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Research Article

Ecological effects of anthropogenic litter on marine mammals: A global review with a “black-list” of impacted taxa

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Abstract

In this work we would define an historical arrangement of the state of knowledge regarding the ecological impact of anthropogenic litter on marine mammals, assessing the role of different type of impacts (ingestion vs. entanglement) and pressures (three size-based categories). Analyzing 203 references (from 1976 to 2016), we obtained a “black-list” of 101 species impacted by marine litter (78.9% on 128 species totally known). At species level, four cetacean (*Megaptera novaeangliae*, *Physeter macrocephalus*, *Tursiops truncatus*, *Eubalaena glacialis*) showed the highest number of bibliographic citations. A significant higher number of species was impacted by entanglement when compared to ingestion. Macro-litter represents the main factor of pressure in all groups; micro-litter showed the highest frequency in Mysticeti, probably explained from their food filtration behaviour. Both intrinsic eco-biogeographic traits (e.g. trophic niche, food catching behaviour, species range) and extrinsic methodological biases could explain our patterns. Since the entanglement is easier to record because of imply only an external observation without further post-mortem examination, and that large litter is easier to detect in respect to meso- and micro-litter, we hypothesize that both this information could be largely biased. Moreover, we observed a direct correlation between the research effort on species (obtained from Scholar recurrences) and the number of citations related to marine litter events, although some exceptions are present: therefore our “black” list of impacted species is not complete and could be increased focusing research on poor-studied neglected species. After 2005 the number of studies on this topic showed a large increase: however, literature appeared extremely heterogeneous. In this sense, we suggest the use of a standardized nomenclature for pressures and impacts to reduce the loss of information.

Introduction

Nowadays some studies estimate that over 7 million tons of waste reach the oceans every year (Valavanidis and Vlachogianni, 2012) with the result that anthropogenic litter in marine environment (hereafter called marine litter or marine debris) has become an environmental threat on a global scale (Sheavly and Register, 2007; Barnes et al., 2009; UNEP, 2009). Marine litter, better defined as “any manufactured or processed solid waste material that enters the marine environment from any source” (Coe and Rogers, 1997), is globally distributed and we find it across all oceans and seas (Moore et al., 2001; Suaria and Aliani, 2014) including sea floors (Bergmann and Klages, 2012; Angiolillo et al., 2015) and beaches (Bouwman et al., 2016; Poeta et al., 2016a). This threat is named in the related IUCN threat taxonomy with the code 9.4 (“Garbage and solid waste”: i.e. “Rubbish and other solid materials including those that entangle wildlife”; IUCN-CMP, 2012; Battisti et al., 2016 for a review).

Accumulation rates and abundance of marine litter are influenced by many factors, responding to both maritime and land-based activities (Galgani et al., 2015). This anthropogenic materials moved throughout the world’s oceans by winds and currents or washed ashore on beaches, creating different spatial distribution pattern with local or regional accumulation areas and with different extension or density of litter (Eriksen et al., 2014; Mansui et al., 2015; Williams et al., 2016). However, despite these differences, plastic is the most abundant material type worldwide, accounting for more than 80% of all marine litter (Gregory, 2009; Ryan, 2013; Poeta et al., 2016a,b; Eriksson et al., 2013).

It is now clear that marine and plastic litter has become a widespread factor of pressure in the marine environment representing a serious threat for a wide range of marine species that are increasingly exposed to it. In fact, since the first evidences of the impact of litter on marine organisms (Turner, 1904; Gudger and Hoffmann, 1931; Kenyon and Kridler, 1969), the frequency of events has increased over time with well documented records for birds, turtles, fish and marine mammals (Laist, 1997; Derraik, 2002; Gall and Thompson, 2015). In recent years, new impacts on molluscs and other invertebrates have been reported (Yoshikawa and Asoh, 2004; Booth et al., 2015; Poeta et al., 2015; Paul-Pont et al., 2016). In addition, the introduction of anthropogenic debris in the marine environment can pose a serious threat, providing new habitats for various sessile organisms (Aliani and Molcard, 2003; Wright et al., 2013), facilitating the dispersion of alien and invasive species (Barnes, 2002), and modifying the structure of benthic communities (Katsanevakis et al., 2007). Finally, marine debris may also induce changes in the physical conditions of seafloors (Akoumianaki et al., 2008).

