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Ingestion of macroplastics by odontocetes of the Greek Seas, Eastern Mediterranean: Often deadly!

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A B S T R A C T

Plastic pollution is an omnipresent problem that threatens marine animals through ingestion and entanglement. Marine mammals are no exception to this rule but their interaction with plastic remains understudied in the Mediterranean Sea. Here we highlight this problem by analyzing the stomach contents of 34 individuals from seven odontocete species stranded in Greece. Macroplastic (> 5 mm) were found in the stomachs of nine individuals from four species (harbour porpoise *Phocoena phocoena*, Risso's dolphin *Grampus griseus*, Cuvier's beaked whale *Ziphius cavirostris* and sperm whale *Physeter macrocephalus*) with the highest frequency of occurrence in sperm whales (60%). Gastric blockage from plastic was presumably lethal in three cases, with plastic bags being the most common finding (46%). Plastic ingestion is of particular conservation concern for the endangered Mediterranean sperm whales. A regular examination of stranded cetaceans with a standardised protocol is critical for allowing spatiotemporal comparisons within and across species.

1. Introduction

Anthropogenic marine debris (or interchangeably litter, hereafter termed debris) is defined as anything solid, made or processed by people and deliberately discarded into or unintentionally lost in the coastal and oceanic environment (Coe and Rogers, 1997). Although debris can include wood, metal, glass, rubber, clothing or paper, plastic is its most prevalent and widespread component (Cózar et al., 2014) with estimates reporting that plastic makes up 60–80% of debris found in the marine environment (Derraik, 2002).

Plastic has existed for over a century (Gorman, 1993) with mass production starting in the 1950s (Beall, 2009). Since then, annual global production of plastic has risen from 1.5 million tons to 288 million tons in 2012 and is presently doubling approximately every eleven years (PlasticsEurope, 2013) due to its convenience for everyday products. About 5–13 million tons of plastic are discarded into the ocean annually (Jambeck et al., 2015) finding their way from coastal areas to mid-ocean gyres (van Sebille et al., 2015) and abyssal depths (Chiba et al., 2018). Plastic pollution is one of the most pervasive, ubiquitous and long-lasting anthropogenic impacts in the marine environment (Barnes et al., 2009; Moore, 2008) that are not restricted by national borders and may not be easily reversible. Since the degradation time for plastics is unknown and presumably varies with the type of plastic, this type of pollution extends far beyond the lifespan of the current human population with severe impacts on future generations.

Despite the aesthetic, financial and human health implications this plastic age has (Thompson et al., 2009; UNEP, 2009), the durable character of plastic has been also proven a major threat for a wide variety of animal taxa (Kühn et al., 2015). At least 693 species ranging from invertebrates (e.g., cnidarians and crustaceans) to vertebrates (fish, sea birds, sea turtles and marine mammals) have been described interacting with marine debris, with 92% of these encounters involving plastics (Gall and Thompson, 2015). Two fundamental types of interactions between organisms and debris occur: entanglement and ingestion. Lethal effects of entanglement include drowning while sub-lethal ones involve skin lesions, compromised feeding, limited predator avoidance capabilities, and reduced reproductive capacity and growth that eventually lead to reduced fitness (Gregory, 1991; Katsanevakis, 2008; Laist, 1997). Lethal and sub-lethal effects of debris ingestion cannot be easily identified but available evidence suggest that ingestion can cause ulcerations, perforations and obstruction of the digestive tract followed by disrupted digestion, feeling of satiation, starvation and general debilitation (Brandão et al., 2011; Jacobsen et al., 2010; Walker and Coe, 1990).

Ingestion of debris is well documented in sea birds (e.g., Moser and Lee, 1992; Rodríguez et al., 2012) and sea turtles (e.g., Tomás et al.,

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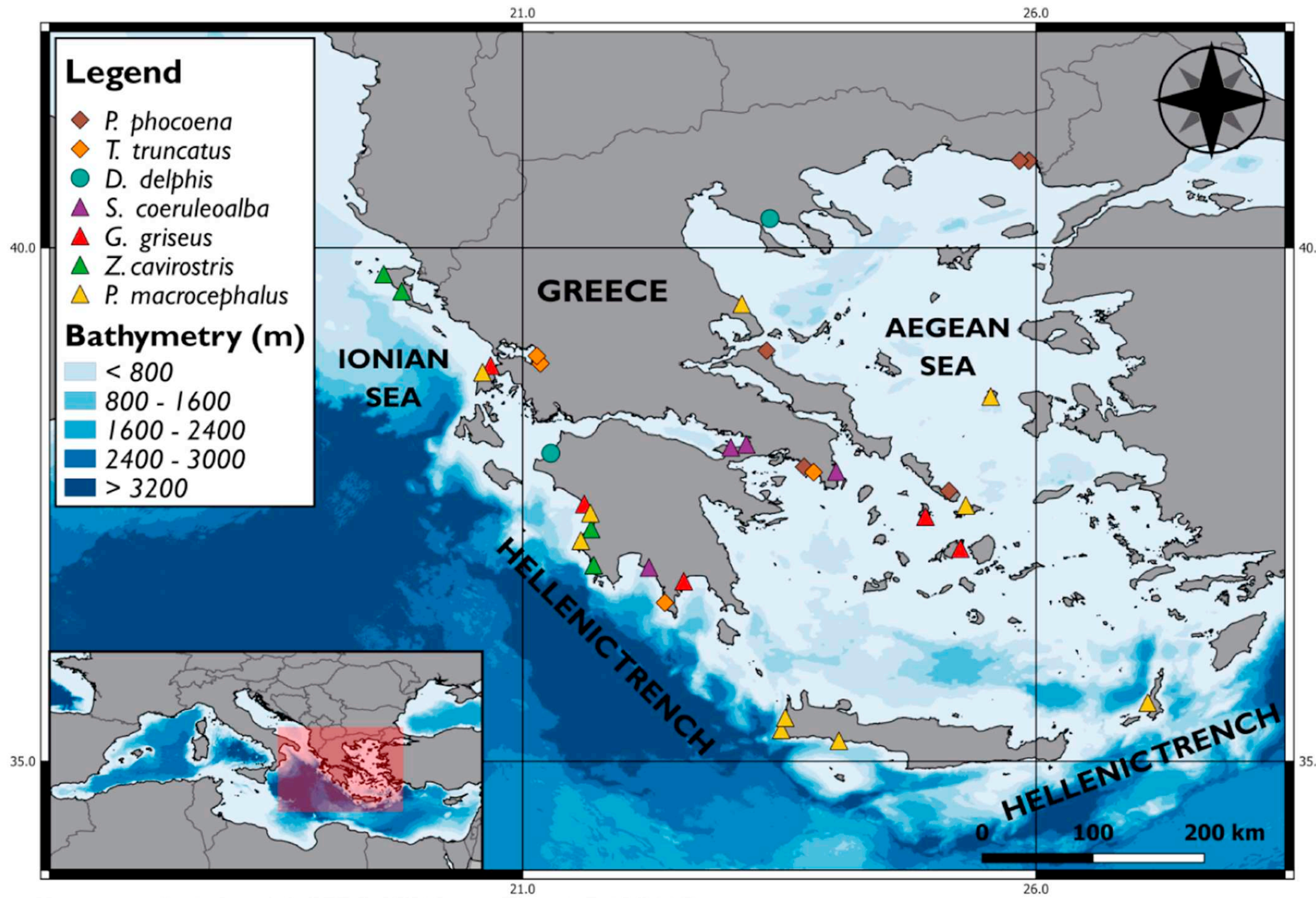

