter rates, only sighting data collected in 'favourable conditions' (not over Beaufort 3) and in 'on-effort' modality were included in the analysis.

Group size values used to provide mean, standard deviation, and range values were best estimates recorded at sea. The sightings made during 'off-effort' conditions were considered only for presence/absence data and were not used in the computation of encounter rate analyses. Differences in group size values between season and year were tested with a non-parametric Kruskal–Wallis test.

Study area

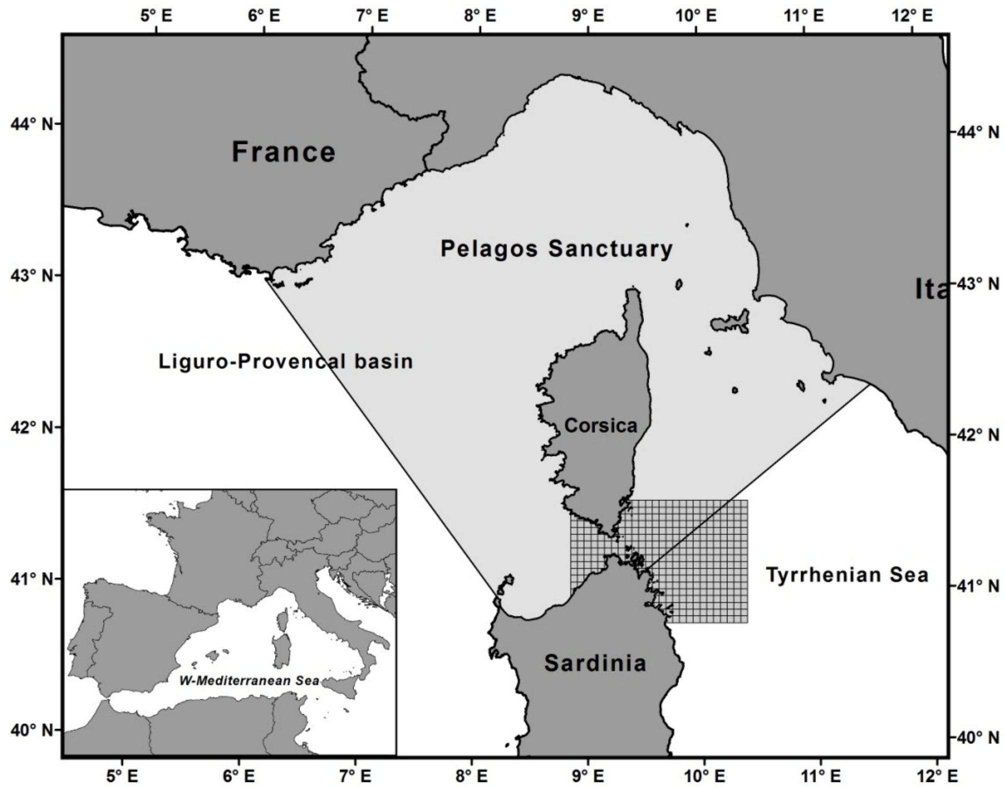

Fig. 4 Study area and the Pelagos Sanctuary boundaries (light gray).

The study area extends from the Eastern Corsican-Sardinian coast to longitude 10°16'E and between 41°05' and 41°35'N latitude. The area surveyed encompasses 5300 km^2 within the central Tyrrhenian Sea, including the Bonifacio strait and, eastward, just beyond the south-eastern border of the Pelagos Sanctuary (Figure 1) with 2950 km travelled in 'on-effort' conditions.

The depth range of the study area ranges from the coastline to 1400 m. The physiography of the study area is very complex, resembling that of the entire central Tyrrhenian Sea basin. It includes some cetacean habitats such as the continental shelf, slope, canyons and seamounts. The major canyon systems are the Caprera and Mortorio canyons (Gamberi and Marani, 2004).

A wide shelf is present along much of the North-eastern Sardinian, East of Bonifacio and the Archipelago of La Maddalena. In the northern area the shelf reaches ca. 20 km in width breaking into a slope, gentler to the north (average dip of around 2°) and steeper towards the south. The North-eastern Sardinia slope is incised by some canyon systems and bounded seaward by the Etruschi and further south by the Baronie seamounts (Dalla Valle, 2007).

Spatial and temporal distribution of effort

Visual surveys were conducted from 2011 to 2013 by the Department of Science for Nature and Environmental Resources of the Sassari University (DIPNET) *ca.* 15-40 nautical miles off the North-eastern coast of Sardinia. Sampling effort was widely distributed mainly across the major axis of the Caprera Canyon area (see effort data, Tab. 1) which was the core of the investigated area in ‘on-effort’ mode. Transects during opportunistic surveys did not follow a systematic design with random probability sampling, but the resulting routes crossed depth contours almost perpendicularly, covering as much as the possible habitats, from the continental shelf to deep sea.

The research effort varied, being greatest off 12 nautical miles the coast, and seasonal mainly from June to October. A total of 70 one-day survey were carried out, 54 of which were opportunistic and 16 additional systematic surveys, covering around 2,300 km^2 in ‘on-effort’ conditions. The systematic surveys were designed and carried out by using the same boats and field protocol during the three years, in order to better cover in space and time areas not enough investigated by opportunistic surveys. Even though most surveys were opportunistic survey, we at least randomized the choice of the starting point of the ‘on-effort’ tracks.

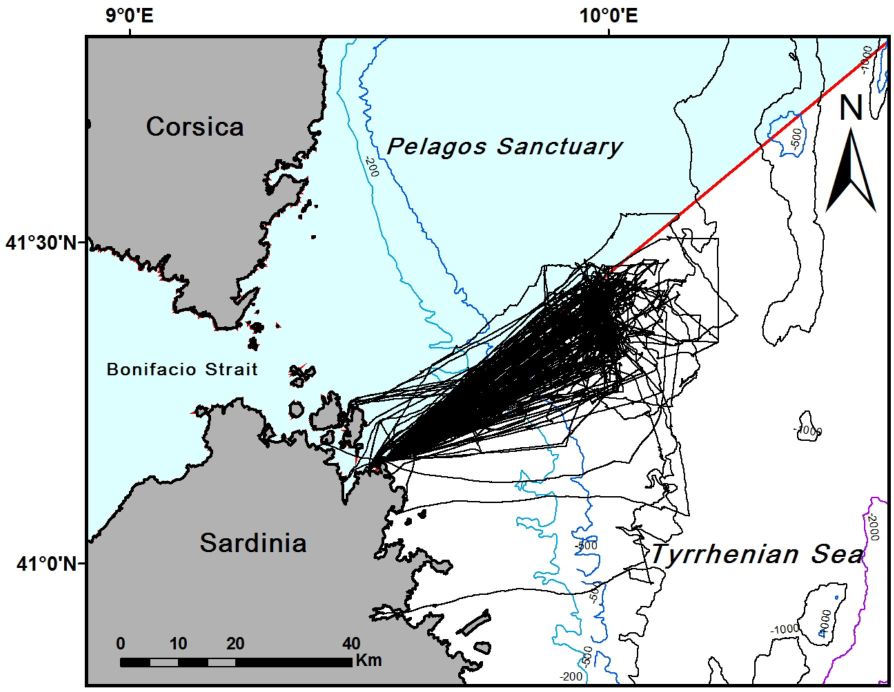

Fig. 2 Study area with distribution of effort. Depth contours (200 m, 500 m, 1000 m, 2000 m) and survey tracks are shown. The red line indicates the South-eastern boundary of the Pelagos Sanctuary.

DATA ANALYSIS METHODS

The statistical analysis of data include: (1) an analysis of the interannual variability of the fin whale densities; (2) an analysis of the seasonal variability of the fin whale Encounter Rate (ER); (3) a comparison of the characteristics (depth, slope, and aspect) of the sightings dataset; (4) a qualitative comparison of the fin whale data with Chl *a* and Sea Surface Temperature maps during the study period.

Interannual variability of fin whale densities: a Chi-square test of independence for given probabilities was used to assess whether the fin whale encounter rate changed significantly along the three years. The expected frequencies were fixed in proportion to the amount of kilometres "on effort" travelled in each year.

The seasonal variability of the fin whale's encounter rate (ER) was estimated, in order to assess any change in relative abundance. The ERencounter rate values were calculated as the number of encounters with distinct groups per 100 kilometres travelled in 'on-effort' conditions (ER = n/L*100 Kms) (Ferguson *et al.,* 2006). The data from tracklines and sightings 'off-effort' were excluded from the ER counts.

MCMCglmm (generalized linear mixed models - GLMM with a Bayesian Markov chain Monte Carlo - MCMC approach implemented in the R package “MCMCglmm”; Hadfield, 2010) were used to search for seasonal trends in the fin whale relative abundance in the study area.

The fin whale encounter rate values were added to four different models as dependent variables. The season was a factorial variable with four levels (winter: 1/12 - 28/2; spring 1/3 - 31/5; summer 1/6 – 31/8; autumn 1/9 - 30/11) and was added to the models as fixed effect; the year of survey (2011-2013) was fitted as random effect. All the models are based on 70 observations from 2950 km of ‘on-effort’ navigation. MCMC Gaussian models were run for 13000 iterations with a burn-in period of 3000.

The level of non-independence between successive samples in the chain was checked for all models with the autocorr function of MCMCglmm, while the convergence of the chains was checked by visual inspection. Reported credible intervals (CI) are the 95 % highest posterior density intervals. The MCMC mean posterior estimates of the dependent variables with their credibility intervals are reported.

A comparison of the sighting locations properties: the depth, the seabed slope, and the aspect at each sighting point (including both ‘on- and ‘off effort’ sightings) were obtained with cartographic software GIS ArcMap 9.3 (ESRI), while the group size was estimated directly in the field. To test if there are any differences in these covariates for the different species inhabiting the study area, the data collected at each sighting point were compared with a Kruskal–Wallis (KW) test. A series of Wilcoxon-Mann-Whitney (WMW) tests were used as post hoc tests to check which pairs of species showed different covariate values. All the statistical analyses were performed using R version 2.12.1 (R development core team, Pinheiro, *et al.*, 2010).

Following Pirotta *et al.* (2011, 2013) further approach with a Generalized Additive Model (GAM) framework was used to model the relationships between fin whale presence/absence at each GPS fix and the covariates described (Hastie & Tibshirani 1990; Wood, 2006). An autocorrelation function (ACF) plot was used to visualize the level of autocorrelation in the GAM residuals, and Generalized Estimating Equations (GEEs; Liang & Zeger 1986) were then used to explicitly model this observed autocorrelation (see also Dormann *et al.,* 2007; Pirotta *et al*., 2011; Bailey *et al*., 2013). Results is still in progress, in order to better explore the relationships between the different variables taken together and to investigate whether this combination can be considered as a proxy of any spatial and temporal pattern.

Physiographical features

Three features depth, slope gradient (hereafter ‘slope’), and slope aspect (hereafter ‘aspect’) were measured and used as static covariates for describing the physiography of the study area. Depth data were derived from the Italy CNR-Ismar bathymetric data (GRID resolution 200 m) and was expressed as a negative value in metres. Slope gradient was defined as the maximum rate of change in depth in a given grid cell and expressed as percent slope. Slope gradient was defined as the maximum rate of change in depth in a given grid cell and expressed as percent slope. Slope was computed using GIS software (ESRI ArcMap 9.3). Slope aspect was defined as the compass orientation of the slope, ranging from 0 to +359°, with respect to true north. In addition to ecological and physiographical variables, the behavioural trait ‘group size’ was also employed in the analysis.

Tab. 1 Environmental and ecological covariates treated in the analysis.

Covariate	Unit	Spatial scale	Temporal scale
Depth	m	200x200m	-
Slope	%	200x200m	-
Aspect	°	200x200m	-
Chl *a*	mg m^{-3}	4x4 Km	8 days
SST	°C	9x9 Km	8 days
group size	n	-	-

Our analysis consisted to determine the depth of each whale position and the depth of any points during the survey tracks. We therefore performed an extraction of the depth corresponding to coordinates of the total sightings and the positions without any observation. A Geographic Information System (GIS) of the study area was constructed using Environmental Systems Research Institute (ESRI) ArcView 9.3 software where the overall sightings and effort were mapped.

ESRI Arcview 9.3 was used to divide the study area into a 374grid cells, each measuring 5x5Km (2.7x2.7 nautical miles), and also to integrate sighting data to a set of environmental characteristics (Tab. 1) such as depth data, slope and aspect. The occurrence of fin whales in relation to depth and gradient was examined and tested. Finally we tested even the temporal variability in group size of any fin whale sightings from both 'on-effort' and 'off-effort' observations.

