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Workshop Communications

Revising interactions of plastics with marine biota: evidence from the Mediterranean

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Abstract

Quantifying the interaction of marine biota with marine litter requires understanding the mechanisms of response of different taxa. Plastic ubiquity and size fraction preclude large impacts over the organisms exposed to marine litter. The Mediterranean, a semi-enclosed Sea, is one of the most affected by plastic concentrations. Different effects have been identified: ingestion, entanglement, toxicity, invasions, and physical harm, among others. This paper reviews studies on marine organisms and marine litter with emphasis on main taxa affected, habitats, feeding strategies, IUCN category. Further this review provides updated data, identifies knowledge gaps and provides suggestions for further research to be undertaken under the scenario of increasing plastic loads to the Mediterranean.

Keywords: litter, plastic, fish, marine mammals, invertebrates

Introduction

In the Mediterranean, a number of studies have been conducted to assess impacts of marine litter on marine biota (Akoumianaki *et al.*, 2008; Camedda *et al.*, 2014; Fossi *et al.*, 2014a). Most studies deal with mere quantification of debris (Sanchez *et al.*, 2013; Erya ar *et al.*, 2014) while others aim to investigate different sizes and classes of plastic material interacting with fauna (Tomás *et al.*, 2002; Campani *et al.*, 2013; de Stephanis *et al.*, 2013). Studies have tended to focus on marine mammals and turtles, with fewer on fishes or invertebrates, although the ingestion of microplastic by fish was discovered many years ago (Carpenter *et al.*, 1972; Hoss and Settle, 1990). Still in the Mediterranean, only one study did investigate plastic ingestion by fish (Anastasopoulou *et al.*, 2013) while several studies on diet and stomach content analysis of Mediterranean fish have detected marine litter (Deudero, 1998; Massutí *et al.*, 1998; Madurell, 2003). Research on litter impact on invertebrates is rather restricted to controlled laboratory experiments, mostly in UK (Browne *et al.*, 2008; Anastasopoulou *et al.*, 2013; Farrell and Nelson, 2013). In general, the bio-accumulation of plastic components along the food web are poorly understood.

Plastics may fragment but are not biodegradable, persisting in the environment for thousands of years (Derraik, 2002; Barnes *et al.*, 2009). Plastic debris enters in the marine environment in a wide range of sizes from micrometric to metric dimensions (Barnes *et al.*, 2009). In the environment, microplastic litter (<5 mm-NOAA) proliferates, migrates and accumulates in natural habitats world-wide. Different potential trophic routes transfer microplastics across marine ecosystems and therefore, environmental microplastics are available to every level of the food web, from primary producers (Oliveira *et al.*, 2012) to higher trophic-level organisms (Wright *et al.*, 2013). Thus, marine organisms, either from pelagic to benthic compartments are under threat but our knowledge remains fragmented since most studies tackle groups of species (for example cetaceans, fish, reptiles) separately (Anastasopoulou *et al.*, 2013; Camedda *et al.*, 2014; de Stephanis *et al.*, 2013).

Various impacts have been described in the interaction of fauna and plastics: digestion, entanglement, toxicity, invasive species facilitators, carcinogenesis, endocrine disruption and physical harm, such as internal abrasion and blockage (Laist, 1997; Oehlmann *et al.*, 2009; Talsness *et al.*, 2009; Wright *et al.*, 2013). For marine fauna, the primary impacts of marine litter are ingestion and entanglement, especially in mammals and reptiles (Gregory, 2009). Additionally, hydroponic pollutants available in seawater may adsorb onto plastic litter in ordinary environmental conditions (Teuten *et al.*, 2007; Thompson *et al.*, 2009b; Cole *et al.*, 2011) and be transferred across organisms. As these contaminants are persistent, bioaccumulative and toxic, they are of particular concern for human and environmental health (Engler, 2012). Deciphering future scenarios of change is essential to predict ecological shifts and consequently address key issues with regard to minimising alteration of biota by marine litter interactions.

Material and methods

Experimental design and data analyses

A review of 79 documents concerning marine litter interactions with marine biota (scientific papers, grey literature, EU projects reports and personal observations) was conducted. Research criteria were based only on studies of the Mediterranean Sea without any date limitation.