Map projection: Greek National Grid (EPSG: 4120), Map units: Metres, Scale: 1:3,000,000

Fig. 1. Stranding locations of cetaceans from which stomach contents were analysed for debris.

2002) but not in cetaceans. Although several instances have been reported worldwide and their number increases year after year (see Baulch and Perry, 2014; Fossi et al., 2018 for reviews), the threat posed to cetaceans by the ingestion of debris is still poorly understood (Simmonds, 2012). Plastic is the most commonly observed debris type (46%) ingested by cetaceans (Baulch and Perry, 2014) with most reported cases involving large items of plastics (> 5 mm) which are collectively known as macroplastics (sensu lato, Baulch and Perry, 2014). The ingestion of microplastics (1–5 mm in size) has been only recently highlighted in cetaceans (e.g., Besseling et al., 2015; Fossi et al., 2014; Nelms et al., 2019). Mechanistic explanations behind the ingestion of macroplastics remain to a large degree hypothetical (see Puig-Lozano et al., 2018 for a brief review). Ingestion may be: (1) intentional when cetaceans mistake plastic items such as bags for prey species during playful and inquisitive behaviours (Laist, 1987) or due to foraging inexperience of juveniles (Di Beneditto and Ramos, 2014); or (2) accidental when plastic is close to the prey target (Walker and Coe, 1990). Risk factors that have been proposed to increase the likelihood of plastic ingestion by cetaceans are poor body condition and deep-diving behaviour (Puig-Lozano et al., 2018).

Due to the impracticality of conducting controlled studies on the interactions between cetaceans and debris, the investigation of macroplastic ingestion has been historically based on the examination of the gastrointestinal tract from stranded animals. These opportunistic observations, albeit valuable, provide a snapshot of the real impact since only a small fraction of cetacean carcasses reach the shore or are documented (Peltier et al., 2012; Williams et al., 2011) and very few among them are subject to a full necropsy or dissection. While producing evidence for causal links between debris ingestion and mortality is difficult and only in few cases data are published, there is presumably bias from evaluating mainly sick, injured or deceased animals found stranded (Laist, 1997). The unknown population mortality rates of cetaceans due to the ingestion of plastic debris and the difficulty of identifying sub-lethal effects (Simmonds, 2012) further reinforce the cryptic character of this conservation and welfare issue (Laist, 1997).

The Mediterranean Sea is a biodiversity hotspot (Coll et al., 2010) currently hosting populations of eleven cetacean species (Notarbartolo di Sciara, 2016) with eight of them regularly found in the Greek Seas (Frantzis, 2009). Contrary to this biological richness, the Mediterranean Sea is considered to have one of the highest concentrations of debris in the world (Barnes et al., 2009; Cózar et al., 2015; Eriksen et al., 2014). As a result, records of macroplastic ingestion have been reported in several Mediterranean toothed whale species that are also found in Greece (Frantzis, 2009), such as sperm whales *Physeter macrocephalus* Linnaeus, 1758, Cuvier's beaked whales *Ziphius cavirostris* Cuvier, 1823, Risso's dolphins *Grampus griseus* (*G. Cuvier*, 1812) and bottlenose dolphins *Tursiops truncatus* (Montagu 1821) (Baulch and Perry, 2014; Cagnolaro et al., 1986; Centro Studi Cetacei, 1988, 1991; de Stephanis et al., 2013; Dhermain, 2004; Gomerčić et al., 2006; Levy et al., 2009; Mazzariol et al., 2011; Panti et al., 2019; Podestà and Meotti, 1991; Roberts, 2003; Shoham-Frider et al., 2002; Viale et al., 1992). Several instances of macroplastic ingestion have been published worldwide for these cetacean species highlighting their susceptibility to this type of pollution (e.g., Baulch and Perry, 2014; Poeta et al., 2017; Puig-Lozano et al., 2018; Unger et al., 2016).

According to our knowledge, a few records regarding plastic ingestion by cetaceans exist for the Eastern Mediterranean Sea, with only 33 cases available in the literature (Baulch and Perry, 2014; Gomerčić et al., 2006; Levy et al., 2009; Mazzariol et al., 2011; Panti et al., 2019; Roberts, 2003; Shoham-Frider et al., 2002). Most of these records were not focused on plastic ingestion (but see Baulch and Perry, 2014; Levy et al., 2009; Panti et al., 2019) and only one of them followed a standardized approach (Panti et al., 2019). Moreover, only the study by Roberts (2003) concerned cetaceans stranded along the Greek coasts and specifically a single sperm whale.