Satellite remote sensing data

The satellite data used for this analysis were the surface chlorophyll-*a* (hereafter Chl-*a* in mg m^{-3}) from the MODIS sensor (Moderate Resolution Imaging Spectroradiometer, available on http://oceancolor.gsfc.nasa.gov) on the NASA Aqua satellite. Chlorophyll *a* and Sea Surface Temperature values (hereafter SST, in °C). Variables were extracted from the average values in the investigated area from January 2011 to September 2013. We used the 8 days Chl *a* and SST content available both at wide coverage synchronously and at a medium resolution (geo-projected data at 9 km for SST and 4x4 Km for Chl *a*). The oceanographic variables used to calculate the statistical correlation were:

- Time-series average of Chl *a* and SST in 8 days;
- Time-series standard deviation of Chl *a* and SST in 8 days;
- The absolute value (sum) of the zonal gradient of Chl *a* and SST;
- The absolute value of the southern gradient of Chl *a* and SST;
- The average latitude of the position of the front;
- The latitude of the front along the meridian 10° E.

RESULTS

Fin whale sightings

During three year of surveys (2011-2013) in the study area (Fig. 1) 2950 Km were performed in 'on-effort' conditions out of 9644 Km totally covered. Data were collected during 70 one-day visual surveys between 16 January 2011 and 26 July 2013 using both whale watching and dedicated vessels with the same field method/protocol. Positions of visual fin whales observations are shown in Fig. 3.

These observations are consistent with other published sighting data in the same area (Bittau *et al.*, 2012, 2013). Total sightings of *B. physalus* ('on-' + 'off-effort' encounters) were 87, with an estimate of 146 counted individuals. Seventysix sightings were made in 'on-effort' condition out of a total of 131 spotted individuals. Effective visual effort data and fin whale sightings by year are showed in Tab. 1.

Tab. 3 Study period, number of days worked, total number of Km surveyed, number of sightings of fin whale referred to the study area.

Year	First Date	Last Date	No. of days worked	Tot. Km travelled	Km surveyed 'on-effort'	Tot. No. of sightings	No. of sightings 'on-effort'
2011	16 Jan	27 Nov	28	3774.66	1147.03	44	40
2012	18 Jan	24 Nov	25	3634.08	1155.68	25	22
2013	16 Mar	26 Sep	17	2235.15	647.57	18	14
Total			**70**	**9643.89**	**2950.27**	**87**	76

The total mean encounter rate of fin whale relative to the entire three year period was ER = 2.52 school/Km on effort (n=76; SD±0.85; SE±0.49). Fin whale Mean Group Size (MGS) of the entire period was 1.64 (n=87, mode=1; SD±0.82; SE±0.09, range = 1-5). We found a yearly increase of the group size values from 1.55 (mean group size, summer 2011) to 1.68 (2012) until 1.78 (2013). On all sightings, isolated animals were located 47 times, representing the most frequent case.

Tab. 2 summary of the fin whale sightings (2011-2013)

species	Sightings Bp	%	Specimens
2011-2013 Tot sightings	87	20.76	146
2011-2013 'on-effort' sightings	76	23.31	131

Interannual variability of fin whale abundance

To test the interannual variability of the fin whale sightings, we used a Chi-square test in order to determine whether the yearly trend of fin whales abundance was significantly different trough the years. Fin whale in 2011 showed significantly higher encounter rates than in 2012 ($\chi2$ =5.3621, df = 1, P = 0.02058), but not significantly different with respect to 2013 ($\chi2$ = 1.938, df = 1, p-value = 0.1639).

Finally, in 2012 the encounter rate of fin whale was not significantly different with respect to 2013 ($\chi 2 = 1.938$, df = 1, p-value = 0.1639).

Seasonal variability of abundance

As for the effect of seasonality on fin whale's distribution the graphical analysis of the four seasons not allowed us to find any pattern (Fig. 3a), then we explored the data by a subset of the seasonal dataset. We used the time variable of the year's weeks, to have the best seasonal detail and to graphically better represent any trend, anyway we did not found seasonality in the relative abundance as well as the difficulty of seeing any clear seasonal trend (Fig. 3a). Despite this, we cannot exclude with certainty a potential seasonal pattern of fin whales occurrence (see Figs 3a-b) due to the lack of our data during the winter period. Anyway, in the summer and autumn a low decreasing trend is noted in the scatter plot (Fig. 3b).

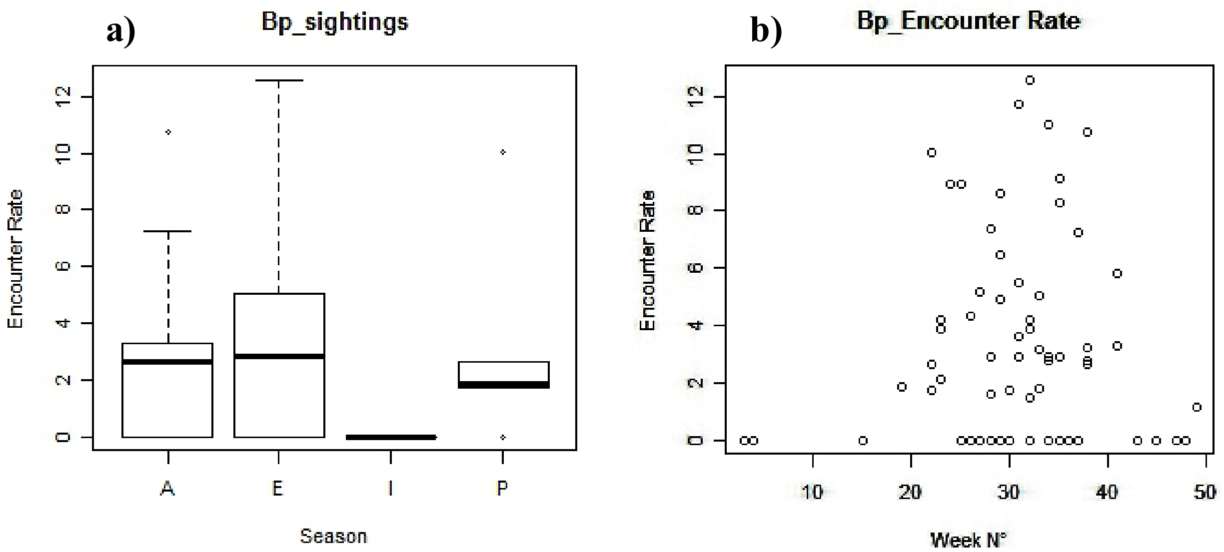

Fig. 5 a) Box plot with the variation in the fin whale ER (*Balaenoptera physlus*; Bp, n=76) in different seasons during the study period (2011-2013), A = Autumn, E = Summer, I = Winter, P = Spring; b) Scatter plot showing the number of sightings by comparing 56 weeks.

Spatial distribution

The fig. 4 shows the distribution of observations of fin whales within the study area. Fin whale is the largest species occurring the study area off North-eastern Sardinia. Out of the 87 observations made during the 70 surveys within the study area, 76 were in 'on-effort' conditions. The spatial distributions of fin whales differ within the study area. Most of the observations are distributed in the deeper waters of the sampled area as well as between the 500 and the 1000 m isobaths., The fin whale occurred however both in deep and shallow waters but showed a clear preference for the slope around the Caprera Canyon (Fig. 6c). Behavioural displays recorded in the deeper waters were feeding, resting, travelling, breaching and socializing. Seven defaecation events were observed during the feeding activity in the study period, always in summertime (n=4 in 2011, n=2 in 2012, and n=1 in 2013). The analysis of faecal material, according to Orsi Relini *et al*. (1992b) and Relini *et al*. (1992b, 1997), revealed the presence of crustacean exoskeletons belonging to the euphasiacean *M. norvegica*, which is the main trophic resource of fin whales in the Mediterranean Sea (Viale, 1985; Orsi Relini & Giordano, 1992b; Notarbartolo di Sciara *et al*., 2003). An indirect indication of the abundance of these euphasiaceans in the area is supported by several records of beach strandings recorder in wintertime along the North and North-eastern coasts of Sardinia (Bittau pers. obs.; Lutzu, pers. comm.). In addition to the effort data by present at sea surveys several incidental sightings of fin whales occurred from 2007 to 2013 very close to the Sardinian coastline and within the Bonifacio Strait due to occasional entering of animals in small bays, channels and harbours (Bittau *et al.*, 2013) according with Notarbartolo di Sciara *et al.* (2003).

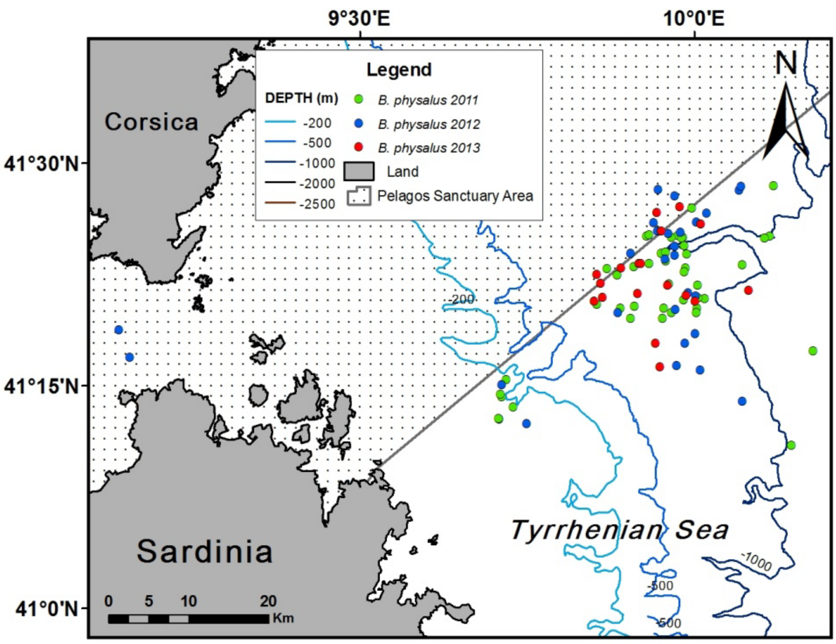

Fig. 6 Distribution of fin whale sightings off North-eastern Sardinia during the entire study period (2011-2013). The shallow water observations occurred only during 2011 and 2012.

Distribution of fin whale sighting primary position in relation to physiographical features

Bottom depth relative to the entire fin whale dataset at initial sighting positions ('on-' and 'off-effort' sightings) ranged from 1292 to 91 m (mean = 743 m, SD = ± 253, SE = ± 12, n = 419) (Tab. 4).

Tab. 4 Mean (± SD) of main covariates and respective ranges; depth, slope, aspect, and school size for fin whale sightings positions in the study area.

Species	**Depth (m)**	**Slope (%)**	**Aspect (°)**	**School size (n)**
B. physalus	757.02 (256.05)	6.58 (7.18)	153.71 (111.59)	1.6 (0.82)
	Depth range (m)	**Slope range (%)**	**Aspect range (°)**	**School size range (n)**
B. physalus	91-1292	0.95-33.34	7.09-355.91	1-5

Fin whale distribution pattern shows a wide depth range (91-1292 m, mean 757.02 m, SD=256.05, SE=27.14) and even sea floor slope range spanning from 0.10 to 33.34 % (mean 6.58, SD=7.18, SE=0.96). Arcangeli *et al.* (2012) found that in the central Tyrrhenian Sea mean depth and slope of fin whale, in 1900s and 2000s, were relatively similar. Mean depth had a value of 1012 m (SD=49) in 1990s and 1066 m (SD=36) in 2000s whereas slope was 4.03 % (SD=0.21) in 1990s and 4.05 % (SD=0.24) in 2000s.

As the plots in Fig. 4 indicate, the fin whale depth distribution we found off North-eastern Sardinia during the late summer time frame was bimodal, with 90.8 % of sightings occurring in the deeper portion of the study area (mean water depths of 757 m) and 9.2 % (n=8) in shallower water (≤ 200 m) over the wide continental shelf off North-eastern Sardinia.

Sightings in shallow water occurred during the sampling effort (August-September 2011; August 2012) and are all referred to young individuals with small group size range (n=1-2). Moreover, the fin whale in the Western Mediterranean Sea is primarily observed in deep offshore waters, although its occurrence over the continental shelf is not unusual (Aissi *et al.*, 2008; Notarbartolo di Sciara *et al.,* 2003) due to feeding on small fishes as observed by Beaubrun *et al*. (1999) in the Gulf of Lions, or even on the euphausiid *Nyctiphanes couchi* (Bell, 1853) as described by Canese *et al*. (2006) in the waters surrounding the island of Lampedusa, deep less than 100 m. The mean group size we recorded off North-eastern

Sardinia was 1.6. whereas the larger group size was recorded in June 16, 2013 (n=5) when a large group was spotted socializing and breaching.