Studies were included in the analysis if they contained quantitative data on marine litter (more specifically marine plastics) and their interaction with marine biota (macroalgae, seagrass, invertebrates, turtles, fish and cetacean). Only *in situ* studies or experimental work carried out at sea were incorporated, excluding all documents of litter in Mediterranean seashores and beaches. Litter affectation in seabirds was not evaluated in the search. The citation list was examined and in total 29 studies (37%) satisfied the above criteria for inclusion and analysis of our study.

Knowledge of the species was backed up by specified databases of species (fishbase (www.fishbase.org), the reptile base (www.reptile-database.org), world cetacean base (www.marinespecies.org/cetacea/) and the IUCN Red List of Threatened Species).

Only species registering over 5% of litter impact were considered. Presence or absence of general debris, plastic and non-plastic (wood, metal, glass, fishing gear, monofilaments and ropes and others) and ingestion, entanglement, colonization and rafting processes were defined as the dependent variables.

Results

As shown in Table 1, and detailed further in Figure 1, litter impact in the Mediterranean has been more widely studied for cetacean (41.2%) followed by fish (24.1%), turtles (20.7%) and finally invertebrates (13.8%) and a majority of studies concerned some type of plastic litter (plastic bags, plastics sheets, plastic monofilaments and ropes).

Table 1. Range of studies covered in this review.

References	Taxa	Study Area	Study depth (m)	Study year
Akoumianaki et al. (2008)	Invertebrates	Greece, Western Saronikos Gulf	16-20	2005-2006
Aliani and Molcard (2003)	Algae, Seagrass and Invertebrates	Ligurian Sea	0.10	1997
Anastasopoulou et al. (2013)	Fish	Greece, Cephalonia Island	300-850	2010
Aparicio, personal comm.	Cetacean	Spain		1990-2012
Camedda et al. (2013)	Turtles	Italy, Sardinia		2008-2012
Campani et al. (2013)	Turtles	Italy, Tuscany coast and Pelagos Sanctuary		2010-2011
Casale et al. (2008)	Turtles	Italy, Lampedusa		2001-2005
Colligon et al. (2012)	Fish	French-Italian coast	0.10	2010
de Stephanis et al. (2013)	Cetacean	Spain, Granada		2012
Deudero (2001)	Fish	Spain, Balearic Sea	0-30	1994-1998
Duras, personal comm.	Cetacean	Croatia		1990-2013
Estarellas personal comm. (2014)	Invertebrates	Spain, Balearic Sea	0-20	2014
Fossi et al. (2014)	Fish, cetacean	Italy, Pelagos Sanctuary		2007-2013
Gramentz (1988)	Turtles	Malta		1986
Katsanevakis (2008)	Cetacean	Greece, Mykonos Island		2006
Katsanevakis et al. (2007)	Invertebrates, Fish	Greece, Saronikos Gulf	16 -20	2005-2006
Lazar and Gracan (2011)	Turtles	Croatia and Slovenia		2001-2004
Levy et al. (2009)	Cetacean	Israel, Port Haifa		2007
Madurell (2003)	Fish	Greece	500	1999-2000
Massuti et al. (1998)	Fish	Spain, Balearic Sea	70-500	1990-1991
Mazzariol et al. (2011)	Cetacean	Italy, Adriatic coast		2009
MEDITS project	Fish	Spain, Balearic Sea	10-800	2007-2012
Nadal personal comm. (2014)	Fish	Spain, Balearic Sea	40-70	2014
Pace et al. (2008)	Cetacean	Italy, Capo Palinuro		2004
Roberts (2003)	Cetacean	Greece, south coast of Crete		2011
Shoham-Frider et al. (2002)	Cetacean	Israel		1993-1999
Tomás et al. (2002)	Turtles	Spain, catalonia		not available
Tonay et al. (2007)	Cetacean	Turkey, Black Sea		2002-2003
Viale et al. (1992)	Cetacean	France, Lavezzi Islands		1989