Therefore, due to the scarcity of related data and the conservation need for a better understanding of the impact plastic has on marine mammals, the aim of this paper is to investigate the extent of plastic ingestion by all toothed whale species regularly found in Greece and classify the consumed plastic debris by examining the stomach contents of stranded individuals for macroplastics.

2. Materials & methods

Dissections on 34 individuals of seven odontocete species (i.e., 5 *Phocoena phocoena* (Linnaeus, 1758), 4 *T. truncatus*, 2 *Delphinus delphis* Linnaeus, 1758, 4 *Stenella coeruleoalba* (Meyen, 1833), 5 *G. griseus*, 4 *Z. cavirostris* and 10 *P. macrocephalus*) stranded along the Greek coasts were conducted from 1993 to 2014 (Fig. 1). We measured the total length of each animal and determined its sex (Table 1). We opened the abdominal cavity and collected the stomach content to examine it for debris ingestion. Upon transferring the stomach contents to the Pelagos Cetacean Research Institute in Athens, Greece, we washed the debris items and subsequently dried them.

Any debris item found was then labelled, weighted, photographed and measured with a measure tape. Most of the debris was plastic (especially user plastics, i.e., non-industrial remains of plastic objects); therefore we classified it into five main categories (following Provencher et al., 2017): sheet plastics (including the sub-categories: plastic bags, burlap sacks, food packaging, wrap and other), threadlike plastics (including the sub-categories: fishing gear, rope and other), foamed synthetics, hard fragments, and miscellaneous. To further categorize every plastic item, we used sensu stricto the most commonly reported size classes (Sanchez et al., 2014): mega- (> 100 mm), macro- (> 20–100 mm), meso- (5–20 mm) and microplastics (< 5 mm); and eight broad color categories (Provencher et al., 2017): off/white-clear, grey-silver, black, blue-purple, green, orange-brown, red-pink, and yellow. The term macroplastics is hereafter used sensu stricto to avoid any confusion. Any debris item with weight < 1 g was not used for the calculation of weight summary statistics. Lastly, we used frequency of occurrence (%FO) for each cetacean species to describe the extent of macroplastic ingestion:

$$FO_i = \frac{n_i}{n}$$

where n_i is the number of stomachs containing macroplastics for whale species i and n is the total number of stomachs examined for this species.

3. Results

Debris was found in stomachs of individuals from four odontocete species: *P. macrocephalus, Z. cavirostris, G. griseus and P. phocoena*, with none of these individuals being a newborn. *P. macrocephalus* had the highest %FO for plastic (%FO = 60, 6/10), while *Z. cavirostris, G. griseus* and *P. phocoena* had respectively 25% (1/4), 20% (1/5) and 20% (1/5). No debris was found in the stomach of individuals from the three

Table 1
Information about the stranded cetaceans included in this study. The first two letters of each individual code refer to the ones from the binomial name of the corresponding species. The stomach of the newborn sperm whale (Pm9) contained milk but no prey remains.

Individual code	Stranding date	Location	Total length (m)	Sex	Most probable cause of death	Presence of prey remains	Debris found	Debris type
Pm1	13/03/2001	Loutro, Chania	12.8	m	Ship strike	y	y	Plastic
Pm2	15/04/2005	Tholo, Ileia	5.4	f	Ship strike	y	n	–
Pm3	25/02/2006	Parisaina, Magnesia	9.7	m	Ship strike	y	n	–
Pm4	18/04/2006	Armenistis lighthouse, Mykonos	5.3	m	Gastric blockage	y	y	Plastic, paper
Pm5	20/06/2007	Chrysoskalitissa, Chania	6.8	m	Ship strike	y	y	Plastic
Pm6	11/11/2007	Lefkos, Karpathos	8	f	–	y	y	Plastic
Pm7	15/05/2010	Psara, Chios	5.9	m	Ship strike	y	n	–
Pm8	16/01/2011	Livadia, Chania	7.9	f	Bycatch	y	y	Plastic, metal
Pm9	30/06/2011	Potisies, Lefkada	3.6	m	–	n	n	–
Pm10	15/02/2014	Agia Kiriaki, Messinia	10.5	m	Ship strike	y	y	Plastic
Zc1	05/11/1993	Pylos, Messinia	5	–	Gastric blockage	y	y	Plastic
Zc2	12/05/1996	Kartelas, Messinia	4.5	m	Military sonar	y	n	–
Zc3	30/11/2011	Kontogialos, Kerkyra	4.3	m	Military sonar	y	n	–
Zc4	30/11/2011	Arillas, Kerkyra	4.9	m	Military sonar	y	n	–
Gg1	08/01/1994	Skoutari, Laconia	2.9	f	Sick and deliberate killing	y	n	–
Gg2	29/04/2006	Megas Gialos, Syros	3.1	m	Sick	y	n	–
Gg3	07/06/2008	Gyra, Lefkada	3	f	Gastric blockage	y	y	Plastic
Gg4	04/04/2011	Tsoukalia, Paros	3.1	m	–	y	n	–
Gg5	18/10/2012	Zacharo, Ileia	3.1	f	–	y	n	–
Pp1	20/03/2000	Apalos, Evros	1.1	m	–	y	n	–
Pp2	19/07/2006	Psaropouli, Evia	1.4	f	–	n	n	–
Pp3	09/03/2008	Kavouri, Attica	1.4	f	–	y	n	–
Pp4	19/08/2011	Apothikes, Tinos	1.2	–	–	n	y	Plastic
Pp5	13/03/2013	Alexandroupolis, Evros	1.4	f	–	y	n	–
Dd1	14/02/2006	Kotychi, Ileia	1.7	f	Bycatch	y	n	–
Dd2	14/02/2010	Kalives, Chalkidiki	1.2	f	–	y	n	–
Sc1	21/03/2007	Ritsa, Messinia	1.6	m	–	n	n	–
Sc2	27/01/2008	Schinos, Corinthia	2.1	f	–	y	n	–
Sc3	02/09/2010	Keratea, Attica	1.9	m	–	y	n	–
Sc4	27/12/2012	Alepochori, Attica	2.3	m	–	n	n	–
Tt1	06/01/1994	Paliavli, Amvrakikos Gulf	2.5	m	Bycatch	y	n	–
Tt2	08/02/1994	Mpoukka, Aetolia-Acarnania	2.2	m	Bycatch	y	n	–
Tt3	19/03/2009	Mezapos, Messinia	1.9	m	Bycatch	y	n	–
Tt4	17/10/2009	Vouliagmeni, Athens	1.8	m	–	n	n	–