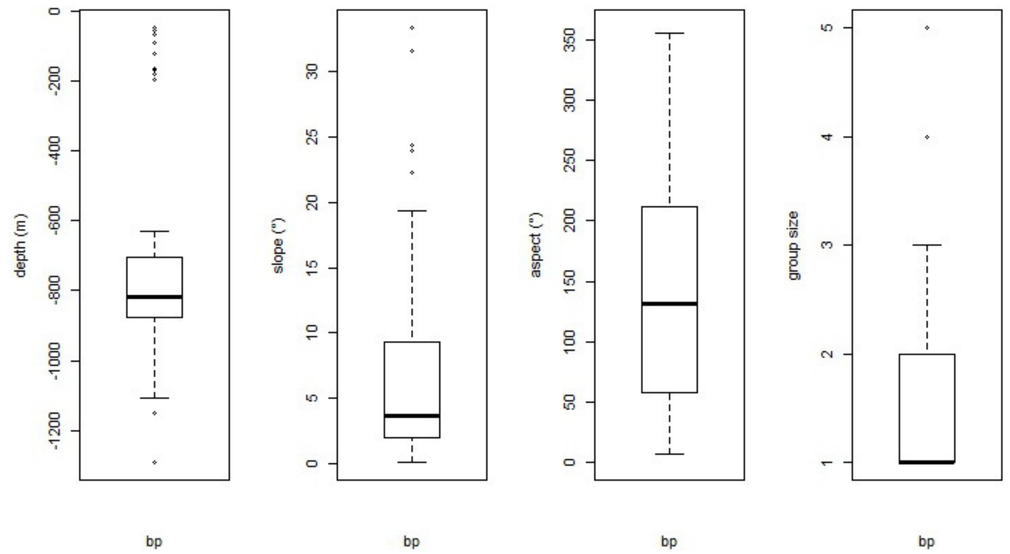

Fig. 7 Box plots exploring the comparative analysis between the distributions of the covariates (depth, slope, aspect, and group size) *vs*. fin whale primary sightings positions during the entire study period (2011-2013) off North-eastern Sardinia.

Qualitative comparison with oceanographic variables

A qualitative comparison of the sightings distribution with respect to remote sensing Chl-a data in the study area was performed. Sightings (Figs 10, 12, 14) occurred in areas with lower average SST (Figs 6-8) and higher spring productivity (Figs 6-8), indicating that fin whales generally preferred the deep, nutrient-rich region of the study area, where there was a thermal front influence.

As shown by the SST satellite images (Figs 6-8) the distribution of fin whales in the study area during the summer from 2011 to 2013 was concentrated mainly in the region where the average temperature was lower (mean SST=23°C in 2011; 23.6°C in 2012; 23.7°C in 2013).

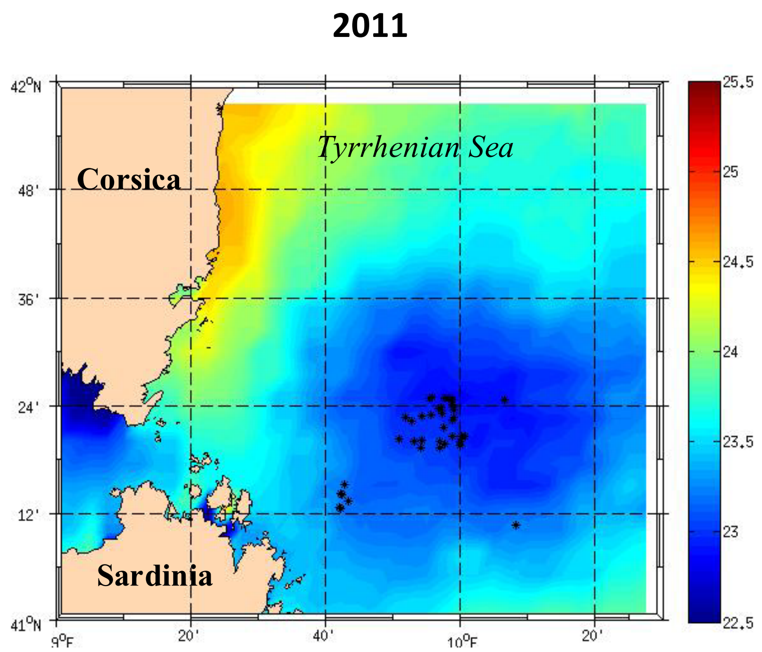

Fig. 8 Map of the study area showing the mean summer SST (°C, scale bar on the left) compared with the positions of the fin whales' sightings (dots) in June-September, 2011 (Andreotti, 2013).

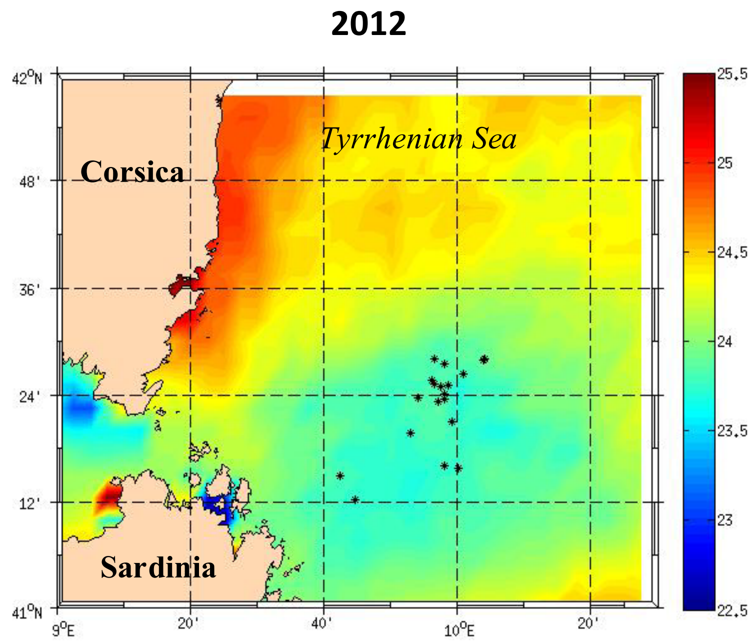

Fig. 9 Map of the study area showing the mean summer SST (°C, scale bar on the left) compared with the positions of the fin whales' sightings (dots) in June-September, 2012 (Andreotti, 2013).

2013

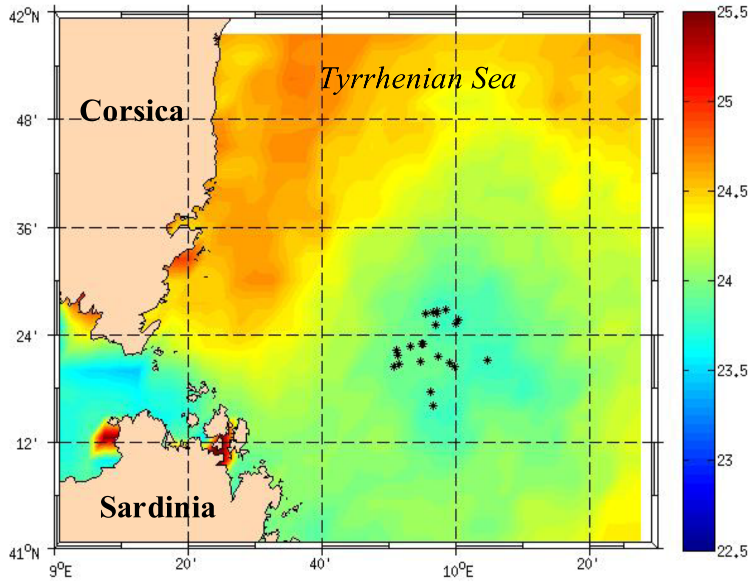

Fig. 10 Map of the study area showing the mean summer SST (°C, scale bar on the left) compared with the positions of the fin whales' sightings (dots) in June-September, 2012 (Andreotti, 2013).

Statistical analysis of oceanographic variables

We used the Pearson correlation coefficient to assess the linear relationship between the data of SST and Chl-*a* and locations of fin whale observations. This coefficient allows to express the linearity between the covariance of two random variables and the product of their standard deviations.

For the correlation were used both the total Encounter Rate, and then were taken into consideration both the surveys with no fin whale sightings, which are equal to zero, and the encounter rate corresponding to surveys with sightings of fin whales. The correlation values, according to the statistical tests are not to be taken into consideration, then it is confirmed null Hypothesis ($P > 0.05$).

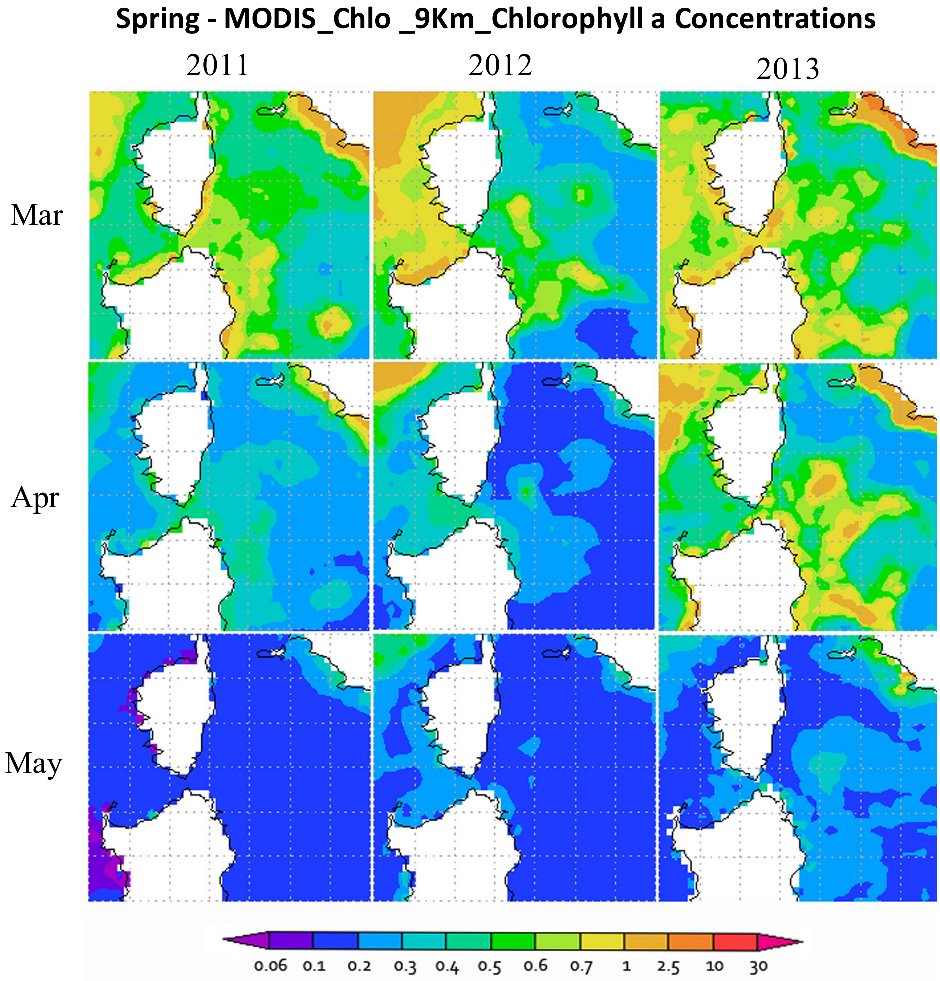

Fig. 11 Spring monthly Chlorophyll *a* averages concentration off north-eastern Sardinia, during 2011. Satellite data: from MODIS/NASA Giovanni.

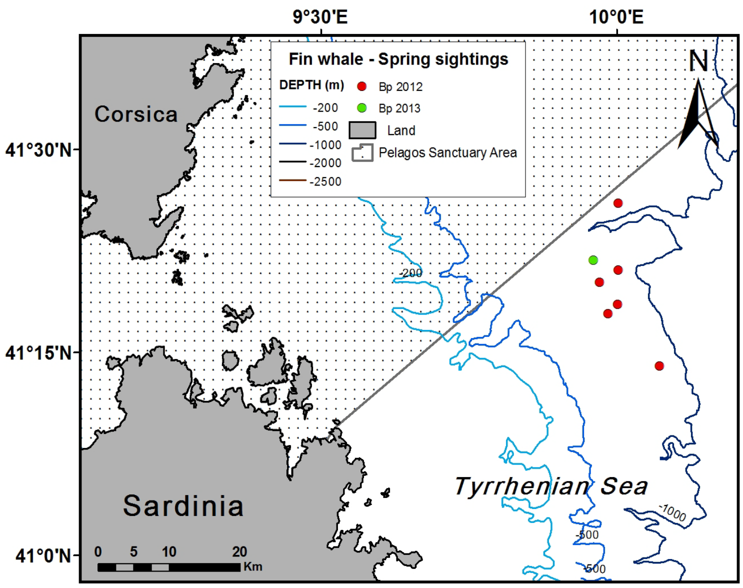

Fig. 12 Spring distribution of fin whales sightings off north-eastern Sardinia during Spring (2011-2013). The 200, 500 and 1000 bathymetric contours are shown, with the Pelagos Sanctuary south-border.

