As main meal for sperm whales: Plastics debris

Renaud de Stephanis [a,*], Joan Giménez [a], Eva Carpinelli [b], Carlos Gutierrez-Exposito [a], Ana Cañadas [c]

[a] GEMA, Department of Conservation Biology, Estación Biológica de Doñana (CSIC), Americo Vespuccio S/N, Isla Cartuja, 41013 Sevilla, Spain
[b] CIRCE (Conservation, Information and Research on Cetaceans), C/Cabeza de Manzaneda 3, Pelayo, Algeciras, Cádiz, Spain
[c] Alnilam Research and Conservation, C/Cándamo 116, 28240 Hoyo de Manzanares, Madrid, Spain

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A B S T R A C T

Marine debris has been found in marine animals since the early 20th century, but little is known about the impacts of the ingestion of debris in large marine mammals. In this study we describe a case of mortality of a sperm whale related to the ingestion of large amounts of marine debris in the Mediterranean Sea (4th published case worldwide to our knowledge), and discuss it within the context of the spatial distribution of the species and the presence of anthropogenic activities in the area that could be the source of the plastic debris found inside the sperm whale. The spatial distribution modelled for the species in the region shows that these animals can be seen in two distinct areas: near the waters of Almería, Granada and Murcia and in waters near the Strait of Gibraltar. The results shows how these animals feed in waters near an area completely flooded by the greenhouse industry, making them vulnerable to its waste products if adequate treatment of this industry's debris is not in place. Most types of these plastic materials have been found in the individual examined and cause of death was presumed to be gastric rupture following impaction with debris, which added to a previous problem of starvation. The problem of plastics arising from greenhouse agriculture should have a relevant section in the conservation plans and should be a recommendation from ACCOBAMS due to these plastics' and sperm whales' high mobility in the Mediterranean Sea.

1. Introduction

Until the late 1970s little attention was paid to non-degradable waste that was discarded in the ocean. Today the fragmentation and accumulation of plastic debris in the marine environment is proposed as one of its major problems (Prouter, 1987; Stefatos et al., 1999) or as the "most ubiquitous and long-lasting recent changes to the surface of our planet" (Barnes et al., 2009). A recent review on the topic (Gregory, 2009), has brought to light how over the past five or six decades, contamination and pollution of the world's enclosed seas, coastal waters and wider open oceans by plastics and other synthetic, non-biodegradable materials has become an increasing phenomenon (Gregory et al., 1984; Derraik, 2002; Eriksson and Burton, 2003; Barnes and Milner, 2005; Barnes et al., 2009; Ryan et al., 2009). Marine plastic pollution is becoming an issue also in remote areas of the world previously thought to be unaffected so we are facing a worldwide problem that is affecting the marine fauna (Aumanet al., 2004; Provencher et al., 2010). The consequences of marine debris are varied, as are its sources (land- or marine-based), and origins (local or distant). In the same way, the more widely recognised problems in marine animals can be varied (entanglement, ingestion, suffocation, general debilitation, etc.). Over 250 marine species (including crustaceans, fish, sea-turtles, sea-birds, sea-otters, pinnipeds, sirenians and cetaceans) are known to be impacted by entanglement and ingestion (Laist, 1997). The literature on ingestion and entanglement of plastic debris is wide. The main problems identified are wounds (internal and external), suppurating skin lesions and ulcerating sores; blockage of the digestive tract followed by satiation, starvation and general debilitation often leading to death; reduced life quality and reproductive capacity; drowning and limited predator avoidance capabilities; impairment of feeding ability, etc. (e.g. Gregory, 1978, 1991; Laist, 1997). Until now, most of the existing information regarding interactions between large marine mammals and marine debris is related to entanglement, but not ingestion. Pinnipeds have been reported to die from strangulation or starvation due to entanglement (Croxall et al., 1990; Boren et al., 2006; Dau et al., 2009). In cetaceans the usual problems are related to injuries to fins (pectoral or caudal) or mouth (Northridge, 1991; Moore et al., 2009; Neilson et al., 2009). In the case of sperm whales, gill net entanglements have been reported in Ecuador (Haase and Félix, 1994) and in the Mediterranean Sea (Pace et al., 2008). Ingestion of marine debris is well documented in marine birds (Moser and Lee, 1992; Spear et al., 1995; Rodríguez et al., 2012) and sea-turtles (Tomas et al., 2002), but less so in cetaceans, although several cases have been reported worldwide (Walker et al., 1989; Laist, 1997; Baird and Hooker, 2000; De Meirelles and De Barros, 2007;

* Corresponding author. Tel.: +34605998195.
E-mail addresses: renaud@stephanis.org, renaud@ebd.csic.es (R. de Stephanis).