For marine fauna, the most common impacts of marine debris are associated with ingestion or entanglement (Gregory, 2009) and both types of interactions can cause the injury or death of animals of many different species (Laist, 1997). Ingestion occur when debris items are intentionally or accidentally eaten (e.g. through predation on already

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contaminated organisms or by filter feeding activity, in the case of large filter feeding marine organisms, such as whales) and enter in the digestive tract (Laist, 1997; Wright et al., 2013; Fossi et al., 2014). Entanglement is defined as "an interaction between marine life and anthropogenic material whereby the loops and openings of various types of anthropogenic debris entangle animal appendages or entrap animals" (Laist, 1997). Generally, the materials observed in entanglements are active or discarded fishing gear, hooks and line, rope but also other items such as six-pack drink holders, packing bands and balloons (Moore et al., 2009; Butterworth, 2016). Also direct fisheries interactions pose a serious threat to many populations; for example the "bycatch", as the unintended mortality in fishing gear (Baker et al., 2006; Read et al., 2006; Read, 2008).

Marine mammals seem particularly susceptible to these threats and so many cases of ingestion and entanglement have been reported around the world (Cawthorn, 1984; Geise and Gomes, 1992; Denuncio et al., 2011; Simmonds, 2011, 2012; Besseling et al., 2015; Butterworth, 2016). In these animals, the ingested debris could damage their digestive system due to obstructions, perforations and other injuries (Andersen et al., 2007; Jacobsen et al., 2010), also reducing the feeding stimulus (Di Beneditto and Ramos, 2014) or inducing long-term pathologies (e.g. Martineau et al., 2002). Furthermore, marine debris, particularly plastics, could also facilitate the transfer of lipophilic chemicals (specially POPs — persistent organic pollutants) into the animals bodies(Teuten et al., 2007; Fossi et al., 2012, 2014).

The impact of this threat depends either on intrinsic morpho-anatomic, evolutive, and eco-ethological traits of the species or on extrinsic characteristics of litter (e.g. size, abundance, composition, shape, floatability, etc.). Among the different criteria to assess the impact of marine litter as a threat, the size criterion has been widely investigated as factor of pressure (Barnes et al., 2009; Ryan et al., 2009; Browne et al., 2010; Sanchez et al., 2014; Romeo et al., 2015; Cannon et al., 2016).

In this work we collected and analysed a large amount of bibliographic sources about the ecological impact of marine debris on marine mammals, carrying out a comprehensive review of the state of knowledge on this topic. In particular, we would to quantify: (i) the general impact of anthropogenic litter on marine mammal species, assessing if there are differences among groups and subgroups in terms of number of species impacted and number of citations in literature; (ii) the role of both two main different types of impact (ingestion and entanglement) and of three size-based types of pressures (micro-, meso-, macro-litter), (iii) the temporal trend in terms of number of published papers in the last decades. Finally, we enquired if, at single species level, the number of citations regarding the impact of marine litter depends on the worldwide species-related research effort. In this work we do not discriminate in terms of (i) pressure resulting from different categories (and origins) of marine litter, (ii) type of injuries on animals (see Andersen et al., 2007), and (iii) extent of impact in terms of amount of individuals involved.

Methods

Data collection

We conducted a review of scientific papers (including international and national or local journals) and international reports documenting impact of anthropogenic litter on marine mammals.

We considered the last forty years (period 1976–2016) as temporal range of research. We used Google, Google Scholar, and Web of Science search engines using "marine litter, marine debris, litter (or debris) impact, litter (or debris or plastic) ingestion (or entanglement), marine mammal (or cetacean) impact, ghost fishing, microplastic" as key words.