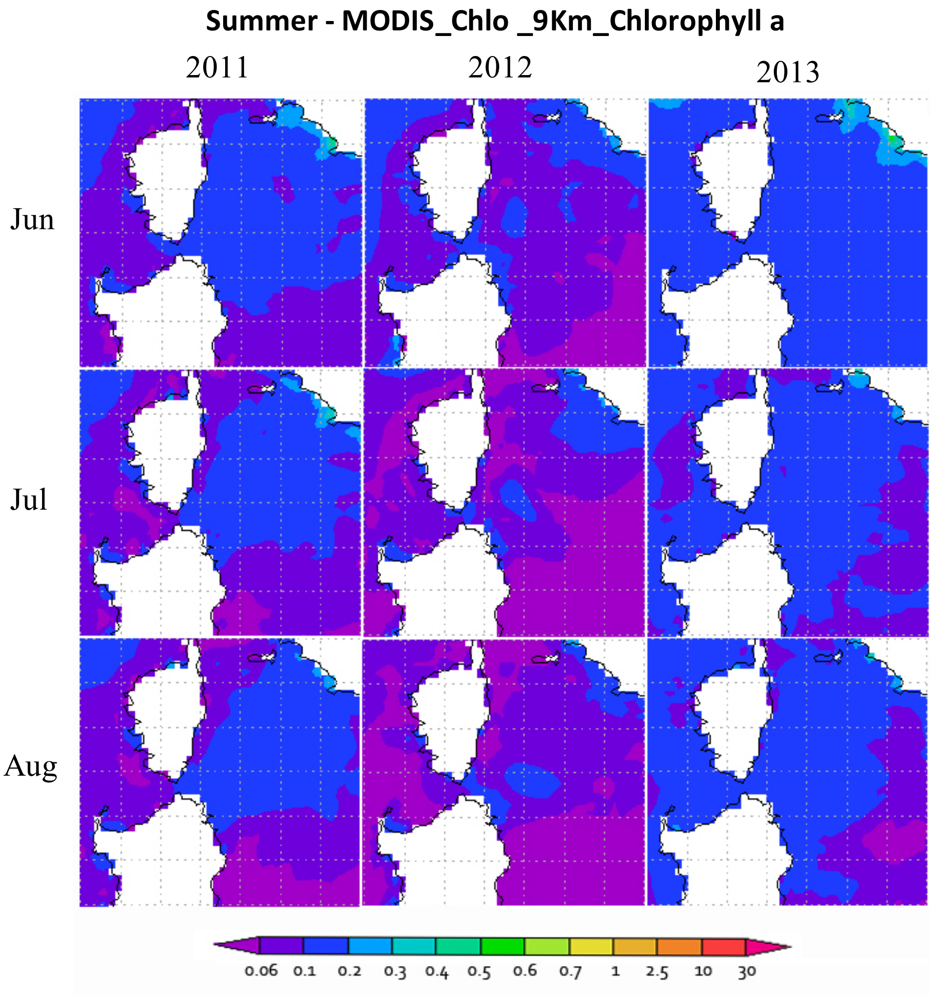

Fig. 10 Summer monthly Chlorophyll *a* averages concentration in the study area, off north-eastern Sardinia, during 2012. Satellite data: from MODIS/NASA Giovanni.

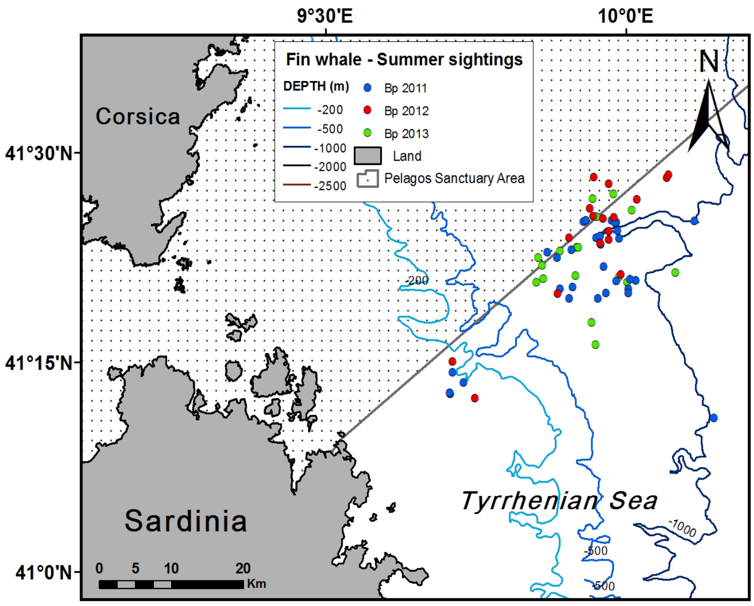

Fig. 13 Summer distribution of fin whales sightings off north-eastern Sardinia during the study summer (2011-2013). The 200, 500 and 1000 bathymetric contours are shown, with the Pelagos Sanctuary south-border.

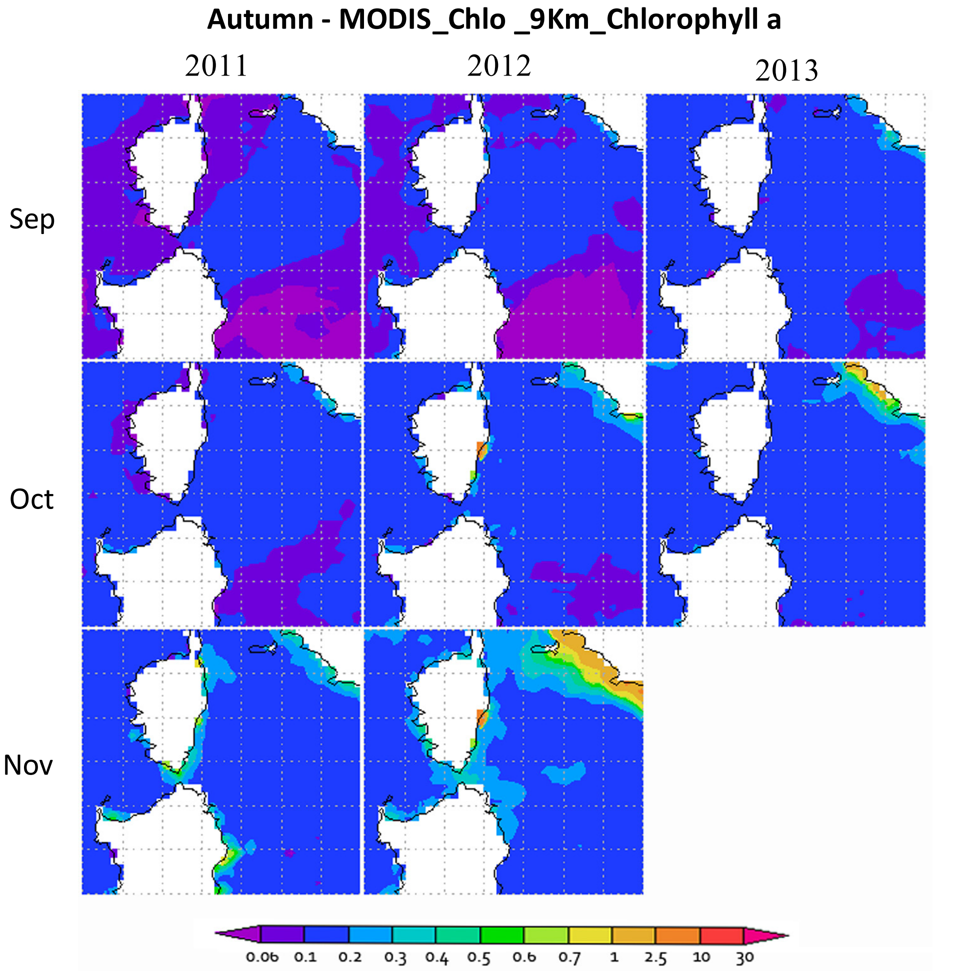

Fig. 14 Autumn monthly Chlorophyll *a* averages concentration in the study area, off north-eastern Sardinia, during 2013. Satellite data: from MODIS/NASA Giovanni.

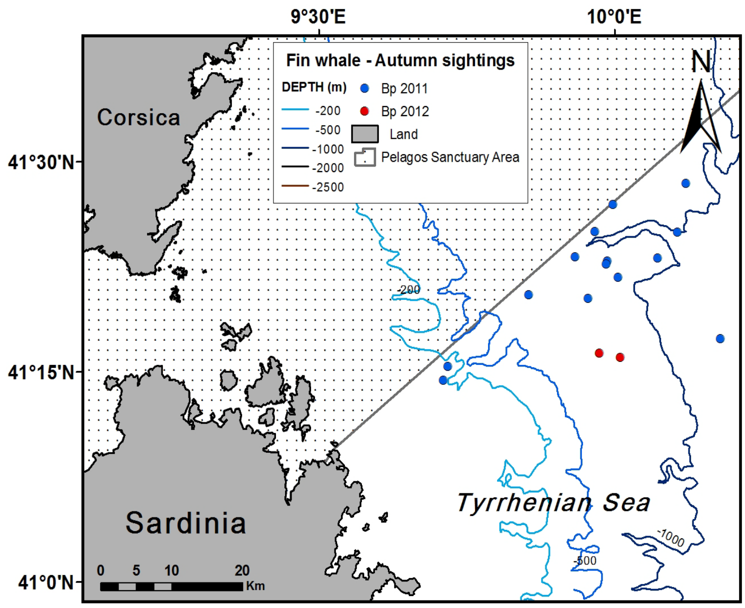

Fig. 15 Autumn distribution of fin whales sightings off north-eastern Sardinia during the study period (2011-2013). The 200, 500 and 1000 bathymetric contours are shown, with the Pelagos Sanctuary south-border.

SEASONAL *MODELLING*

Modelling seasonal fin whale distribution and diversity

To explore the effect of seasonality, we modelled the seasonal cetacean distribution with GLMM, using a subset of the seasonal dataset, as the graphical analysis of the only four seasons (Fig.7) not allowed us to find any pattern. Therefore, we explored the data with the time variable of the year's week, to have a best seasonal detail and to graphically better represent any trend in the data description.

Statistical analysis did not allow us finding any significant seasonal pattern for the fin whales encountered in the study area, off North-eastern Sardinia. Modelling with GLMM the seasonal analysis on fin whale, it is evident that during the study period, there were no significant statistical differences between the different seasons (Tab. 8), with very similar post-mean values and a high overlap of the credible intervals (CI) of the seasonal ER posterior estimates. Models are based on 76 'on-effort' sightings records.

Tab. 8 GLMMs results, with posterior estimates and credible intervals for fin whale encounter rate, with year (2011-2013) as random effect and season (Spring, Summer, Autumn, Winter,) as fixed effect. Data was collected in North Sardinia from 2011 to 2013. Models are based on 76 sightings from 2950 km of navigation during survey monitoring. *NS*: non significant MCMC probability value.

B. physalus					
Factor		**Post.mean**	**Lower-95% CI**	**Upper-95% CI**	**pMCMC**
(Intercept)		2.700	0.555	4.721	$p < 0.001$
Season					*NS*
	Spring	3.414	0.250	6.440	
	summer	3.340	1.931	4.309	
	Autumn	2.870	0.750	4.725	
	Winter	0.085	-4.841	5.172	

Creating and evaluating several models, rather than a single, allows to compare models of relatively equal fit that contribute to depict a more defined scenario. These models are complementary rather than competing (Planque *et al.,* 2011), and avoid erroneous conclusions about particular effects and their influence on animal distribution (Loots *et al*., 2011). Since that the GLMM did not give significant results, we further explored the data by means of a novel analytical framework that can make use of combined covariates data and account for autocorrelation in such data, following Pirotta *et al*. (2012, 2013).

We modelled the fin whale presence/absence in each survey using binary Generalized Additive Models (GAM; Wood, 2006). An autocorrelation function (ACF) plot was used to visualize the level of autocorrelation in the GAM residuals, and Generalized Estimating Equations (GEEs; Liang & Zeger 1986) were then used to explicitly model this observed autocorrelation following Pirotta *et al.* (2011, 2013). GEEs relax the assumption of independence between model residuals within blocks of data.

We used the blocking variable, and the Quasi-likelihood under the model Independence Criterion (QIC; Pan, 2001) to select between competing correlation structures. We checked multicollinearity between explanatory variables using the generalized variance inflation factor (GVIF). Models were fitted using the library geepack in R, together with the library splines to extend the GEE-generalized linear models to GEE-GAMs. An approximated version of the QIC, known as the QICu (Pan, 2001) was used for model selection.

We used the QICu to compare different forms in which an explanatory variable could be included in the model. Specifically, we tested each predictor as a linear term, as a B-spline with four degrees of freedom (hereafter 'd.f.') with one internal knot positioned at the average value of that variable and as a B-spline with 5 d.f. and two knots at the quartiles. Cyclic splines are currently not available in the library splines, so the use of GEEs to correct for autocorrelation was prioritized, and B-splines were used for circular covariates. By this framework, further analysis are in progress and will be processed modelling the oceanographic variables (Sea Surface Temperature and Chlorophyll *a* concentration) with the others physiographic covariates.