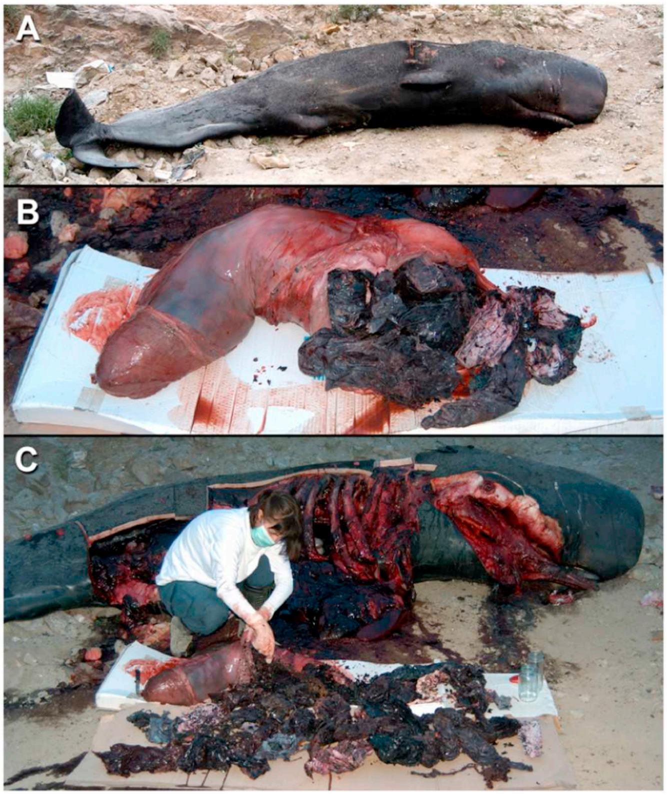

Fig. 2. Excessive plastic ingestion in the young sperm whale stranded in Mykonos island in 2006 (Pm4, Table 1). A. The stranded whale was emaciated. B. The stomach was abnormally big when removed from the body of the whale since it contained compacted plastic debris. C. Many tens of plastic bags, burlap sacks and some ropes and fishing nets are visible as the stomach is opened.

remaining odontocete species investigated in this study (i.e., *D. delphis, T. truncatus* and *S. coeruleoalba*).

Among the individuals that had consumed debris items, three of them (Pm1, Pm5, Pp4, Table 1) were found to have only one item (which was plastic) in their stomach, while the remaining six (Pm4, Pm6, Pm8, Pm10, Zc1 and Gg3, Table 1) had more than one item. The only item found in the stomach of the harbour porpoise (Pp4) was one sheet plastic (0.01 m^2) with a total weight of 4 g and of off/white-clear color. The highest number of debris items was found in sperm whales (155 items) and specifically Pm4 (135 items; Figs. 2 and 3). The vast majority of debris was plastic (98.7%). While plastic bags were the most common finding (46.4%), uncommon plastic debris items included food packaging (3.9%), wrap (1.3%), a wicker and a mesh (Figs. 3 and 4). A metal wire tied at the top of a plastic bag to keep it closed was also found in the stomach of Pm8 (Fig. 4C). Most plastic items were either off/white-clear (68.7%) or black (11.2%, Table S1 in Appendix A). Fishing related items (i.e., nets and ropes) were found in three sperm whales (16 in Pm4, 1 in Pm6 and 5 in Pm10; Figs. 3, 4D and E) with the total length of netting pieces being 7.4, 0.8 and 1.8 m respectively (Figs. 3 and 4). Three out of six netting pieces were seines while the origin of the remaining three could not be determined. The median mesh size and diameter of these pieces (n = 6) were 82.55 mm (30.75–220 mm) and 3.25 mm (1.5–5 mm) respectively, while the median diameter of the ropes (n = 10) was 5 mm.

The stomachs of three toothed whales (Pm4, Zc1 and Gg3, Table 1) contained excessive quantities of plastic debris (Figs. 2, 3 and 5). Both the sperm whale and the Risso's dolphin (Pm4 and Gg3) were clearly emaciated (Figs. 2A and 5A) with the transverse processes of their vertebrae being prominent. Since no photos are available for the Cuvier's beaked whale (Zc1), the body condition remains unknown. The Risso's dolphin (Gg3) had been observed two days prior to her stranding

Fig. 3. Aerial photograph showing the total amount of debris found in the stomach content of the young sperm whale (Pm4, Table 1) laid on a tennis court. The first and last authors of the paper (1.71 m tall each) are used as an approximate scale at the right of the photo.

swimming with difficulty close to the coast. These two stomachs (i.e., Pm4 and Gg3) contained a very large number of worn-down cephalopod beaks (19,733 and 893 respectively) that were trapped inside the stomach in-between the plastic debris (see Foskolos et al., in review for the sperm whale). No prey flesh remains were found, an indication that the whales had not recently fed before their stranding. The stomach of the young sperm whale was abnormally big (Fig. 2B) due to a large mass of plastic debris (Fig. 3): 118 sheet plastics (2632.5 g and 33.3 m^2) and 17 threadlike plastics of various colors (571 g and 11.9 m, Table S2) along with a piece of carton box (55 g and 0.2 m^2). This sperm whale had by far the highest number (135) and burden (3.2 kg) of debris items (Fig. 3) among all examined odontocetes.