Jacobsen et al., 2010). Even small quantities of debris have the potential to exert a large effect on the animal – for instance, through occlusion of the intestinal tract (Tarpley and Marwitz, 1993; Gorzelany, 1998; Stamper et al., 2006; Gomerčić et al., 2009; Levy et al., 2009). One interesting example is the case of two stranded sperm whales in the coast of northern California. During necropsy, a total of 24.20 kg and 73.63 kg of marine debris including ropes, plastics and different types of nets made of floating material were extracted from their stomachs. In the first case, gastric rupture following impaction with debris was presumed to be the cause of death, whereas in the case of the second whale, the emaciated body condition the animal was found in suggested starvation following gastric blockage (Jacobsen et al., 2010). More recently, a case of a young sperm whale (5.3 m) individual has been described, in the Mykonos Island in Greece Sea with more than 100 plastic in its stomach that caused its death in Katsanevakis (2008) and Notarbartolo-di-Sciara et al. (2012).

The sperm whale (*Physeter macrocephalus*, Linneus 1758), the largest of the toothed whales, has a cosmopolitan distribution, with a large latitudinal range (Whitehead, 2003). Genetic analyses suggest that the Mediterranean sperm whales constitute a separate population (Drouot et al., 2004; Engelhaupt et al., 2009). At the moment there are no overall abundance estimates for the Mediterranean subpopulation. Even though recent bioacoustic data indicate a more consistent and frequent presence of sperm whales than previously thought in some areas of the Mediterranean Sea, like in Sicily (Pavan et al., 2008), but the Mediterranean population appears to have declined over the last 20 years, mainly due to bycatch in driftnets targeting swordfish (Reeves et al., 2006), in addition to ship strikes (Panigada et al., 2006). The species is distributed throughout the Alboran Sea and Strait of Gibraltar (Cañadas et al., 2002, 2005; De Stephanis et al., 2008; Carpinelli et al., 2011, 2012), Balearic Islands (Gannier et al., 2002; Pirotta et al., 2011), Ligurian Sea (Gannier et al., 2002) and Greece (Frantzis et al., 2003, 2011), and can travel long distances between different areas (Carpinelli et al., 2011, 2012; Frantzis et al., 2011). Little is known about the species in the Alboran Sea (Cañadas et al., 2002, 2005), in particular regarding anthropogenic interactions in this area, and, as far as we are aware, the ingestion of plastic debris has not been described as a key issue for the conservation of the species in the Mediterranean Sea.

In this study we describe the second reported case of mortality of a sperm whale related to the ingestion of large amounts of marine debris in the Mediterranean Sea (4th reported case worldwide to our knowledge), and discuss it within the context of the spatial distribution of the species and the presence of anthropogenic activities in the area that could be the source of the plastic debris found inside the sperm whale.

2. Materials and methods

2.1. Sperm whale stranding

On March 28th 2012, a sperm whale (Fig. 3) was found dead on a beach near Castell de Ferro (Granada, SE Spain). The animal was weighed, measured, and the abdominal cavity opened. All the stomach contents (Fig. 7) were recovered and transported to the Estación Biológica de Doñana-CSIC (Spain) where they were washed and dried for subsequent labelling, weighing and measuring. Type of material, diameter, colour, and putative origin of the anthropogenic remains of more than 4 cm^2 were determined when possible. All of these characteristics were used to categorize each piece of plastic into a distinct type. All the items of less than 4 cm^2 were weighted together and labelled as small plastics. The fluke of the sperm whale was compared with the catalogue created by Carpinelli et al. (2011, 2012). The catalogue includes identifications of 47 sperm whales from the Strait of Gibraltar (collected between 1999 and 2011), 57 from the Balearic Islands (1994–2004), 35 from the Corso-provençal basin (1994–2011), 33 from the Hellenic Trench (1998–2009), 105 from the Ligurian Sea (1990–2010) and from the 5511 pictures of 34 contributors included in the NAMSC (North Atlantic Ocean and Mediterranean Sea) catalogue.