Seasonal analysis of fin whale dataset

Similarly to the entire dataset analysis, the fin whale data did not show that any significant abundance differences between seasons. This may partly be due to the lack of data during winter and spring, but there is no difference even for those well-sampled seasons (e.g. summer-autumn), suggesting that fin whales at least stay for a long time within the study area. However, as the graphical analysis of ER suggests, this cannot be considered as a definitive result. In fact, the decrease in ER during autumn season in 2011 and 2012 (Fig._) may be due to a gradual movement of whales away from the area during the early winter season. We can consider the possibility of nomadic behavior rather than actual seasonal migrations, in according to winter spread- and summer congregate-behaviour of Mediterranean fin whale, like aggregation-dispersion scheme according to Notarbartolo di Sciara *et al* .(2003). This hypothesis need new winter and spring surveys, necessary to implement the annual dataset.

Incidental and historical sightings

In total, we collected 25 incidental sightings of B*. physalus* (for a total of 44 individuals). The fin whales observations referred to the continental shelf (≤ 100 m of depth) between the Bonifacio Strait and the La Maddalena Archipelago from 2007 to 2011**.** We collected two records in 2007 (n=5 individuals) and one record (n=2) in 2008 (Fig. 8). These data were gathered from waters within the National Park of La Maddalena. Other incidental sightings were collected between 2010 and 2012. Photographs were used to confirm sightings and assess species and group size. Observations before 2007 were not considered, due to the lack any reliable geographic position of the sightings. It is certain however that these whales occurred along the coastal waters of Sardinia not infrequently in the past, as evidenced by the historical data collected by the DIPNET-Sassary University and the accounts of the local sport and professional fishermen (unpublished data) or the news of the local press. The majority of collected reports are often with no details and it was impossible to reliably determine the species identity. However, in several case it was possible to assess an identification to species level both on the basis of collected photographic material and descriptions of the whale behaviour (these 25 observations were provided by the personnel of ferries, cargo ships, fishermen, press releases, personal of MPAs or National Parks, and by the Italian Coast Guard reports).

Behavioural observations in shallow waters

Based on the behavioural data collected on *B. physalus* sightings in shallow coastal waters, it was possible to describe three repeated behaviours, observed also by DIPNET in other sightings of the species along the north-eastern Sardinia (unpublished data).

The following describes the following behaviours:

- Moving behaviour ("**travelling**") with animals moving from East to West and opposite, between the islands of the La Maddalena Archipelago and the Bonifacio Strait;
- "Entrapment behaviour" ("**trapping**") with animals sighted between the islands of La Maddalena, Caprera and Santo Stefano, moving in different directions before finding the "way out" towards the open sea;
- "**surface feeding**" behaviour: with animals observed in apparent surface feeding activity on the basis of pictures and/or movies collected at sea.

On the occasion of these records group size values ranged from 1 to 3 animals, with no calves noted. The largest single group (3 whales) also was recorded within the La Maddalena Archipelago with a depth range of 50-70 m. In the same area, we documented on video footage one event of a fin whale involved in surface feeding activity in shallow waters, less than 50 m of depth. During 2011, there was the highest number of records with 3-5 casual sightings each month from February to August, with a further record in November, suggesting year-round presence. All observations and data collected (Tab. 2) and described, clearly indicate that the coastal area to the East of Sardinia and Bonifacio is regularly frequented by fin whales each year. These observations were all made in shallow water (less than 100 m) and more frequent during late winter (January-February) and August.

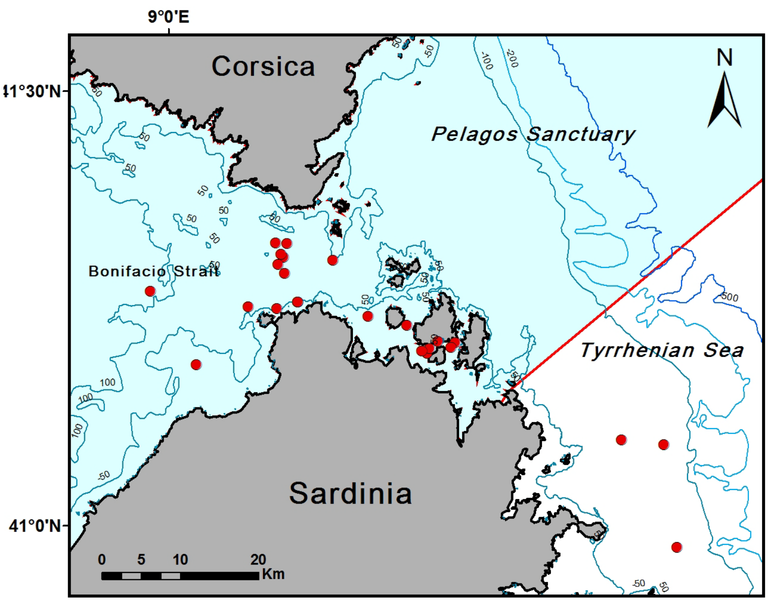

Fig. 16 Distribution of the 25 incidental sightings (red spots) of fin whales in shallow waters of North-eastern Sardinia from

Although human pressure affects regularly the North-eastern Sardinia coast, even during the winter months due to the vessels traffic (commercial and recreational) several sightings were recorded with the three behaviour described, including surface feeding. These observations provide valuable information on the probable use of the coastal waters of Sardinia as a feeding/travelling area for fin whales movements (Bittau *et al.,* 2013).

Tab. **9** Groups size and behaviour of 10 incidental sightings of fin whales occurred from 2007 to 2012 in coastal water North-East of Sardinia.

date	location	group size	behaviour
18/07/2007	La Maddalena archipelago (NE Sardinia)	3	travelling
21/08/2007	La Maddalena archipelago (NE Sardinia)	2	trapping
05/01/2008	La Maddalena archipelago (NE Sardinia)	2	trapping
21/02/2010	La Maddalena archipelago (NE Sardinia)	1	surface feeding
22/02/2010	Bonifacio Strait	3	travelling
05/06/2011	La Maddalena archipelago (NE Sardinia)	3	trapping
18/08/2011	La Maddalena archipelago (NE Sardinia)	1	travelling
25/08/2011	La Maddalena archipelago (NE Sardinia)	1	travelling
07/12/2011	La Maddalena archipelago (NE Sardinia)	1	travelling
05/11/2012	La Maddalena archipelago (NE Sardinia)	1	travelling

DISCUSSION

As recommended by Druon *et al*. (2012) it would be required to spread the effort of our study also in winter, when the fin whale encounter rate was particularly low.

Oceanographic features such as Sea Surface Temperature (SST), chlorophyll a concentrations and currents, related to the prey availability, are key factors for the occurrence of fin whales rather than physiographic factors such as distance from the coast, depth and slope. The Mediterranean Fin Whale population is exposed, year-round, to intense shipping traffic, as the three busiest Mediterranean ports (Barcelona, Marseille, and Genova) are adjacent to the main fin whale summer foraging grounds (Forcada *et al*., 1996; Monestiez *et al.,* 2006; Cotté *et al*., 2009). This study may contribute to provide further knowledge for conservation and management of the Mediterranean fin whales population.

The presence off North-eastern Sardinia of small, close-spaced canyons with steep slope and seamounts together with a water mass circulation inducing persistent upwelling may enhance the productivity, affecting cetacean species distribution in both direct and indirect ways. Off Sardinia, the Caprera Canyon has a high diversity and relative abundance of cetaceans than the adjacent shelf waters, with seven of the eight regularly occurring species in the Western Mediterranean Sea. This high abundance may be relate the Caprera Canyon area to an 'hot spot' of cetaceans (Bittau & Manconi, 2011; Bittau *et al*., 2013) identified as location where the cetacean species occurred at a significantly greater frequency than expected, according to Moulins *et al.* (2008).

In this study, the use of both opportunistic platforms and systematic surveys with dedicated platforms allow us to assess first, relevant information about the occurrence, distribution and relative abundance of fin whales. Platforms of opportunity, such as whale watching vessels, are a valuable means of monitoring cetaceans and can be used on a long-term basis. In this study, they enabled access to offshore areas off Sardinia for a very low cost. However, the use of this kind of platforms often incurs limitations and biases in spatial and temporal coverage. Nevertheless, the protocols used in this study enabled surveying to be completed through several habitat types (shelf, shelf edge, and canyon systems) thanks to good cooperation with the companies to define the both standard protocols and guide lines. The data collected enabled us to investigate how cetaceans distribute in relation to different habitats, particularly of depth, slope and aspect. The data on encounter rates and group size presented help to provide an accurate picture of the temporal distribution of the different species, with the use of effort-related data, in relation to the main habitat types.

Most species were sighted mainly within continental slope habitat. The fin whale is the second most frequently recorded species, with a bimodal distribution, particularly concentrated in deepwater, over the continental slope and the Caprera Canyon and even, to a lesser extent, over the continental shelf in shallower water. Fin whales showed a yearly and seasonally variability in occurrence and distribution, probably reflecting his ecology and highly mobile pattern. Higher occurrence was detected in 2011 and 2013 with a decrease due in 2012. No sightings of fin whales were detected in winter months on deep water of the study area, probably because of a lack of sampling occurred due to weather constrains that affected the surveys, but several incidental sightings occurred in very shallow waters in late winter. GLM highlighted a decrease of the probability to detect fin whales over the years, but in contrast an increased group size was recorded throughout the three years. Over the three years of study, calves have been observed during summer. Several coastal and shallow-water incidental sightings with reliable species identification occurred over the continental shelf, within the Bonifacio Strait and between the narrow inlets and archipelagos of north-eastern Sardinia since 2007. The use of responsible whale watching platforms allows us to collect data for unambiguous species identification and group composition. Carrying out systematic survey enabled us to collect data even in areas not covered by the opportunistic routes. Therefore, we were able to record sightings of fin whales in shallow waters, above the continental shelf.

The high density of fin whale recorded in the study area, point out the special conservation interest of the study area supporting the proposal of an open sea SPAMI in the Tyrrhenian Sea. Despite the positive biased encounter rates the area off North-east of Sardinia appears to have a high density of cetaceans, compared to other areas in the western Mediterranean Sea. Although the Corsican Ligurian Sea is the most productive pelagic waters of the entire Mediterranean Sea which harbouring a richer cetacean fauna, our study points out that even small-scale survey are needed to highlight other areas of high density of fin whales. The incidental sightings of fin whales reported in this paper occurred over the continental shelf, North-eastern coast of Sardinia, between the islands of the La Maddalena Archipelago and within the Bonifacio Strait. They affected a more Western geographical area than our effort sightings of fin whale, confirming a wider distribution of this species even in the shallow waters around northern Sardinia. The most of these sightings were in La Maddalena Archipelago National Park waters, with the largest single group also being recorded there. During 2011, there was the highest number of incidental sightings, suggesting year-round presence. In one case we documented on video footage a fin whale during surface feeding activity in shallow waters, less than 50 m of depth.

For relatively low cost, the integration of datasets from platform of opportunity and dedicated vessels may offer potential for identification of areas of relative high density that help conservation management. Nevertheless, more systematic studies covering a larger temporal and spatial range need to be developed off North eastern Sardinia, because several new records have been documented (Sassari University, unpublished data) from incidental sightings. Finally, new further investigation should be required as mark-recapture methods via photo-identification studies, in order to provide further information on movements, site fidelity and population parameters (as in Hammond, 1986, 1990).

CONCLUSIONS

Before this study, little was known about the distribution of fin whales in the Caprera Canyon and north-eastern Sardinia. The monitoring of three consecutive years of the Caprera Canyon area allowed collecting important information about the presence and distributions of cetaceans, within the Central Tyrrhenian Sea. This study showed that species occurrence, diversity and relative abundance indices have little variability in the study area that we investigated. Overall, the high diversity of cetacean recorded off North-eastern Sardinia may be linked to the diversity of habitat types occurring there and the presence of a high productivity area together with a Canyon system. The high diversity of species combined with the high level of encounter rate underline the importance of the Caprera Canyon area to cetaceans conservation, just a little outside the Pelagos Sanctuary boundary. Our results provide significant, descriptive information that is critical for conservation and management efforts off North-eastern Sardinia, within a proposed open sea SPAMI area, the central Tyrrhenian Sea. Human activities, especially maritime traffic fishing pressure and pollution are growing off North-eastern Sardinia, due to the presence of important neighboring ports. Further effort is needed to assess the spatial and temporal interactions between maritime human activities and cetaceans around this probable 'hot spot' for cetaceans, but certain 'hot spot' for several human impacts. We suggest that a year-round Marine Protected Area is necessary for the Caprera Canyon as a core area within the proposed open sea SPAMI, the central Tyrrhenian Sea.