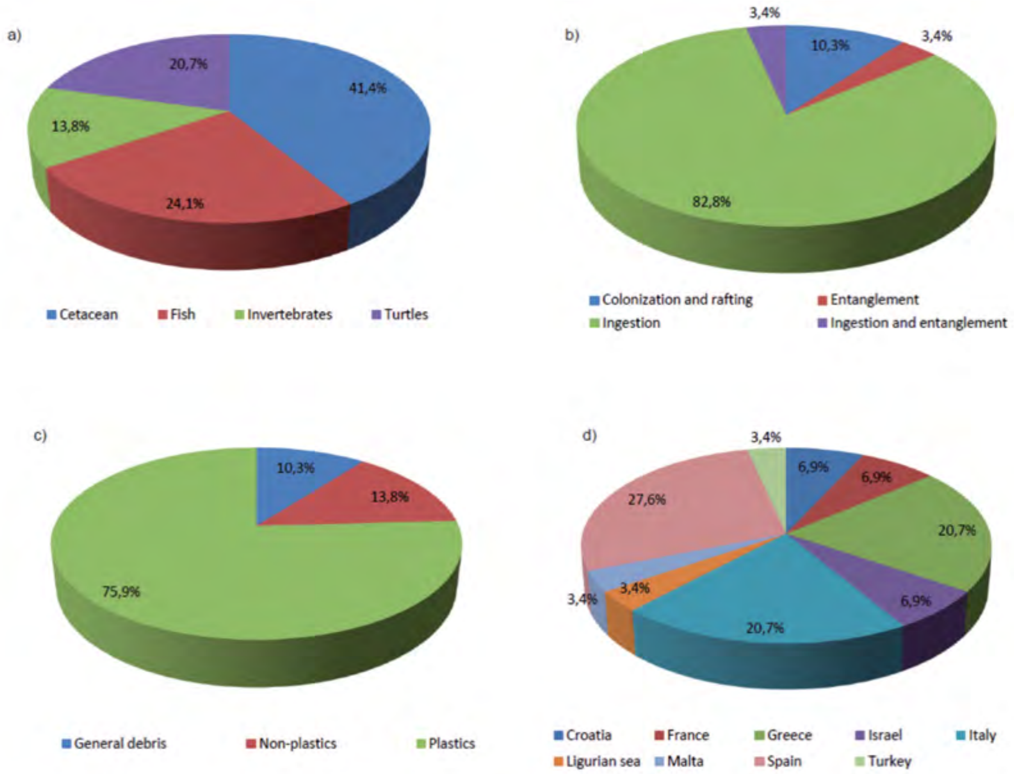

Figure 1 a,b,c,d. Bibliometric data classifying the documents reviewed according to taxa (a), type of impact (b) type of litter (c) and study area (d).

As seen in Figure 2, cetaceans are the most affected taxa with regard to ingestion and entanglement followed by turtles. Indeed half of the cetaceans studied presented plastic ingestion. Filter feeders were the most affected. No detritivorous organisms were affected by litter ingestion and