2.2. Spatial distribution

Data were collected during surveys carried out throughout several research projects under the umbrella of the NGO Alnitak from 1992 to 2009 (Cañadas et al., 2005; Cañadas and Hammond, 2006, 2008; Hooker et al., 2011; Druon et al., 2012). A total of 74.187 km were sailed. There were 34 groups of sperm whale recorded involving 55 individuals during these surveys. The study area (the entire Alboran Sea, reaching from the Strait of Gibraltar to Cabo de Palos-Spain) was characterized according to several spatial and environmental variables (depth, slope, distance to 200 m and 1000 m isobaths, sea surface temperature (SST), chlorophyll a concentration (Chla), primary production, and altimetry (Cañadas and Hammond, 2006, 2008), and model-based density estimation based on spatial modelling was applied following the general methodology described in Cañadas and Hammond (2006, 2008).

3. Results

3.1. Sperm whale stranding findings

On March 28th 2012, a 10.0 m long male sperm whale (Fig. 3) was found dead on a beach near Castell de Ferro (Granada, Spain). The whale weighed around 4500 kg, and seemed to be in a state of advanced emaciation. There was no evidence of entanglement scars or other injuries. The animal was opened on April 2nd 2012. During inspection of the abdominal cavity, squid beaks were found on the exterior portion of the small intestine, and inside the stomach compartments. A large mass of compacted plastics could be seen protruding through a rupture in the first stomach compartment (Fig. 4). No fresh remains of squids were recovered. The intestines were empty. Cause of death was presumed to be gastric rupture following impaction with debris, which added to a previous problem of starvation. All of the plastic pieces and other debris were recovered. A description of the contents can be found in Table 2, and Figs. 5 and 6. The matching of the sperm whale's fluke revealed that the animal had not been photographically matched before in the Mediterranean Sea.

3.2. Density surface models: Alboran Sea

The final model for group abundance included two covariates: depth and longitude (as a proxy to distance from the Strait of Gibraltar), both highly significant, and explaining 18% of the deviance. Group density increased very steeply with depth from 0 to 500 m, slightly towards deeper waters, and showed a bimodal distribution with respect to longitude, with the highest densities towards the Strait of Gibraltar and a second smaller peak around the south of Almería (see Fig. 1). The final model for group sizes included distance from the 200 m depth contour as the only but highly significant co-variable, explaining 34.2% of the deviance. Group sizes tended to increase towards shallower waters (closer to the 200 m depth contour (see Fig. 2).