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SECOND PART

Presence of rare and cryptic species:
Sowerby's beaked whale

Chapter 3

***How many mesoplodonts are in the Mediterranean Sea?* First record of a free ranging Sowerby's beaked whale (*Mesoplodon bidens*) in the Mediterranean Sea**

How many mesoplodonts are in the Mediterranean Sea? First record of a free ranging Sowerby's beaked whale (*Mesoplodon bidens*) in the Mediterranean Sea

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ABSTRACT

The first Mediterranean record of a free ranging *M. bidens* (Sowerby, 1804) is reported. The Sowerby's beaked whale was recently sighted in the Caprera Canyon area (off NE-Sardinia) in a mixed species group together with three Cuvier's beaked whales. All the four whales were identified preliminarily as Cuvier's. During the close approach one whale, *ca*. 5 m in length, displayed however a number of morphological and behavioural traits, clearly seen and photographed. Diagnostic morphotraits were long thin beak, melon with prominent bulge, foreheads concave shape, small triangular dorsal fin. The comparative analysis with the characters of the different species of the genus highlighted that the beak is too much long to belong to *M. europaeus*, *M. densirostris* (previously stranded in the Mediterranean) or *M. mirus*. About the behaviour, the animal surfaced to breath at a steep angle displaying its beak way out of the water, as clearly shown by the photos. The observed colour pattern and long rake marks may point out a young male. Any presence of teeth on the lower jaw was not recorded but they may not have erupted yet. These traits, diagnostic at the species level, allowed us to ascribe tentatively the mesoplodont to *M. Bidens*. Although its North Atlantic core range is the North Sea, and no populations are known to live in the Mediterranean, only four previous stranding records can clearly be related to the genus *Mesoplodon* in the whole basin, until now. All these data suggest that the mesoplodont in the Tyrrhenian Sea could be considered as a stray.

Key words: Biodiversity, beaked whales, morphology, behaviour, Caprera Canyon.

INTRODUCTION

The widespread worldwide Ziphiidae Gray, 1850 is one of the most speciose families of Odontoceti Flower, 1867 with 21 species belonging to 14 genera (Perrin, 2013). Their main diagnostic trait is the low number of functional teeth, always in the lower jaw, typical of only adult males.

Beaked whales inhabit deep waters (>200m) in the open oceans and as selective predators they feed on deep-water squid and fish (Leatherwood, 1983; Mead, 1989, 2002). Some of these species are only known from a few stranded specimens or even skeletal remains and others from fortuitous sightings at sea due to their cryptic behaviour (Leatherwood, 1983; Rosario-Delestre *et al.*, 1999). Their displays above the surface are indeed inconspicuous, only showing small body portions for very short time. Long dive times and small size of social groups increase their poor detectability.

The general rarity together with the difficulty in visually detecting and identifying beaked whales in the field, under typical survey conditions, produced the lack of density or absolute abundance estimates of these cetaceans (Barlow *et al*., 2006). Species belonging to the genus *Mesoplodon* Gervais, 1850 sensu Perrin (2013) are among the least known of all the marine mammals. In the last century eight cetacean species out of the 12 described were ziphiids, mostly of the genus *Mesoplodon* (Dalebout *et al*., 2002).

In the framework of a census of cetaceans promoted by the La Maddalena National Park (Bittau *et al.*, 2011, 2012, in prep.) the record of a Sowerby's beaked whale recently sighted in the Caprera Canyon area (off north-eastern-Sardinia) is here reported.

MATERIALS AND METHODS

The present new sighting was recorded in the framework of an ongoing project focused on pelagic cetaceans based on systematic and opportunistic boat surveys off North-Eastern Sardinian (Western Mediterranean Sea).

The study area, surveyed since 2010, is located in the Western-Central Tyrrhenian Sea in the water of the Caprera Canyon, ranging from 41°30'N-41°00'N to 10°15'E up westward to the limit of the North-Eastern Sardinian coast (Fig. 1). Data were collected during at sea opportunistic surveys performed also for photo-identification purposes.

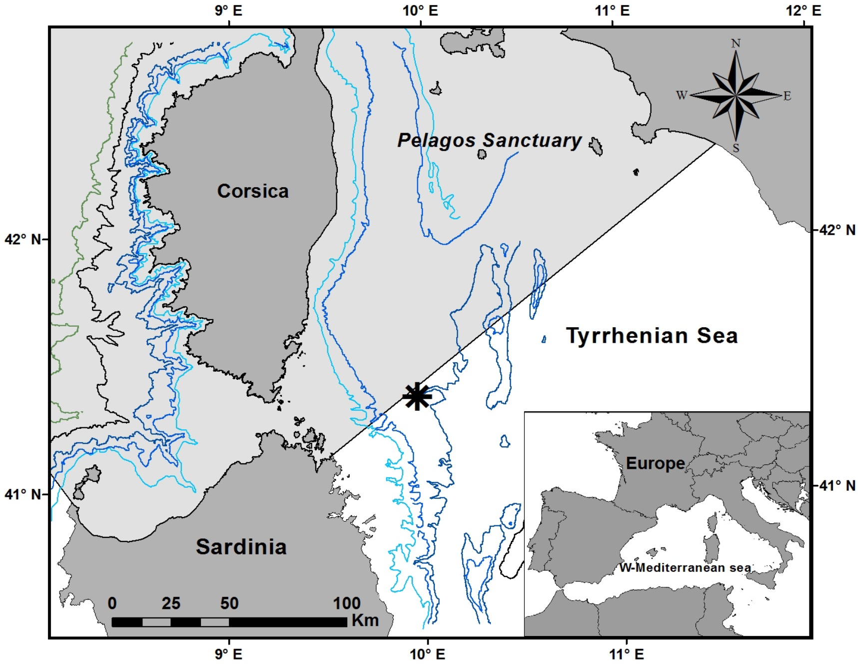

Fig. 1 Map with sighting position off Sardinia relative to the mixed species group, Cuvier's and Sowerby's beaked whales. The first record of *Mesoplodon bidens* is indicated by a star.

All observations were made from a boat as platform of opportunity, an 11 m motor-catamaran 'Orso Cat' of a local private company (Orso Diving) based in Poltu Quatu (Sardinia) used for whale watching trips and hosting almost two researchers each survey. Cetacean surveys were carried out from this platform on a monthly basis in this study area since 2010.

During survey work, two observers were located on the roof of the boat and one on the top of observation tower, which elevates the observer up to 6 m eye height, above sea level. The sightings occurred during on effort condition, following standard protocol, when observers were searching actively with the naked eye supplemented by two binocular scans (7x10X Nikon with compass). GPS (Garmin -Trex) position, field notes, behavioural and environmental data were logged continuously throughout the sighting.

During the sighting ca. 250 photographs of the beaked whale pod were taken from the observation deck using a Canon EOS 40D camera with a 70-200 mm zoom set at different focal lengths. The second camera used was a Canon EOS1-Ds with a 28-300 mm zoom set at 300 m focal. Good quality photographs of right and left side of the animals were taken, for a total of ca. 100 pictures of the *Mesoplodon* specimen. All the photos were subjected to a grading process to assess both the Photographic Quality Values (focus/clarity, contrast, angle, environmental interference) and the Individual Distinctiveness Values, following standard protocols. Species identification was based on the comparative analysis of morphological and behavioural diagnostic traits of the new record vs. all the species belonging to the genus *Mesoplodon* (see Mead, 1989). Results were supported by experts' opinion.

Tab. 1 Field data collected during survey on 17 June 2012**.**

Description	**Field data**	
Total area covered	277Km^2	
Total navigation route	140 Km	75,6NM
Track length on effort	30Km	16.2NM
Total navigation time	08h 06'	
Total survey time on effort	03h 10'	
Total time with beaked whales miked group	08' 50''	
Average dive time recorded	14' 24"	
Sea surface temp. on sighting position	21.8°C	
Average vessel speed on effort	9.44Km/h	5.10Kts
Max distance from the coast	50Km	27NM

RESULTS

The new record occurred at 13:50 (UTC+1), 24 miles off NE-Sardinia on 17 June 2012 in the Caprera Canyon area (Central Tyrrhenian Sea, Western Mediterranean Sea) during a whale watching survey carried out from Poltu Quatu (NE-Sardinia) in good sea conditions. Total time with the animals was 8' 50'', with sea surface temperature on sighting position 21.8°C and a depth of *ca*. 1000 m. Beaufort sea state during the navigation time ranged from 0 to 1, and visibility was > 10 Km. Position of the sighting was 41° 23.075' N, 9° 57.672' E (Fig. 1, map; Tab. 1), ca. 23.9 miles from the promontory of Capo Ferro (NE-Sardinia) at the south-eastern geographic border of the Pelagos Sanctuary.

Description

A single subadult specimen *ca*. 4-5 m long ascribed to the genus *Mesoplodon*, was sighted in a mixed species group. Also, it was a very slender specimen, as showed by the frontal photographs (Fig. 4a; 5a-d). All the 4 whales were preliminarily identified as *Ziphius cavirostris* Cuvier, 1823 when observed from a distance.

One whale displayed however, during the close approach, a number of morphological and behavioural diagnostic traits typical of the genus *Mesoplodon* namely long thin beak, melon with prominent bulge, foreheads concave shape, small triangular dorsal fin, laterally compressed body (Fig. 3a-d, 7).

The other three animals were hence identified as Cuvier's for their morphotraits, probably a male, a female and a juvenile. The adult male Cuvier's beaked whale showed fresh scars and an odd shape of the head, which seems to have suffered a fracture.

Early in the observation, the mesoplodont performed one breach, where the whole body, except the tail fluke, left the water. The animal surfaced to breathe at a steep angle, displaying its beak way out of the water, as is typical of Sowerby's (Hooker & Baird, 1999). Also, it was a very thin animal, as showed by the frontal photographs (Fig. 5a-d). The morphological comparative analysis *vs.* other species of the genus highlighted that the beak is too much long to belong to *M. europaeus*, and *M. densirostris* (previously stranded in the Mediterranean Sea) or *M. mirus*.

Any presence of teeth on the lower jaw of the observed *Mesoplodon* was not recorded but they may not have erupted yet. Moreover the colour pattern of the mesoplodont we sighted showed a dark head and a pale blaze across the back (Fig. 4a-d).

As for scarring traits, ca. 15 linear scars were observed ranging from ca. 1 to 2 m in length, mostly located on the left and right flanks (Fig. 4a-d). Scars were parallel. Three small, not recent, oval scars were observed on the left side of the body, below the dorsal fin (Fig. 7), and at least a couple more on the right, behind the eye (Fig. 5b, d).

DISCUSSION

The beaked whale described here showed clear diagnostic morphological and behavioural traits typical of the genus *Mesoplodon*. The body of the specimen was laterally compressed. The recorded colour pattern is in agreement with Turner's (1882) description, and to Dr. Pitman opinion (pers. comm.) although this trait is poorly known in the genus *Mesoplodon*, also because it tends to rapidly change upon death and exposure to the air and light (Mead, 1989). The observed colour pattern matches well adult males. Long rake marks could confirm a young male due to their low number. Turner (1882) described *M. bidens* as bluish grey back or slate coloured with the side lighter, while Rothschild (1893) reported dark dorsally and white ventrally males, and dark all over females. Variation in colour may be due also to dilation of blood vessels near the skin (Mead, 1989).

The long scarring occurring in pairs seems to indicate inter-specific fighting which is known to occur between beaked whales (see Mead *et al*., 1982; Heyning, 1984). Linear scars we observed and photographed on both side of the *Mesoplodon* specimen were likely the result of tooth rakes inflicted, on the basis of the parallel scars width, by adult males bearing terminal teeth at the tip of the lower jaw. The close-spaced parallel scars are typical of ziphiids species like *Z. cavirostris* or *M. mirus* males. Scars in pairs, probably due to the mixed species group, may result from inter-specific interaction with *Z. cavirostris* (the second species in the mixed species group) regularly occurring in the study area (Bittau *et al.*, 2011, 2013). On the other hand, observed oval scars are probably due to cookie-cutter sharks scarring, although the genus *Isistius* is not recorded in the Mediterranean Sea.

M. bidens is considered endemic to the Atlantic Ocean (Mead, 1989). Although the North Atlantic core range of the species is the North Sea and no Mediterranean populations are known (McLeod *et al.*, 2006). All traits, diagnostic at species level, suggest to ascribe the specimen recorded off Sardinia to *M. bidens*.

Currently, the literature data indicate that the *Mesoplodon* in the Mediterranean Sea could be considered as a stray. Photo-ID matching has not been tried yet between this specimen and the NE-Atlantic Sowerby's BW records. However, this represents, to date, the first observation of a live free ranging *M. bidens* in the Mediterranean Sea documented with photos as evidence to confirm the species presence. The positive identification of the pod's whales as a mixed species group of Cuvier's and Sowerby's was possible thanks to the close approach and good quality of the photos we collected.