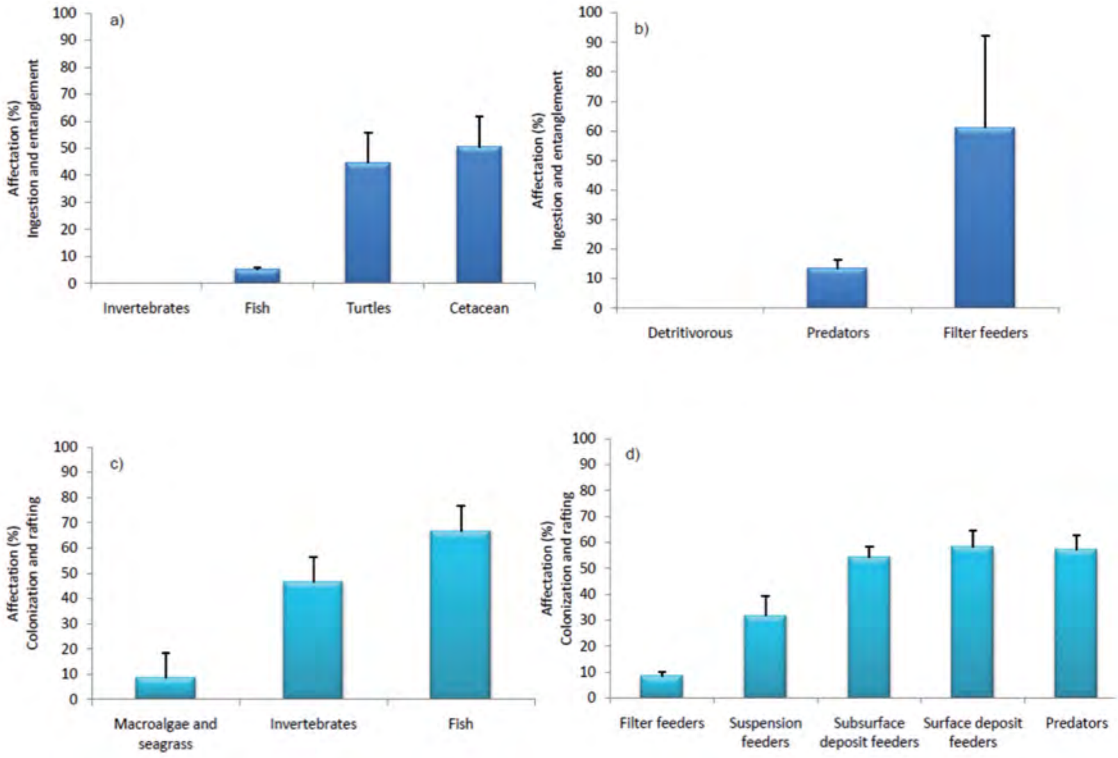

Figure 2 a,b. Impact of litter due to ingestion and entanglement for a) different taxa and b) according to different feeding strategies (Number of studies (n): invertebrates (n=1), fish (n=8), turtles (n=6), cetacean (n=12), detritivorous (n=1), predators (n=23) and filter feeders (n=2). Figure 2 c,d. Impact of litter due to colonization and rafting for c) different taxa and d) feeding strategies (Number of studies (n): macroalgae and seagrass (n=1), invertebrates (n=1), fish (n=1), filter feeders (n=1), suspension feeders (n=1), subsurface deposit feeder (n=1) study, surface deposit feeder (n=1) and predator (n=1)).

entanglement. Impact of litter due to colonization and rafting processes was large in fish (66.8%) followed by invertebrates (46.5%).

Non-multidimensional scaling showed dispersion of litter impact values according to pelagic species taxa (Figure 3a). Large filter feeders *Cetorhinus maximus* and *Balaenoptera physalus* grouped together while sea turtles were not bound to any other species, like *Coryphaena hippurus* which is the least affected pelagic species. Marine mammals such as *Grampus griseus* and *Phocoena phocoena*, which were sampled in the easternmost sector of the Mediterranean basin, were closely associated in the MDS. For benthic species, MDS results did not show a marked trend. However, bryozoans, macroalgae and seagrasses grouped together away from other taxa, while primary producers appear clumped with suspension feeders in the scaling graph (Figure 3b).