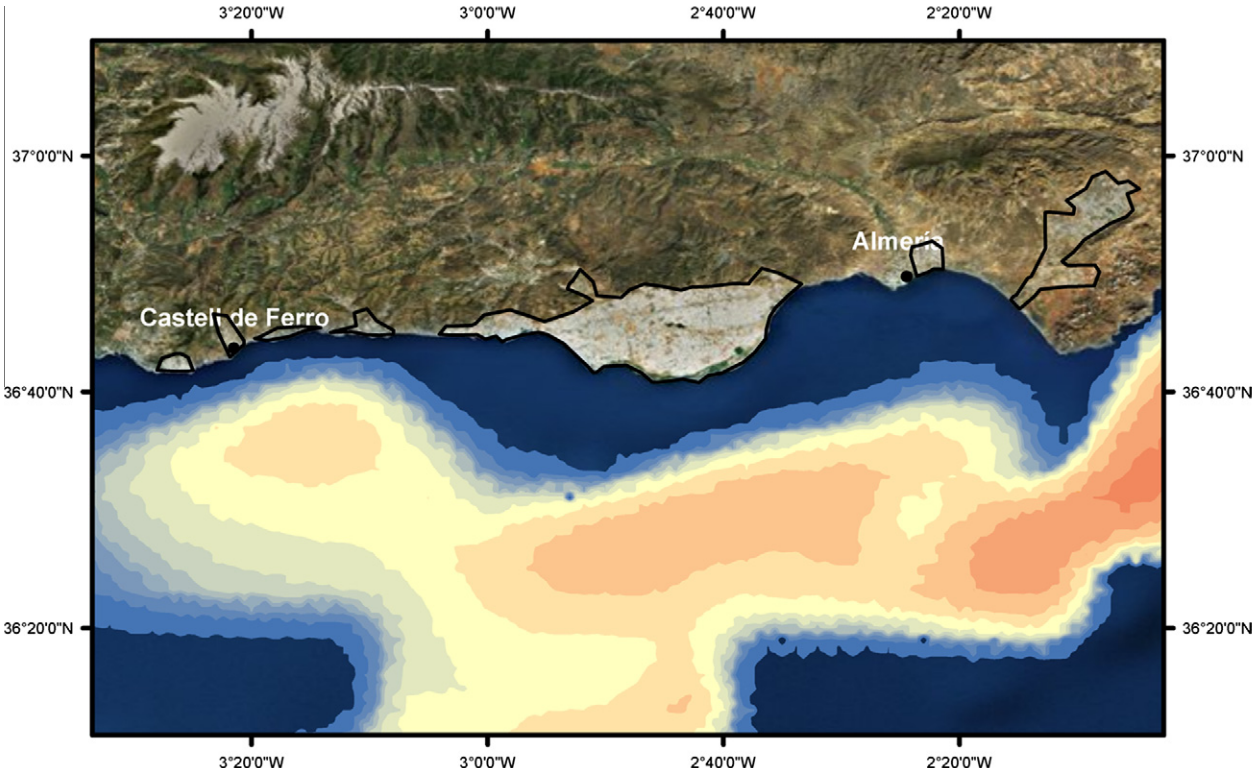

Fig. 1. Predicted density surface map of sperm whales in the Area of Almeria from spatial modelling and greenhouse situation in the area (in black).

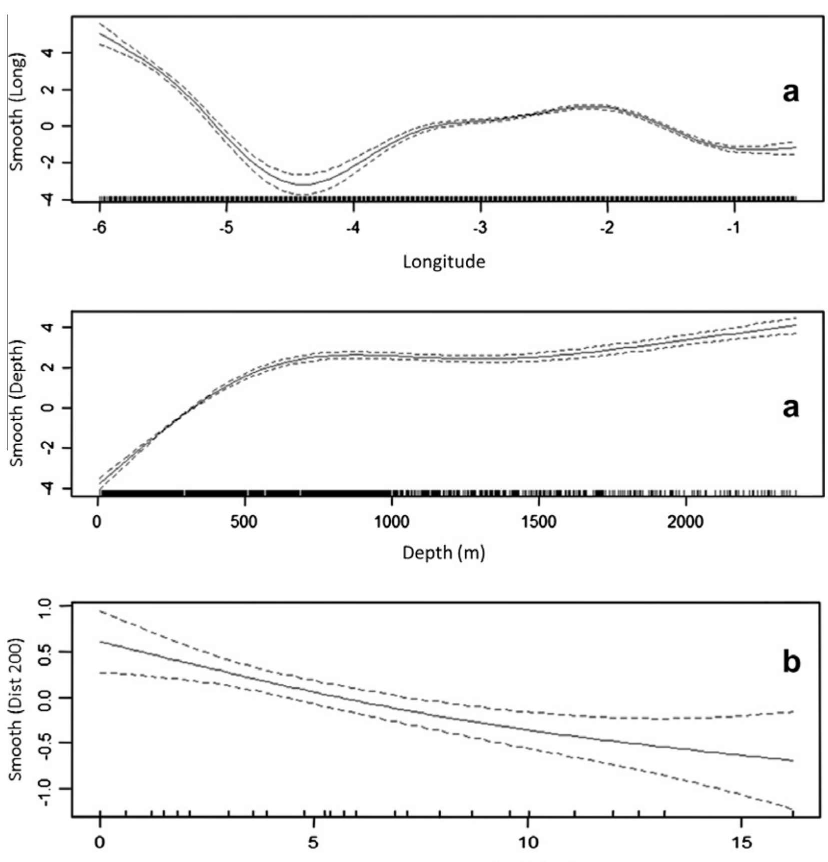

Fig. 2. Smoothed functions for the selected predictive covariates in the model of abundance of groups (a) and the model of group sizes (b) for the Alborán Sea and the Strait of Gibraltar. Continuous line represents the point estimate and dashed lines represents ±1 se.

Fig. 3. Picture of the sperm whale.

Fig. 4. Picture of the plastic contains in the sperm whale. The arrow indicates the remains.