In order to obtain temporal trends, we subdivided all the bibliographic sources for 5-years periods starting from 1976 to 2016.

For taxonomic nomenclature and systematic order we refer to recent List of Marine Mammal species and subspecies (SMM Committee on Taxonomy, 2016). We excluded from analysis the level of subspecies and the species actually extinct or possibly extinct for a total of 128 species of marine mammals actually known at global level: 36 Carnivora, 88 Cerartiodactyla Cetacea (14 Mysticeti, 74 Odontoceti), 4 Sirenia (SMM Committee on Taxonomy, 2016).

Data analysis

In this work we separated the concept of impact (entanglement, ingestion) from the concept of pressure (in this last case following a general and uniformly adopted size-based criterion). We considered as "impact" any interaction between animals and marine litter, or where it has led to the death or not. We considered "pressure" an anthropogenic cause (in this case: a category of size-defined litter) which induces an impact, affecting populations and determining a change in their state (review of concepts in Battisti et al., 2016).

Data were reported in an Excel matrix-sheet with species in the rows and type of impact (considering two main categories: ingestion and entanglement), type of pressure (three size categories: micro-litter: <5 mm; meso-litter: ranging from 5 to 25 mm; macro-litter: >25 mm) and references in columns.

For each species we obtained the total number of species citations reporting at least one record of impact (hereafter "species citations"). Since the analysed bibliographic sources were quite heterogeneous and that most of them did not report the number of impacted animals, we decided to use only the binary occurrence (presence or not of an impact on a species in a publication), independently from the number of impacted individuals.

Summing species with at least one species citation, we obtained the number of impacted species (subdivided for Orders, Sub-Orders and Families) and percentage frequency on total and for subgroups. Among them, we obtained the number of species: (i) impacted (from ingestion and/or entanglement); (ii) for which there are evidences of different type of size-based pressures (micro-, meso-, macro-litter, as before; subdivided for Orders, Sub-Orders and Families), and percentage frequency on total and for subgroups.

To test if the number of species citations on the topic "marine litter" depends on the species-related research effort, we calculated the number of total species recurrences reported in Google Scholar (accessed: 20 November 2016; hereafter "species recurrences"). Species recurrences have been considered as a proxy of the global species-specific research effort reported in this search engine (Jacso, 2005; Pomerantz, 2006; Harzing, 2013; Haddaway et al., 2015). Then, we correlated the number of species recurrences with the number of species citations reporting at least one impact or pressure. If the number of species citations on the impact of marine litter is a consequence of the research effort, we should obtain a direct and significant correlation between these two metrics. We used a non-parametric Spearman rank correlation test (2 tail), reporting the relationship in a bi-variate semi-log transformed diagram explicating the plot and the related better-fit line (with their equation and coefficient of the determination, R^2).

To compare frequencies, we performed a χ^2 test. To compare paired median values of species citations between paired Orders and Sub-Orders and between categories, we used the non-parametric Mann-Whitney U test. To compare median values among >2 categories, we used the Kruskal-Wallis test (Dytham, 2011). We used the software SPSS 13.0 for Windows (SPSS Inc., 2003). Alpha was set at 0.05 level.

Results

By analysing 203 references, we obtained evidence for 101 species impacted by marine litter (78.9% on 128; "black list" in Tab. 1). Excluding Sirenia (all the four species impacted, 100%), percentage frequency of impacted species ranged from 75 to 80% at level both of Orders and, inside Cetacea, of sub-Orders (Mysticeti and Odontoceti; Tab. 2). We did not observe significant differences in frequencies among three Orders (Carnivora, Cetacea and Sirenia: χ^2=1.421, p=0.491, d.f.=3) and sub-Orders (Mysticeti and Odontoceti: χ^2=0.069, p=0.793, d.f.=2).

At lower hierarchical taxonomic level (Families), data were reported in Tab. 3. Among the richer Families (>5 species), frequencies of impacted species ranged from about 64 to 89%.