Although the occurrence of Sowerby's beaked whale populations is unlikely in the Mediterranean, it is necessary to consider that also Cuvier's beaked whale sightings in the latter basin were regarded as rare events in the past, on the basis of the supposition that all sighted individuals of *Z. cavirostris* entered accidentally in the Mediterranean from the Atlantic Ocean (Tortonese, 1957). It was only after a number of mass strandings occurred since the 60s (Tortonese, 1963; Podestà *et al*., 2006) and with the increasing in sightings that this species has been considered common since 80s in the north-western Mediterranean Pelagos Sanctuary (Moulins *et al.*, 2006).

Due to the difficulty in identifying the species of beaked whale at sea, especially from a great distance, it is likely that some previous sightings in the Mediterranean waters cannot be attributed with certainty to *Z. cavirostris*. As Mead (1989) focused only a large sample of strandings from the same area can confirm the geographic pattern, but care must also be taken to negative distributional data. Thus, while it is known that in the Mediterranean there is not a significant number of beaked whales strandings from the genus *Mesoplodon* to justify at least the presence of a small number of individuals in the basin, it is likely that especially where the genus is thought to be absent, some mesoplodonts encountered in the wild may have been misidentified as Cuvier's beaked whales.

The poor detectability of the species belonging to the genus *Mesoplodon*, whenever sea state exceeds Beaufort sea state 2 (Barlow *et al*., 2006), the several traits shared with *Z. cavirostris*, especially if observed from a distance, the need to look at the morphological characters of the head or produce good photographic material for the unequivocal species identification makes the debate as to whether *M. bidens* occurs in the Mediterranean Sea still open. Although it is difficult that Sowerby's or True's beaked whale survive in the warm eastern Mediterranean, they could both almost survive in some parts of the western basin. The presence of scars inflicted by two parallel teeth, and the Tyrrhenian mesoplodont sighting in a mixed species group with the more common species *Z. cavirostris* raises further questions about how long this animal is living in the Mediterranean waters. This is the only one record in the Mediterranean Sea that could be attributed to a free ranging Sowerby's beaked whale until now.

Distribution

Although the beaked whales are one of the most wide-ranging families of cetaceans, some basic aspects of their life history, population biology, ecology and biogeographic patterns remain poorly defined (Mead, 1989; MacLeod *et al*., 2006). As for the genus *Mesoplodon*, most of the information on geographic ranges at the species level refers to strandings data (Klinowska, 1991). The biogeographic pattern of the genus *Mesoplodon* in the North Atlantic Ocean is characterized by four regularly occurring species: *M. bidens*, *M. densirostris*, *M. europaeus* and *M. mirus* (Moore, 1966; Mead, 1989; MacLeod, 2000). MacLeod (2000) argued that these four species may be stenotermic and differing in their geographic ranges within this area. *M. bidens* is characterised by the most northern distribution, together with *M. mirus.* On the other hand *M. densirostris* and *M. europaeus* generally occur further south and they have an almost certainly cross-equatorial geographic range. *M. bidens* and *M. mirus* should prefer the colder northern and *M. densirostris* with *M. europaeus* the warmer South Atlantic waters. These biogeographic patterns are probably related to deep water temperatures rather than surface temperatures and with the bathymetric distribution of preferred prey species MacLeod (2000). The Sowerby's beaked whale core distribution is in the North Sea although the southernmost record of its geographic range occurred recently (2007) in the Eastern North Atlantic i.e. Canary Islands, (Martin *et al.*, 2011). Presently, *Z. cavirostris* is the only ziphiid known to be regularly occurring throughout the whole Mediterranean basin (Notarbartolo di Sciara & Demma, 1997; Notarbartolo di Sciara, 2002). Although this species is particularly common in the Ligurian Sea (Moulis *et al.*, 2007) its presence in the Central Tyrrhenian Sea (Marini *et al.,* 1996; Bittau and Manconi, 2011, 2012, 2013) suggest this area as a favourable habitat for this beaked whale (Gannier, 2010).

Strandings

The genus *Mesoplodon* was previously recorded in the Mediterranean Sea only for four reliable strandings (five specimens) and only one referred to a live stranding event (Podestà *et al.*, 2006, 2009). A female specimen reported as Sowerby's beaked whale (*M. bidens*) stranded on the western coast of Italy (Foce Verde, Lazio, 9 November 1927) (Brunelli and Fasella, 1928) but either no sample was not preserved nor any clear morphological description was given to provide a less doubtful identification (Podestà *et al*., 2006). The genus *Mesoplodon* was identified by Brunelli and Fasella (1928) from the position of teeth in the mandible, described as 'not on the tip of the lower jaw, but significantly distant'. The original description of morphotraits is enough detailed to conclude that it was not a Cuvier's beaked whale. A Blainville's beaked whale (*M. densirostris*) stranded in Spain in 1980 (Casinos and Filella, 1981; Grau *et al.*, 1986). A Gervais' beaked whale (*M. europaeus*) stranded in Italy in 2001, which was the first record of the species for Mediterranean waters (Podestà *et al.*, 2005). Only a live Mediterranean stranding record in 1996 may be referred to *M. bidens* (Bompar, 2000; Reeves and Notarbartolo di Sciara, 2006) when two live subadults were rescued and released in the Iles de Lérins area (south-western France) without collecting tissue samples or other evidence to confirm species identity.

Podestà *et al*. (2009) stated that all these strandings indicate the presence of the genus *Mesoplodon* in the Mediterranean but there were no live observations data available for the genus. Strandings have provided much of the available information on the geographic range of beaked whales there are however many aspects such as biogeographic patterns that cannot be studied only from stranded specimens. The new Mediterranean record contributes to fill in part the gap of knowledge on biogeographic pattern and behaviour of Sowerby's beaked whale. Further efforts and new sampling campaigns may offer potential opportunities for collecting new data to test if the North Atlantic population might be continuous with Mediterranean free ranging specimens across the Gibraltar Strait.

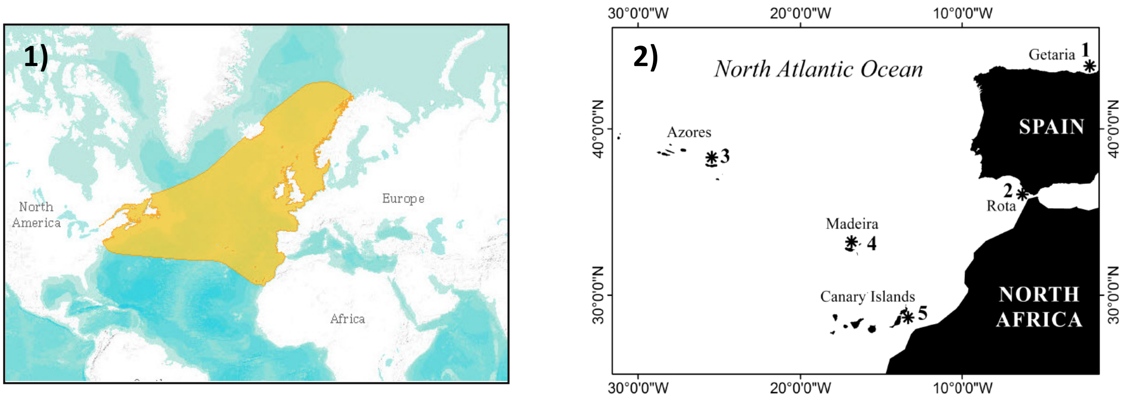

Fig. 2 a) *M. bidens* geographic range (Taylor *et al.*, IUCN 2013); b) Records of Sowerby's beaked whale strandings in the meridional waters of the eastern North Atlantic: 1) – Getaria, Spain, 2006; 2 – Rota, Spain, 2007; 3 – Azores; 4 – Madeira; and 5 – Lanzarote, Canary Islands, Spain, 2007 (from Martin *et al.,* 2011).

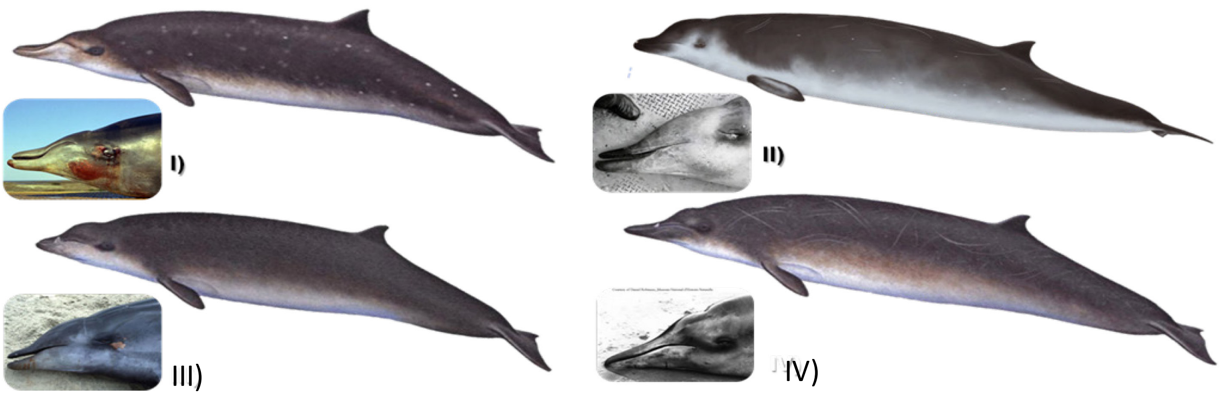

Figura 3 Comparison of four *Mesoplodon* species regularly occuring in the N-Atlantic Ocean: head shape of stranded specimens (Mead, 1989-Smithsonian Institute) and body illustrations (Jefferson et al., 1993); a – I: *M. densirostris*, female; b – II: *M. Mirus*, female; c – III: *M. europaeus*, male, female; d – IV: *M. Bidens*, male, female.

Fig. 4 Photographs of mesoplodont sighted off North-eastern Sardinia on 17 june, 2012. External scarring is usually given by intra-specific mating combats. Scars can be inflicted mainly by the con-specific teeth, but also from those of other ziphiids (see Mead, 1989), so even these parallel scars (a, b, c, e, f) may be produced by inter-specific Cuvier's-Sowerby's interactions. (Photographs credits: a), c), d), f): Paolo Curto; e): Mattia Leone; b): Paola Pegoraro).

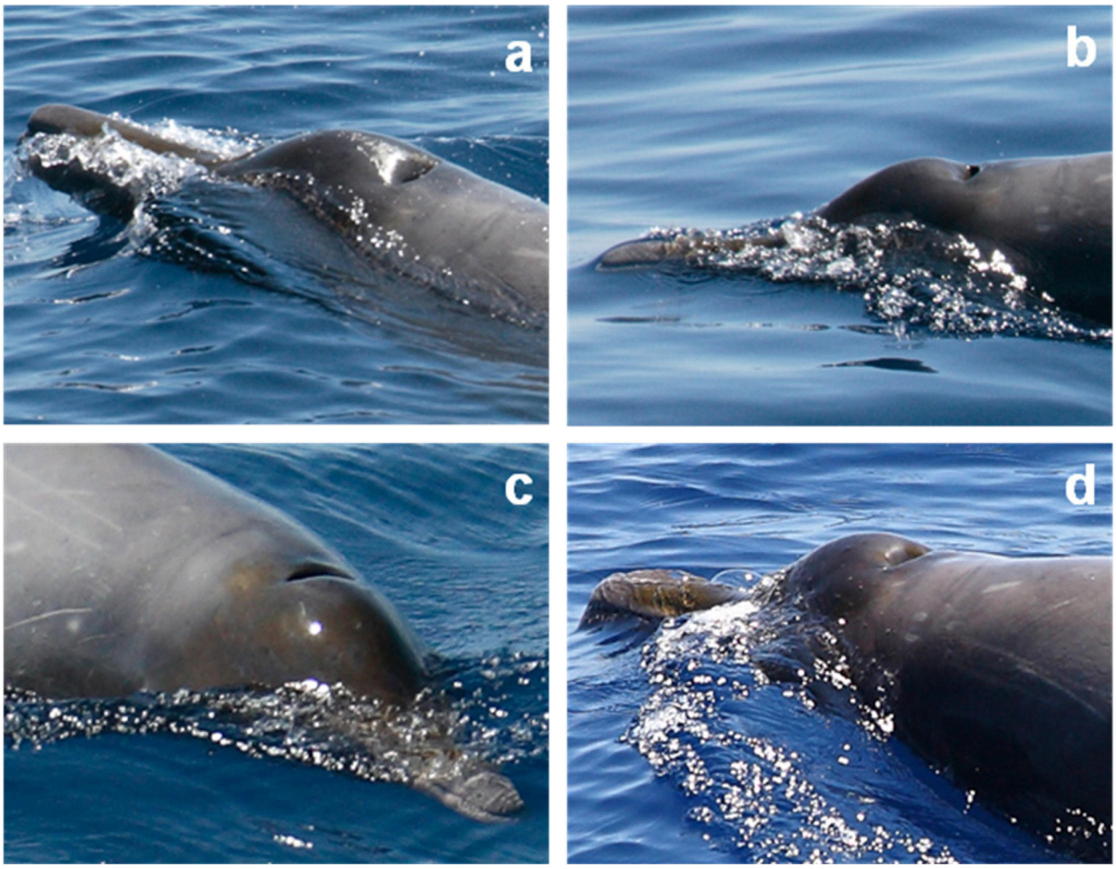

Fig. 5 Head details of the *M. bidens* sighted off Sardinia, showing long beak, prominent bulge and forehead's concave shape. (Photographs credits: a), b), c): Paolo Curto; d): Paola Pegoraro).