4. Discussion

Marine debris has been found in sperm whales since the early 20th century, when Sir William (Turner, 1903) described the presence of fish-hooks in the stomach contents of individuals found in the Shetland Seas. Table 1 shows a summary of the types of marine debris recovered from the stomachs of sperm whales that have been described in the scientific literature. The origins of this debris are varied, but it has mainly found to be material used in fishing activities, such as fish-hooks, fishing nets or ropes (see Table 2). Up until now, none of the marine debris recovered from the stomach contents of sperm whales has been reported to derive from agricultural activities like greenhouses, as is the case we describe.

Greenhouse cultivation has spread rapidly over the last few years in many regions, in particular in the Mediterranean Basin countries, where the mild winter temperatures allow the production of low-cost vegetables all year round. In western Almeria (Andalucía) approximately 25,902 ha of crops were grown under plastics in the 2005 season (Sanjuan, 2007) (Fig. 1). In the same way as in Almeria, this type of culture is beginning to flourish slowly in the regions of Murcia and Granada (Fig. 1). Greenhouses use many plastic materials with different utilities (Céspedes López et al., 2009; Tolón Becerra and Lastra Bravo, 2010). Interestingly, most types of these plastic materials have been found in the individual examined, starting with two flowerpots. The main debris found in the animal (26 items totaling more than 8.1 kg and a total surface of 29.9 m^2) was identified as the plastic cover material of greenhouses, which is typically transparent. Furthermore, 19.3% of greenhouses also apply plastic mulching on their crops. The most widely used material for this practice is black plastic, of which four pieces were found, totaling 0.44 kg (Table 2). The application of plastic burlaps in agriculture has two well defined utilities. One is the production, and the post-production or packing. The animal had seven bits of burlap plastic bags, weighing a total of 1.9 kg. Finally, 9 m of ropes were found, typically used in the construction of greenhouses, and two pieces of hosepipe totaling 4.5 m (Table 2). Apart from this waste, several remains were found (Table 2), which, although not directly related to greenhouse, could potentially be indirectly related, especially in the case of plastic bags and plastic carafes.

The spatial distribution of the species in the region shows that these animals can be seen in two distinct areas: near the waters of Almería, Granada and Murcia and in waters near the Strait of Gibraltar. The model generated could have edge effects in the area of the Strait of Gibraltar, with a relatively low number of sightings (only 3) and a small number of transects in this area. In any case, the species has been described in the Strait of Gibraltar by De Stephanis et al. (2008), so these edge effects, although possible in the model, do not reflect errors in reality. It should be noted that around 55% of the animals found in Almería and Murcia were also seen in the Strait (Carpinelli et al., 2011, 2012), so it would not be unreasonable to think that we are facing the same population/management stock which is in transit or is resident in the two feeding areas. Moreover, as can be seen in Carpinelli et al. (2011, 2012), these animals are not observed uniquely in these two regions, and can sometimes also be seen in the Balearic Islands and the Ligurian Sea. In any case, it is clear that these animals feed in waters near an area completely flooded by the greenhouse industry, making them vulnerable to its waste products if adequate treatment of this industry's debris is not in place. Around 45,000 Tm of waste are generated in the area of Almería itself per year (Ayuntamiento de El Ejido, 2003; Fundación Cajamar, 2008; Tolón Becerra and Lastra Bravo, 2010). In general, the steps involved in the management of plastic waste in the region are: Packaging – Transport – Cleaning – Crushing – Washing – Drying – Pelletizing (extrusion) (Ayuntamiento de El Ejido, 2003). However, at present there, the problem of degraded plastics that are no longer recyclable still remains. The main conundrum is that they are very difficult to collect, and strong winds spread them across the fields (Tolón Becerra and Lastra Bravo, 2010). These annotations are confirmed by the findings of this study, since apart from distributing them all over the field as discussed above, they can end up in the sea, and can be ingested by species such as sperm whales. This highlights the need for stronger management measures in the region to prevent such waste to be near coastal regions, ending up in the sea.

Unfortunately, no data exists on floating debris in the region, so it is impossible to know whether these residues are floating on the surface or not, nor the abundance of plastics arriving to the sea. It is

Fig. 5. Plastic debris found in the stomach coming from greenhouse: (a) flower pot, (b) hosepipe, (c) greenhouse cover material, (d) plastic burlap, (e) rope, and (f) plastic mulch of greenhouse.