A few items of plastic debris found in the stomach of Pm4 still had visible brand signs on them and their origin could be traced (Fig. 6). One plastic bag (Fig. 6A) originated from a Grill/Souvlaki restaurant in Thessaloniki, Macedonia, northern Greece (Fig. 6B) while another bag was sold in a large supermarket chain in Greece (Fig. 6C). We also found a bin bag of Turkish origin (Fig. 6D) and plastic packaging from both Greek (Fig. 6E) and Turkish biscuits (Fig. 6F) as well as from a six pack of a famous iced tea brand (Fig. 6G).

The emaciated Risso's dolphin had fewer but bigger pieces of plastic debris in her stomach: eight black sheet plastics (255 g, 100% megaplastic and 8.6 m^2) and five large, brown pieces of packaging tape (26 g, 100% megaplastic and 11 m total length) still attached on the plastic sheets (Fig. 5B). No fishing related items were found in her stomach. Regarding the Cuvier's beaked whale (Zc1), we did not sample its stomach contents and the only current evidence of plastic ingestion is an archive photo during the dissection, showing the large amount of black sheet plastics found in the stomach.

4. Discussion

Cetaceans usually forage at depth where direct observations of their feeding habits are notoriously difficult. Stomach content analysis of stranded cetaceans is however an indirect method that has been well-established for studying debris ingestion. Ideally, the whole gastrointestinal tract needs to be examined since smaller pieces of debris (i.e., microplastics) can pass from the stomach to the intestines (Panti et al., 2019). Since the investigation of macro- and megaplastic ingestion was the main aim of this study, the sole examination of the stomachs can thus be considered a limitation of minor importance. Nevertheless, this method includes other important caveats such as an inherently limited

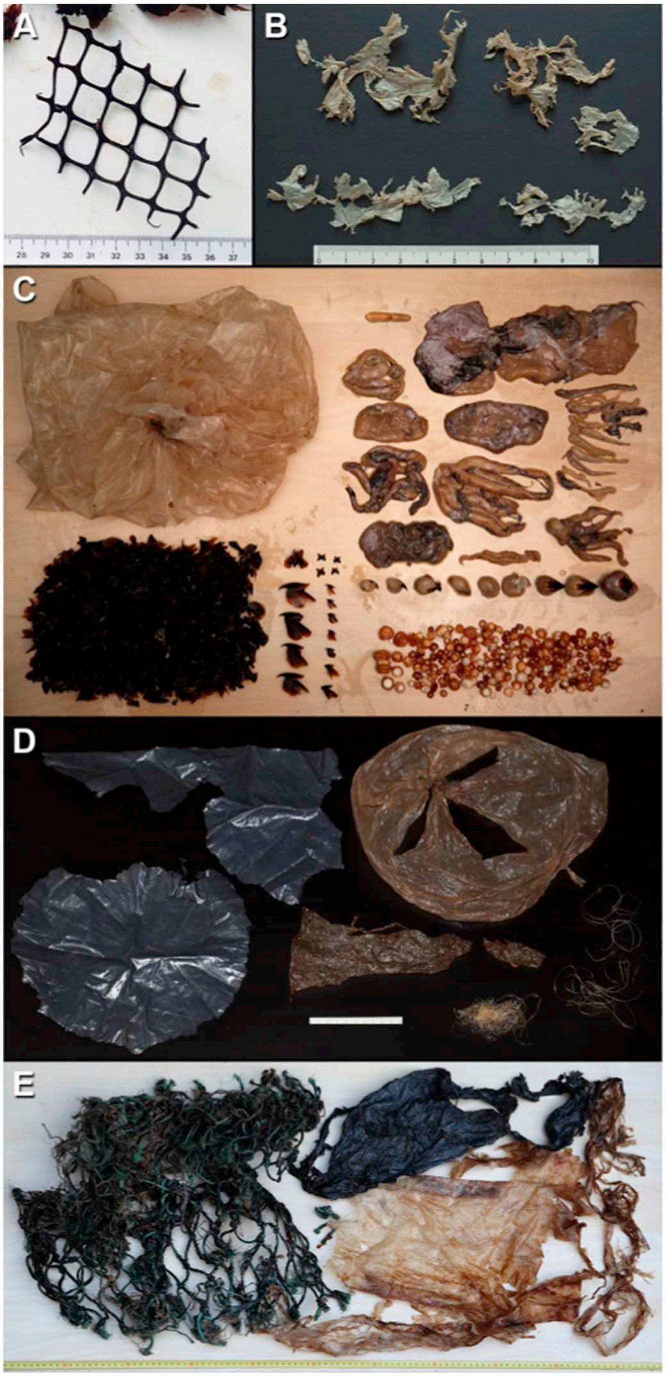

Fig. 4. Plastic debris found in the stomach contents of five sperm whales stranded in Greece from 2001 until 2014 (Table 1). A. Black plastic mesh in Pm1. B. Pieces of a plastic bag in Pm5. C. Plastic bag along with cephalopod fresh, beaks and eye lenses in Pm8. D. Pieces of plastic bags, small ropes and plastic wrap in Pm6. E. Plastic bags, threads and a piece of net in Pm10.

spatial and temporal coverage. This limitation was partly overcome in this study by analyzing several stomach contents from independent strandings which originated from various geographical areas and different years. Another main limitation is that inferences are drawn from stranded cetaceans that are not a representative sample of their free-ranging population. Since these individuals may have been in poor health, this method can underestimate the extent of debris ingestion in healthy individuals or animals that die at sea. Despite these limitations, the analysis of stomach contents from stranded cetaceans has so far provided the bulk of data on debris consumption (Baulch and Perry, 2014) and has also highlighted its lethal effects on these animals (e.g., de Stephanis et al., 2013; Jacobsen et al., 2010).