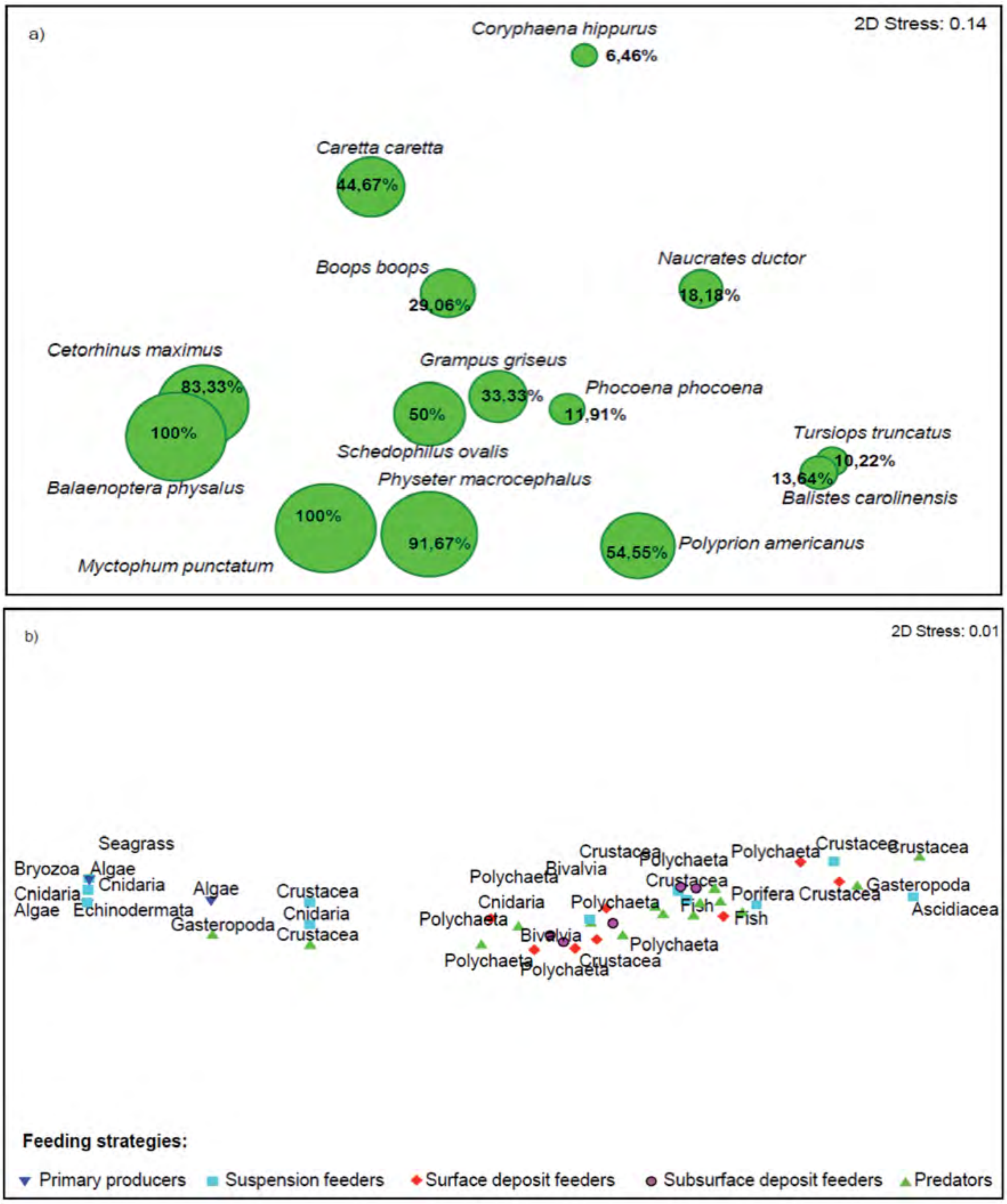

Figure 3 a,b. Non-multidimensional scaling (MDS) a) for pelagic species (cetaceans, fishes, turtles) after normalizing variables and applying the Euclidean distance according to % litter affectation (>5%) and b) for benthic species (macroalgae, seagrass, invertebrates (ascidiacea, bivalvia, bryozoa, cnidaria, crustacean, echinodermata, gasteropoda, polychaeta and porifera) and fish) after >5% litter impact data square root transformation with Euclidean distance according to feeding strategies.

Total litter impact (ingestion, entanglement, colonization and rafting) was as high as 73% for species classified by IUCN as Vulnerable (VU) and reached 41% in Endangered species (EN) (Table 2). In the endangered category, filter feeder species had 50% of litter affectation.

Table 2. Litter impact (%) in various taxa according to IUCN category, and feeding strategy.

	Macroalgae and Seagrass (%)	Detritivorous (%)	Subsurface deposit feedesr (%)	Surface deposit feeders (%)	Suspension feeders (%)	Filter feeders (%)	Predators (%)	Total Affectation (%)
Critically Endangered (CR)							**12**	**12**
Cetacean							12	12
Endangered (EN)						**50**	**38**	**41**
Cetacean						50	0	33
Turtles							45	45
Vulnerable (VU)						**83**	**72**	**73**
Cetacean							93	93
Fish						83	0	28
Near Threatened (NT)							**0**	**0**
Fish							0	0
Least Concern (LC)	**7**						**13**	**12**
Cetacean							21	21
Fish							9	9
Seagrass	7							7
Not Evaluated (NE)	**10**	**0**	**54**	**58**	**32**		**14**	**22**
Algae	10							10
Ascidiacea					98			98
Bivalvia				50				50
Bryozoa					7			7
Cnidaria					12		42	19
Cnidaria					7			7
Crustacea				68	56		62	61
Echinodermata		0			7			4
Fish							5	5
Gasteropoda							51	51
Polychaeta			54	57	56		56	56
Porifera					72			72
Data Deficient (DD)							**8**	**8**
Fish							8	8

Discussion

Not surprisingly there is a vast array of taxa being affected by marine litter, and essentially by plastics, from invertebrates (polychaetes, ascidians, bryozoans, sponges, etc.), fishes, cetaceans up to the largest animals at sea (fin-whale *Balaenoptera physalus).* Consequences of marine debris vary from entanglement, ingestion, suffocation, and general debilitation, among others. In 1997 Laist reviewed over 250 marine species impacted by entanglement and ingestion. In this review, several affectations have been identified, and are split into ingestion and entanglement, colonization and rafting.