Fig. 6. General plastic debris found in the stomach: (a) dishwater plastic pot, (b) hanger, (c) mattress, (d) plastic carafe, (e) tub of ice-cream, (f) small plastic (indicated by white arrows), (g) spray plastic pot, and (h) bag.

Fig. 7. Plastic debris found in the stomach of the sperm whale.

therefore unclear whether sperm whales capture all this debris in the surface, in mid-water or in the seabed. It has been suggested that the bottom feeding habits of sperm whales account for the tendency of this species to ingest a variety of non-food items, including sand, rocks, coconuts and other debris (Nishiwaki, 1972), so this specie pose a greater health hazard than other cetacean species due to its feeding behavior (Lambertsen and Kohn, 1987). Despite their benthic or bathypelagic feeding behavior (e.g. Betesheva and Akimushkin, 1955; Nemoto and Nasu, 1963; Gaskin and Cawthorn, 1967; Clarke and MacLeod, 1976; Clarke, 1980) some of their preys can be taken in mid-water and some may even be taken from near the sea surface at night (Martin and Clarke, 1986). The presence of some buoyant objects such as pieces of plastic in our case and in some stomachs revised in the

Table 1
Review of marine debris found in sperm whales. References: (1) Turner (1903), (2) Gaskin and Cawthorn (1967), (3) J. Harbey unpublished data in Mate (1984), (4) Charleston Museum of Natural History, Charleston, SC in Walker et al. (1989), (5) Martin and Clarke (1986), (6) Sadove et al. (1989), (7) Clarke et al. (1993), (8) Lambertsen and Kohn (1987), Lambertsen (1990), (9) Charleston Museum of Natural History, Charleston, SC in Walker et al. (1989), (10) Viale et al. (1992), (11) Spence (1995), (12) Evans and Hindell (2004), (13) Roberts (2003), (14) Fernández et al. (2009), (15) Jacobsen et al. (2010), (16) Mazzariol et al. (2011), (17) Katsanevakis (2008), Notarbartolo-di-Sciara et al. (2012).

Case	Date	Location	No. of individuals analyzed	No. of individuals with marine debris	Type of marine debris	Origin
1	1895–1901	Shetland Seas (UK)	Several	Several	Fish-hook	Fishing activities
2	1963–1965	Wairarapa coast to the North Canterbury (New Zealand)	151	4	Coal	Rocks
			151	6	Pumice	Rocks
			151	1	Basalt	Rocks
			151	1	Slats of box wood	General debris
3	1979	Florence, Oregon (USA)	38	1	1 l of Tightly packed trawl net	Fishing activities
4	1979	Newfoundland (Canada)	Unknown	1	Small length of nylon rope	Fishing activities
					Unidentified debris	General Debris
5	1977–1981	Iceland and Greenland	221	Not always recorded	Plastic or wood and 0.2 m or less in length	General debris
					Plastic drinking cups	General debris
					Children's toys	General debris
					Small pieces of tree branches	General debris
					A newspaper	General debris
					Small rock fragments of basalt and granite (normally <0.02 kg, but up to 0.1 kg)	Rocks
					Five discarded fishing nets (The largest weighed 63 kg)	Fishing activities
6	1979–1988	New York Bight (USA)	8	3	Synthetic materials	General debris
7	1981–1984	Azores (Portugal)	17	2	Plastic jug	General debris
					Netting	Fishing activities
					Fisherman trawl	Fishing activities
8	1981–1982	Western coast of Iceland	32	12	Large polypropylene fishing net (otter trawl) attached to a coil of polypropylene line about 50 m long.	Fishing activities
					Plastic and metallic debris of human origin	General debris
					Broken 3-gallon plastic bucket	General debris
9	1985	Seaside NJ (USA)	Unknown	1	Mylar balloon	General debris
10	1989	Lavezzi Islands (France)	1	1	100 Square feet plastic bags and sheets	General debris
11	1992	Wrightsville Beach, NC (USA)	1	1	Bleach bottle	General debris
					30 Feet of polypropylene line	Fishing activities
					A fishing float	Fishing activities
					Plastic caps	General debris
					A large piece of what is thought to be unprocessed natural rubber	General debris
12	1998	Tasmania (Australia)	36	4	Small pieces of plastic material	General debris
					Top section of a plastic container (of approximately 2 l in reconstructed volume)	General debris
13	2001	South coat of Crete (Greece)	1	1	Small square piece of rigid plastic mesh 10 × 10 cm	General debris
14	2002–2005	Canary Islands (Spain)	5	2	Plastic debris	General debris
					Plastic bag (size 31 × 20 cm)	General debris
					Fishing hook of approximately 6 cm in length	Fishing activities
15	2008	Northern California (USA)	2	2	Rope (24.2–73.63 kg)	General debris
					Plastic debris	General debris
					134 Different types of nets, all made of floating material, varying in size from 10 cm^2 to about 16 m^2.	Fishing activities
					(Note: the majority of debris in each whale consisted of scraps of netting (81% dry weight), pieces of line (17%) and pieces of bags, made mostly of plastic (2%))	Fishing activities