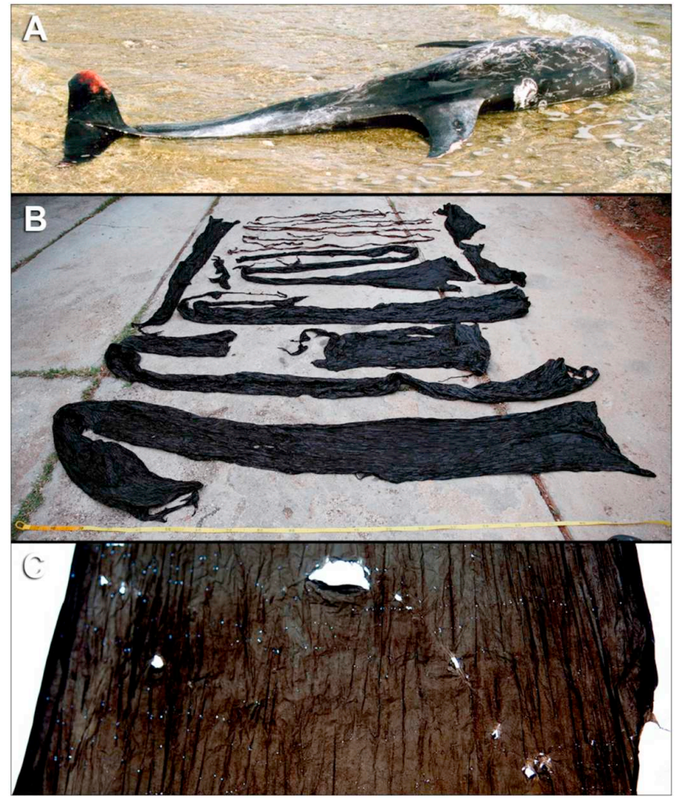

Fig. 5. Lethal consumption of plastic debris by a female Risso's dolphin stranded in Lefkada (Gg3, Table 1). A. The dolphin was emaciated and was seen two days prior to her stranding swimming with difficulty close to the coast. B. Her stomach contained eight black sheet plastics with a total surface area of 8.6 m^2 and five large pieces of packaging tape (total length: 11 m). C. In at least one sheet plastic, holes made by the teeth of the dolphin were evident.

The Mediterranean Sea is considered one of the most polluted areas in the world (Cózar et al., 2015) with surveys of both floating and seafloor debris showing that plastic is the most commonly encountered debris type in the continental shelf (Di-Méglio and Campana, 2017; Fortibuoni et al., 2019; Suaria and Aliani, 2014) and even in submarine canyons (Pham et al., 2014). This may explain why the vast majority of debris found inside the stomachs of examined individuals was plastic. Especially in Greece, plastic is the most abundant debris found in beaches (Kordella et al., 2013). The high percentage of sheet plastics in the stomachs of sperm whales (as also shown in Panti et al., 2019) is probably linked with the fact that plastic bags and packaging have the highest abundance both in the water column (Di-Méglio and Campana, 2017) and at the seafloor (Fortibuoni et al., 2019) among the different types of plastic debris. The high densities of plastic that have been found in the Adriatic Sea (Suaria and Aliani, 2014) may explain why four cetaceans in this study that stranded in the contiguous Ionian Sea (i.e., Pm2, Pm10, Zc1 and Gg3, Table 1) had plastic debris in their stomach. Although fishing related debris is common along the Mediterranean seafloor (Pham et al., 2014), its presence was only sporadic in the stomach contents that were examined in this study.

The discovery of plastic debris in the stomachs of three odontocete species (sperm whale, Cuvier's beaked whale and Risso's dolphin), even though is new for Greece, has been reported in the past along other areas of the Mediterranean Sea (de Stephanis et al., 2013; Gomerčić et al., 2006; Panti et al., 2019; Shoham-Frider et al., 2002). Although ingestion of plastic by harbour porpoises is well known in the North Sea (van Franeker et al., 2018), this study represents the first report for this species in the Mediterranean, where harbour porpoises are only found