Fig. 6 the mixed species group off NE-Sardinia: typical surfacing appearance of Sowerby's (red arrow): the beak appeared first, 30-45° to the water surface, as in Hooker & Baird, 1999.

Fig. 7 Detail showing the oval scarrings on the right side of the M. Bidens spotted off North-eastern of Sardinia. (Photograp: P. Curto)

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Chapter 4

Occurrence of sperm whale (*Physeter macrocephalus*) social units along the north-eastern Sardinian continental slope (Central Tyrrhenian Sea)

Occurrence of sperm whale (*Physeter macrocephalus*) social units along the north-eastern Sardinian continental slope (Central Tyrrhenian Sea)

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ABSTRACT

Three social units of female sperm whales with calves and young individuals were observed over the continental slope and the Caprera Canyon area off the north-eastern coast of Sardinia. These social units during were spotted in summer 2010 and 2013 and were characterized by a group size from six to ten individuals. Some adults were foraging, the calves and females were resting. The observations were carried out during an ongoing research project using one-day visual surveys by opportunistic platforms. These sightings occurred slightly to the north of the 41° parallel, out of the Southern border of the Pelagos Sanctuary. The observations are discussed.

Keywords: Caprera Canyon, behaviour, whale watching, distribution, sperm whale, movements, Mediterranean Sea

INTRODUCTION

The sperm whale *Physeter macrocephalus* Linnaeus, 1758 is the largest odontocete inhabiting the Mediterranean Sea, widely distributed from the Alboràn Sea to the Levantine basin, mainly over steep slope and deep offshore waters. Most sperm whales shift towards higher latitudes in spring and summer, returning to warmer waters in autumn (Notarbartolo di Sciara, 2002).

No estimate of sperm whale population size exists for the Mediterranean Sea. The total number in the whole Mediterranean basin amounts to only a few hundred individuals (Notarbartolo di Sciara et al., 2012, in www.iucnredlist.org). However, at least until the 1950s, there is evidence that sperm whales were once common in some Mediterranean areas, such as the Strait of Messina and the Aeolian Islands (coast of Sicily) where they could be seen in large groups of as many as 30 individuals, while nowadays such sightings are rare (IUCN, 2012). Recently, the sperm whale classification was changed in 'Endangered', under the IUCN criteria (Reeves & Notarbartolo di Sciara, 2006; Notarbartolo di Sciara & Birkun, 2010). Over the last decade a considerable decline in the number of individuals in the region was pointed out by increasingly frequent reports of annual strandings (stranded, floating dead or entangled individuals) from France and Italy. Entanglement in fishing gear (especially swordfish drift gillnets and tuna driftnets), vessel strikes and disturbance by intense boat and ship traffic are the primary causes of the sperm whale endangered conservation status.

It is well-known that female and immature sperm whales form stable social units, to protect the calves and to allow mothers foraging (Gero *et al.*, 2013). In the Ligurian Sea, sperm whale groups usually range from 2 to 4 individuals (Azzelino *et al*., 2008).

Morel & Andre (1991), on the base of satellite imagery of sea surface temperature and primary production, divided the Mediterranean Sea into a southern and a northern region, taking the 41° parallel as divisor line (Fig. 1). Drouot *et al.* (2004a) compared the sizes of sperm whale schools between Mediterranean regions North and South of the 41° parallel.

They speculated that males segregate in the northern region, where school sizes are signficantly smaller, with a maximum of three whales sighted at the surface, while in the southern region, larger schools including calves, seemed to be confined due to the warmer waters, which ould provide suitable breeding and feeding conditions for females and their offspring.

Sperm whale ecology around the Sardinia Island is poorly known, although the Western-central Tyrrhenian Sea is deemed potentially critical for the entire Mediterranean basin both as feeding (Arcangeli *et al*., 2013) and breeding grounds for several cetacean species, but even rich in potential human threats. The Central Tyrrhenian Sea is candidate for the establishment of an open sea SPAMI the by UNEP (UNEP, 2010). Recently, the Caprera Canyon area has been suggested to be a 'hot spot' of cetaceans (Bittau & Manconi, 2011; Bittau *et al*., 2011, 2012, 2013) *sensu* Moulins *et al.* (2008).

We report on the occurrence of three social units of sperm whales off North-eastern Sardinia (central Tyrrhenian Sea) during summertime 2010 and 2013. The whales were identified and followed in order to record their behaviour, and perform photo-identification activity.

STUDY AREA

The Caprera Canyon, just above the latitude of the Strait of Bonifacio (41°18'N) extends approximately from 41°10'N to 41°25'N and from 09°39'E to 10°23E, representing the main bottom-sea morphological features eastward between Sardinia and Corsica islands. The 1000 m isobath of the Caprera Canyon lies ca. 24 nautical miles (ca. 44 Km) from the nearest ground point on the coast of Sardinia. It consists of two meandering tributaries canyons incised in the continental upper slope that join in a single, 2.5 km wide canyon, at a depth of around 1000 m in the lower slope (Gamberi and Marani, 2004). In terms of water circulation, the central Tyrrhenian Sea is characterized by a main, larger cyclonic circulation (the 'Tyrrhenian Gyre') while in the inner sector occur several gyre structures.

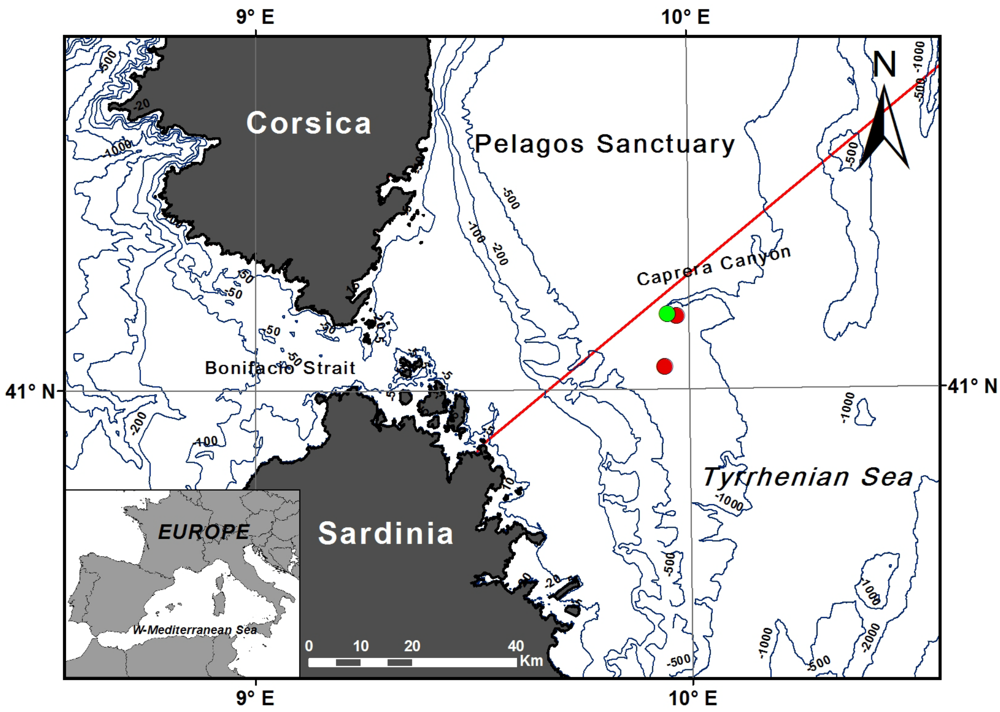

Fig. 1 Bathymetric map of the Caprera Canyon area showing observations sites of three sperm whale social units (green dot = 21 July 2010, n=6; red dots = 17 and 26 July 2013, respectively n=10 and n=11). The Pelagos Sanctuary South-eastern border is indicated by the red line. 41° parallel line is showed.

The circulation in the Western-central sector of the basin presents two main gyres: a cyclonic cell with a variable shape and size depending on the season, mostly located to the east of the Strait of Bonifacio, the "Bonifacio Gyre", and a southernmost anticyclonic gyre adjacent of the first, off the Eastern coast of Sardinia (Small *et al.*, 2012). These gyres are usually considered wind-driven (Artale *et al.*, 1994; Nair *et al.*, 1994) but recent studies revealed that topography may play an important role in determining the cetacean distribution and habitat use (Budillon *et al.*, 2009; Vetrano *et al.*, 2010). The specific wind field, mainly the West and Mistral winds, blow reinforced by the 'Venturi effect' through the Bonifacio Strait inducing the two large counter-rotating vortices and generating a filament of cold water just off the Northeastern Sardinian coast (Bignami *et al.*, 2008). The largest, Northern structure caused by the Bonifacio Strait wind jet stream appears as a quasi-permanent cyclonic circulation (Moen, 1984; Vetrano *et al*., 2010) that produces eastward an upwelling of deep, cold water and creates water fronts affecting the study area.

OBSERVATIONS

We present three records of social units occurred in 2010 and 2013 during an ongoing project focused on pelagic cetaceans in the central Tyrrhenian Sea.

Visual surveys were conducted using a 11 m whale watching catamaran (the 'Orso Cat') employed as platform of opportunity. Data were collected only by one-day visual surveys and included boat coordinates, sighting positions, photo-identification and weather conditions.

The sightings occurred in the Caprera Canyon area, located off north-eastern Sardinia, north of the 41° parallel that is a particularly productive area outside the South-eastern border of the Pelagos Sanctuary. A social unit was sighted on July 21, 2010, 40 Km off NE-Sardinia, in a 770 m deep primary position (41° 22.86'N, 9° 77.038E). The group size was estimated of 6 individuals, one of which was a calve of 5-6 m in lenght.

Calve length was estimated ca. 5-6 m, compared to the vessel length.

On July 17, 2013 a second social unit with 3-4 calves was sighted, 44 Km off the coast (41° 22.662'N, 9° 58.292E) to a depth of 836 m. Group size ranged from 10 to 13 individuals.

The third sighting occurred on July 26, 2013 and water depth was 653 m (41° 17.25'N, 9° 56.601E).The unit size was of 11 individuals with several calves and young individuals. The three social units displayed different behaviours, during the sightings. The calves displayed the typical behaviour, swimming with their heads more angled from the surface than adults.

In 2010 the animals were on surface, very close to one another. Initiallly we encountered a single, 11 m long individual, resting at the surface and very quite. After 20 minutes a herd of 5 approched the single individual, rejoining and assuming an echelon formation and swimming synchronous side by side. The adult whales swam close together displaying a coordinated swimming pattern at the surface but did not synchronize their blows.

For both the 2013 sightings the behaviours were not similar trough the group components, the sperm whales were indeed dispersed in small sub-groups ranging 2-4 individuals, each with different dive time and surfacing. Probably some individual were foraging, due to defecation observed. Before the vessel approach we observed breaching young individuals.

Sub-groups in the two last social units exhibited a synchronous behaviour, with diving time of about 15-20 minutes. As all of the adult whales measured less than 12m in length (by comparing with the boat) and were closely associated with the calves they were assumed to be females. When the adults fluked, the associated calves followed other individuals and dived but resurfaced few minutes later.

A calves in 17 July, 2013 and two calves in 26 July were observed switch their position alongside different adults in the herd.

Photo-identification allowed us to verify that each sighting represented three distinct social units. The observed group size values are apparently among the higher reported until now for the Mediterranean Sea (Druout *et al.*, 2004).

All the sighting occurred on summer, probably due to the increasing of Sea Surface Temperature. Sperm whales have been sighted a total of nine times in 2013 within 30 nautical miles off North-eastern coast if Sardinia, in the slope and Caprera Canyon area, during surveys conducted by the DIPNET-Sassari University.

Mean Sea Surface Temperature in July 2013 was 26°C (Data from Satellite Remote Sensing MODIS Aqua, NASA). These observations are important if considering that the Mediterranean sperm whale stock is classified as "Endangered" by the IUCN.

Although stranding records and accidental catches in fishermen's nets do not yield reliable information about the timing and location of whale reproduction (Podestà & Bortolotto, 2001) it would appear that the highest concentration of very young sperm whales is to be found in the central and southern Tyrrhenian Sea between February and October. Our sightings confirmed this theory and represent, at time, the only such report of sperm whale social unit off Sardinia.

Fig. 2 The sperm whale social unit sighted in 2010. The two larger animal (righth) is presumed to be females, because of its close association to the left, a offspring. The total length of the small calves is estimated to be about 5-6m. Photograph by Luca Bittau.

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