(*continued on next page*)

Table 1 (*continued*)

Case	Date	Location	No. of individuals analyzed	No. of individuals with marine debris	Type of marine debris	Origin
16	2009	Adriatic coast (Italy)	7	7	Fishing gear (0.0095–4.934 kg)	Fishing activities
					Hooks	Fishing activities
					Ropes	Fishing activities
					Several plastic objects	General debris
17	2006	Mykonos Island in Greece	8	4	General debris	General debris

Table 2
Remains found in the sperm whale stomach. Small plastic refers to plastic items remains of less than 4 cm^2.

Origin	Item type	Amount	Total (g)	Range (g)	Surface (m^2)	Range (m^2)	Length (m)
Greenhouse	Cover material of greenhouse	26	8136	20–1490	29.94	0.04–5.55	–
	Flower pot	2	57	22–35	0.02	0.02–0.02	
	Hosepipe	2	195	75–120	0.58	0.27–0.30	3.1, 1.4
	Plastic burlap	7	1908	58–495	3.50	0.21–0.66	–
	Rope	5	3460	50–2000	–	–	9.06
	Plastic mulch of greenhouse	4	442	50–240	1.69	0.16–0.98	–
General debris	Dishwater plastic pot	1	50	–	0.01	–	–
	Hanger	1	25	–	0.36	–	–
	Mattress	1	20	–	0.002	–	–
	Plastic carafe	2	80	30–50	–	–	–
	Small plastics	–	2500	–	–	–	–
	Spray plastic pot	1	48	–	–	–	–
	Tub of ice-cream	1	20	–	–	–	–
	Bag	5	986	35–500	1.3791	0.10–0.60	–
Cephalopods beaks	Cephalopods beaks	722	1098				
	Total plastic items	59	17,927	20–2500	37.4804	0.002–5.55	9.06

literature (Table 1) demonstrates that sperm whales swallow items from the sea surface. In any case it is likely that sperm whales mistake them for potential prey.

In this study only one animal was analyzed, so it could be an isolated case in the Mediterranean Sea, even if other cases of young animals seems to have died because of massive ingestion of plastic debris (Katsanevakis, 2008; Notarbartolo-di-Sciara et al., 2012). For that reason it is essential to analyze all sperm whales stranding in this region to assess until what point plastic debris is a conservation problem for the species in the Mediterranean. The cryptic nature of the problem is driven by a low probability of recovering carcasses with evidence of harm caused by plastic ingestion or entanglement. If death from debris entanglement or ingestion occurs at sea, documentation of the event generally requires the carcass to come close to shore to be detected by a person, reported to the competent authority, and subjected to a full necropsy before the carcass decays. So there are several processes that reduce the likelihood of the event being detected and documented, and that may ultimately bias our perception of the problem if we based it solely on opportunistic observations (Williams et al., 2011) as the one we have described. Until 2008, mainly in the area of Almería, the necropsy of large animals has not followed a comprehensive protocol. This is the first case where the stomach content of a sperm whale is analyzed in the region. Nevertheless, more than 14 strandings of this species have been recorded in the region since 1996 (Fernández Maldonado pers.com). This kind of analysis, with established protocols and coordination in all the geography are fundamental for a correct management of the species. It would also be interesting to carry out studies of floating debris in the region to quantify their presence and tendencies. According to Spanish Biodiversity Law, and taking into account that sperm whales are listed as vulnerable in the National Catalogue of Endangered Species, as well as in the regional catalogues of Murcia and Andalucía, the problem of plastics arising from greenhouse agriculture should have a relevant section in the conservation plans and should be a recommendation from ACCOBAMS due to these plastics' and sperm whales' high mobility in the Mediterranean Sea.

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