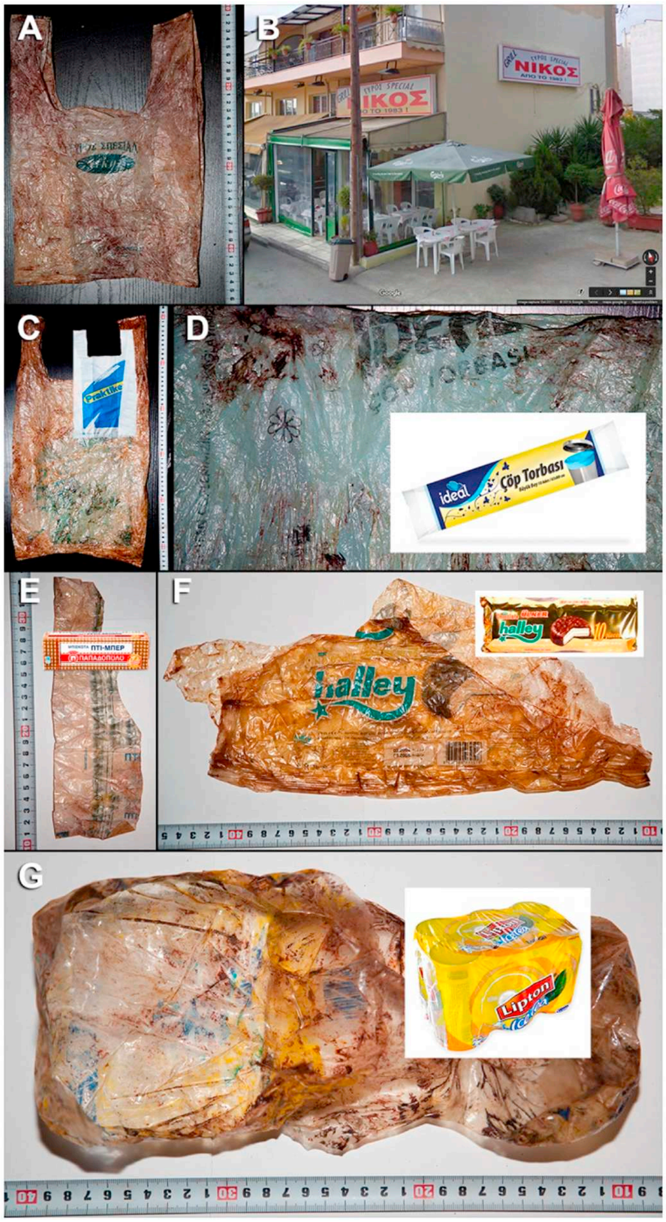

Fig. 6. Eponymous plastic debris found in the stomach of the young sperm whale stranded in Mykonos island (Pm4, Table 1). A & B. Plastic bag from a Grill/Souvlaki restaurant in Thessaloniki, Macedonia, northern Greece. C. Bag sold in a large supermarket chain in Greece. D. Bin bag of Turkish origin. E & F. Packaging from Greek and Turkish biscuits, respectively. G. Packaging from an Iced tea six can pack.

in the northern Aegean Sea (Cucknell et al., 2016).

All four odontocete species found to have consumed plastic in this study ingest their prey whole via suction (Heyning and Mead, 1996; Kastelein et al., 1997; Werth, 2004, 2006) making them prone to accidental ingestion (passive) of debris found adjacent to their prey. Harbour porpoises display bottom feeding at shallow depths over the continental slope (Milani et al., 2018; Westgate et al., 1995) while sperm whales, Cuvier's beaked whales and Risso's dolphins are pelagic deep-divers (Arranz et al., 2018; Tyack et al., 2006; Watwood et al., 2006) with Cuvier's beaked whales feeding close to the bottom (Shearer et al., 2019; Woodside et al., 2006). Since deep waters can have high concentrations of plastic (Pham et al., 2014), deep-diving odontocetes can be thus further susceptible to plastic pollution (Puig-Lozano et al., 2018). However, the ingestion of plastic can also take place in the water column since items of neutral buoyancy (e.g., plastic bags and food packaging) were found in the stomachs of the stranded cetaceans.

Except from passive plastic ingestion, mistaken identity due to similarities of plastics with prey can presumably explain why plastic is found in the stomachs of cetaceans. This active mechanism, although well known for sea turtles (where plastic is perceived as jellyfish; Schuyler et al., 2014), remains poorly understood in cetaceans. Harbour porpoises feed mainly on fish (Milani et al., 2018) while sperm whales, Cuvier's beaked whales and Risso's dolphins prefer ammoniacal squids (Kawakami, 1980; Santos et al., 2001; Würtz et al., 1992). Since these cetaceans echolocate to forage (Dubrovskij et al., 1971; Johnson et al., 2004; Madsen et al., 2002, 2004), visual cues may not affect the active ingestion of plastic. Unfortunately, the scarcity of data on echo target strength of various plastic materials does not allow us to draw further conclusions on acoustic cues used during plastic consumption.

Plastic debris was not found in any stomach from common, bottlenose and striped dolphins. Records of plastic ingestion by these species exist worldwide (Walker and Coe, 1990) but are absent from the Mediterranean Sea with the exception of a bottlenose dolphin stranded in Israel (Levy et al., 2009). The apparent absence of mega-, macro- and mesoplastics in this study for these species may be related to their raptorial mode of feeding (Werth, 2006) which reduces the chances of passive plastic ingestion. Nevertheless, this absence should be treated with caution since it does not necessarily imply that microplastics were not present in the stomachs of these animals (Lusher et al., 2018). Indeed, microplastics have been found in individuals of all three species stranded in the United Kingdom (Nelms et al., 2019).

With the exception of sperm whales, the %FO values for plastics in the remaining six cetacean species are probably a function of survey effort since only a small number of animals stranded between 1993 and 2014 were subject to full dissection. For sperm whales, a large percentage of all stranded individuals of this given period were indeed dissected and sampled. Their high %FO for plastics (60%) is therefore representative and highlights the extent to which the sperm whale population in Greece is exposed to plastic pollution. This is also corroborated by the fact that sperm whales have one of the highest number of reported cases for plastic ingestion (Poeta et al., 2017). Despite their low %FO for plastics in this study, Cuvier's beaked whales and Risso's dolphins seem to be also prone to plastic consumption (Poeta et al., 2017; Puig-Lozano et al., 2018), probably due to their deep-diving behaviour and suction mode of feeding.

The only newborn in this study (Pm9, Table 1) did not have any plastics in his stomach. Even though relevant records are almost absent from the literature, a single study from van Franeker et al. (2018) did not find any plastic debris in the gastrointestinal tract of 47 newborn harbour porpoises stranded in the Netherlands. This finding may thus suggest that plastic ingestion in cetaceans is tightly linked with the onset of solid food intake.

While most plastic items were small (Table 2) and presumably did not have a major health impact, lethal consequences of plastic ingestion were observed in three cetaceans (Pm4, Zc1 and Gg3, Table 1). The death of these animals was presumably the result of the long-term deleterious effects of plastic rather than acute lethal lesions caused by the plastics. Since volumetric feedbacks from stretch receptors in the gastrointestinal tract provide satiety signals to the brain (Raubenheimer and Simpson, 2018), ingested plastics can have significant negative effects on nutrient acquisition. Loss of body condition can therefore be a chronic case of plastic ingestion while it has also been suggested that poor body condition can lead to an increased ingestion of plastic debris (Puig-Lozano et al., 2018). Emaciation combined with large quantities of plastics in the stomach have previously been observed in stranded sperm whales (de Stephanis et al., 2013; Jacobsen et al., 2010), Cuvier's beaked whales (Gomerčić et al., 2006; Poncelet et al., 2000) and Risso's dolphins (Bermúdez-Villapol et al., 2008; Puig-Lozano et al., 2018). Available data suggest though that even small quantities of plastic debris can have large health impacts due to the occlusion of the

Table 2
Data on debris items found in the stomachs of sperm whales, Risso's dolphins and harbour porpoises stranded in Greece. No data were available for Cuvier's beaked whales. Mean, median and range were calculated after including individuals that contained no plastics in their stomachs. Debris items with weight < 1 g were not used for the calculation of weight summary statistics. FO: frequency of occurrence; SD: standard deviation; SE: standard error.