Ingestion and entanglement

Fishes

While plastic accumulation at the seafloor, continental shelf, submarine canyons (Ramirez-Llodra *et al.*, 2011) has been increasing in past decades, with important areas of accumulation of debris (Pham *et al.*, 2014), differential impacts have been detected among the different taxa surveyed. For instance most benthic fishes seem unaffected by plastic ingestion while pelagic fishes, such as *Boops boops*, present a high degree of plastic ingestion, with 70% of affected individuals. Possibly, prey selectivity on seafloor allows debris rejection. These results are relevant since bioaccumulation through the food web is known (Farrell and Nelson, 2012; Rochman *et al.*, 2013a; Wright *et al.*, 2013). Offshore epipelagic species are also exhibiting moderate levels of plastic ingestion, with several species ingesting marine litter such as *Coryphaena hippurus, Seriola* *dumerilii, Schedophilus ovalis, Naucrates ductor* (Deudero, 2001). In the pelagic realm, optimised feeding is linked to a more voracious and visual behaviour for chasing the prey; in this sense, particle selection is linked more to mouth biometry than to nutritional quality.

Cetaceans
Cetaceans are highly affected by ingestion, at worldwide level (Baulch and Perry, 2014). Although most studies rely on stranded individuals, large filter feeders such as *Physeter macrocephalus,* the fin-whale *Balaenoptera physalus*, present large megaplastics, with dominance of plastic sheets. Entanglement is of concern in the sperm whale *Physeter macrocephalus* since many individuals are exposed to driftnets (Pace *et al.*, 2008). Most odontocetes are little affected by plastic ingestion, with the exception of *Grampsus griseus*, where plastics can be confused with squids (Shoham-Frieder *et al.*, 2002).

Turtles
All sea turtle species (*Caretta caretta*) surveyed are affected. Indeed, plastics ingestion in turtles has been chosen as a parameter for quantifying descriptor 10 in MSFD. Preferential ingestion towards white plastics blue and red plastics (Camedda *et al.*, 2014) has been shown, likely due to resemblance of white plastics with jellyfishes. From all turtle species present in the Mediterranean (*C. caretta*, *Chelonia mydas, Dermochelys coriacea, Eretmochelys imbricate, Lepidochelys kempii)* (Camiñas, 2004), only data has been reported from *C. caretta*. However, impact seems very probable in all turtle species.

Litter colonization and rafting

For benthic invertebrates colonization on rafting objects is a major issue, representing a vector of species introduction over large areas driven by current dynamics (Aliani *et al.*, 2003; Hoeksema *et al.*, 2012). Another impact is transport of pollutants (Rochman *et al.*, 2013a) along with these objects.

Experimental studies in aquarium under controlled conditions demonstrate ingestion of nylon plastics and PVC fragments (0.25 – 15 mm) over sediment grains at sedimentivorous benthic species such as holothurians under forced diets (Graham and Thompson, 2009). However, our own data on plastic ingestion analyses in holothurians *Holothuria forskalii* from coastal waters suggest that although microplastics (nylon filaments, plastic grains) are present in shallow-waters sediments (100% of the analysed sediment presented microplastics), mainly at grain fractions 0.5 mm to 1 mm, only one of the 50 *H. forskalii* individuals sampled presented plastics in the faecal pellets.

With regard to feeding strategies, filter feeders are highly affected by ingestion, while predators are more dispersed. Large filter feeders in the pelagic environment are highly exposed to either ingestion or entanglement. In this sense, some sharks such as basking shark *Cetorhinus maximus* are under threat (Fossi *et al.*, 2014a).

Many endangered species are impacted by plastic (41%), a factor to integrate when drafting conservation policies.

Gaps in knowledge and recommendations for priorities

Physical impacts of microplastics on marine organisms are well documented at global level (Wright *et al.*, 2013), but little is known of the impact of Nano and microplastics on the Mediterranean marine biota. Special attention should be given to micro plastic fibers ingested by pelagic species and to southern Mediterranean waters which remain data deficient.

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