Cetacean species	Debris type	Number				Weight (g)			Total weight (g)	Total surface area (m^2)
		%FO	Mean number of pieces per individual (SD, SE)	Median	Range	Mean weight per individual (SD, SE)	Median	Range		
Sperm whales	***All plastics***	60	15.3 (42.2, 13.3)	1	0-135	371.2 (1004.1, 317.5)	0.7	0-3203.5	$3.9 \cdot 10^3$	31.9
	sheets	50	7.8 (21.2, 6.7)	0.5	0-68	275.6 (828.5, 262)	0	0-2632.5	$3.1 \cdot 10^3$	31.2
	bags	50	7 (19.4, 6.1)	0.5	0-62	129.3 (366.4, 115.8)	0	0-1169.5	$1.3 \cdot 10^3$	20.7
	burlap sacks	10	1.4 (4.4, 1.4)	0	0-14	87.7 (277.5, 87.7)	0	0-877.5	877.5	9.8
	food packaging	10	0.6 (1.9, 0.6)	0	0-6	9.3 (24.6, 9.3)	0	0-93.5	93.5	0.7
	wraps	10	0.2 (0.6, 0.2)	0	0-2	-	-	-	-	0.03
	other	10	3.6 (11.3, 3.6)	0	0-36	49.2 (155.6, 49.2)	0	0-492	694	12.2
	threads	30	2.4 (5.4, 1.7)	0	0-17	95.4 (206, 65.1)	0	0-571	954.5	0.7
	fishing	30	1 (2.5, 0.8)	0	0-8	85.5 (183, 57.9)	0	0-495	855	0.7
	rope	20	1.2 (2.7, 0.8)	0	0-8	9.4 (22.8, 7.2)	0	0-71	94.5	-
	other	20	0.2 (0.4, 0.1)	0	0-1	0.5 (1.6, 0.5)	0	0-5	5	-
	miscellaneous	10	0.1 (0.3, 0.1)	0	0-1	0.15 (0.5, 0.15)	0	0-1.5	1.5	0.005
	Other debris	20	0.2 (0.4, 0.1)	0	0-1	5.5 (17.4, 5.5)	0	0-55	55	0.2
	paper	10	0.1 (0.3, 0.1)	0	0-1	5.5 (17.4, 5.5)	0	0-55	55	0.2
	metal	10	0.1 (0.3, 0.1)	0	0-1	-	-	-	-	-
Risso's dolphins	***All plastics***	20	2.6 (5.8, 2.6)	0	0-13	56.2 (125.6, 56.2)	0	0-281	281	8.6
	sheets	20	1.6 (3.6, 1.6)	0	0-8	51 (114, 51)	0	0-255	255	8.6
	other	20	1.6 (3.6, 1.6)	0	0-8	51 (114, 51)	0	0-255	-	-
	miscellaneous	20	1 (2.2, 1)	0	0-5	5.2 (11.6, 5.2)	0	0-26	26	-
Harbour porpoises	***All plastics***	20	0.2 (0.4, 0.2)	0	0-1	0.8 (1.8, 0.8)	0	0-4	4	0.01
	sheets	20	0.2 (0.4, 0.2)	0	0-1	0.8 (1.8, 0.8)	0	0-4	4	0.01
	other	20	0.2 (0.4, 0.2)	0	0-1	0.8 (1.8, 0.8)	0	0-4	4	0.01

stomach (Stamper et al., 2006). Unfortunately, population consequences of plastic ingestion are unknown for cetaceans, thus hindering the assessment of this threat.

To our knowledge, this is the first study in the Mediterranean Sea that systematically reports the size and color of the ingested plastics following the standardized protocol by Provencher et al. (2017). Due to the scarcity of similar data, we were not able to compare the size of the plastics in this study with any other relevant study worldwide. Plastic color was only reported in the study of Panti et al. (2019) where most plastic debris in sperm whale stomachs were either black or white-clear. Unfortunately, no mechanistic explanation can be provided at this point for the use of these colors as visual cues during plastic ingestion. According to the Descriptor 10 of the Marine Strategy Framework Directive by the European Commission, one aspect of the good environmental status is the situation where “properties and quantities of marine litter do not cause harm to the coastal and marine environment”. As a result, the adoption and implementation of a protocol such as the one of Provencher et al. (2017) is urgently needed to consistently assess the threat that plastic poses to cetaceans.

This study has shown via stomach content analysis that plastic is ingested by at least half the cetacean species that regularly occur in the Greek Seas with sometimes lethal consequences, such as in the three cases of excessive plastic ingestion. We showed that among the odontocetes examined, plastic pollution can be a serious threat for sperm whales which are already in great risk (Notarbartolo Di Sciara et al., 2012) due to ship strikes (Frantzis et al., 2019) and noise pollution from oil and gas exploration (Madsen et al., 2006). While current data are not sufficient to evaluate the threat posed by plastic to harbour porpoises - another endangered population (Birkun Jr. and Frantzis, 2008) -, their small population size in the northern Aegean Sea makes them susceptible to the sub-lethal and lethal effects of plastic ingestion. To properly assess this problem, a regular analytical approach with a standardised methodology is needed to allow for comparisons over space, time and different species.

Declaration of Competing Interests

None.

CRediT authorship contribution statement

Paraskevi Alexiadou: Conceptualization, Methodology, Investigation, Resources, Data curation, Writing - review & editing, Supervision, Project administration. **Ilias Foskolos**: Methodology, Validation, Formal analysis, Data curation, Writing - original draft, Visualization, Project administration. **Alexandros Frantzis**: Conceptualization, Resources, Writing - review & editing, Supervision, Project administration, Funding acquisition.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.marpolbul.2019.05.055.

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