Table 1 – "Black list" of impacted marine mammal species by anthropogenic marine litter. For each species, the type of impact (ingestion and/or entanglement) and pressure (three size-based categories) and references have been reported.

	Impact		**Pressure**			
Taxa	**Ingestion**	**Entanglement**	**Micro litter**	**Meso litter**	**Macro litter**	**References**
Order Carnivora						
Family Otariidae						
Arctocephalus australis (Zimmermann, 1783)		●			●	Ramirez (1986); Fowler (1988)
Arctocephalus forsteri (Lesson, 1828)	●	●			●	Cawthorn (1984); Fowler (1988); Page et al. (2004); Boren et al. (2006); Ceccarelli (2009)
Arctocephalus gazella (Peters, 1876)	●	●	●		●	Bonner and Mc Cann (1982); Croxall et al. (1990); Arnould and Croxall (1995); Hucke-Gaete et al. (1997); Hofmeyr et al. (2002); Eriksson and Burton (2003); Waluda and Staniland (2013)
Arctocephalus philippii (Peters, 1866)		●			●	Wallace (1985); Good et al. (2007); Núñez et al. (2011)
Arctocephalus pusillus (Schreber, 1775)	●	●			●	Shaughnessy (1980); Pemberton et al. (1992); Ceccarelli (2009); Lawson et al. (2015); Shaughnessy et al. (2001)
Arctocephalus tropicalis (Gray, 1872)	●	●	●		●	Hofmeyr et al. (2002); Eriksson and Burton (2003); Ceccarelli (2009)
Callorhinus ursinus (Linnaeus, 1758)		●		●	●	Fowler (1987); Stewart and Yochem (1987); Bengtson et al. (1988); Baba et al. (1990); Hanni and Pyle (2000); Kiyota and Baba (2001); Good et al. (2007); Zavadil et al. (2007); Moore et al. (2009); Artukhin et al. (2010); Allen and Angliss (2014)
Eumetopias jubatus (Schreber, 1776)	●	●		●	●	Mate (1984); Hanni and Pyle (2000); Good et al. (2007); Moore et al. (2009); Raum-Suryan et al. (2009); Artukhin et al. (2010)
Neophoca cinerea (Peron, 1816)		●			●	Page et al. (2004); Ceccarelli (2009)
Otaria byronia (Blainville, 1820)		●			●	Ramirez (1986); Crespo et al. (1997)
Phocarctos hookeri (Gray, 1844)	●	●	●		●	Cawthorn (1984); McMahon et al. (1999)
Zalophus californianus (Lesson, 1828)		●		●	●	Stewart and Yochem (1987); Harcourt et al. (1994); Barlow et al. (1997); Zavala-Gonzalez and Mellink (1997); Hanni and Pyle (2000); Good et al. (2007); Dau et al. (2009); Moore et al. (2009)
Family Phocidae						
Cystophora cristata (Erxleben, 1777)		●			●	Good et al. (2007); Ólafsdóttir (2010)
Erignathus barbatus (Erxleben, 1777)		●			●	Ólafsdóttir (2010)
Halichoerus grypus (Fabricius, 1791)		●			●	Fowler (1988); Good et al. (2007); Ólafsdóttir (2010); Allen et al. (2012)
Histriophoca fasciata (Zimmerman, 1783)		●			●	Artukhin et al. (2010)
Hydrurga leptonyx (Blainville, 1820)		●			●	Slater (1990, 1991); Ceccarelli (2009)
Mirounga leonina (Linnaeus, 1758)		●			●	Ramirez (1986); Stewart and Yochem (1987); Hofmeyr et al. (2002); Campagna et al. (2007); Ceccarelli (2009)
Mirounga angustirostris (Gill, 1866)	●	●		●	●	Mate (1984); Barlow et al. (1997); Hanni and Pyle (2000); Good et al. (2007); Dau et al. (2009); Moore et al. (2009)
Monachus monachus (Hermann, 1779)		●			●	Karamanlidis et al. (2008)
Neomonachus schauinslandi (Matschie, 1905)		●			●	Barlow et al. (1997); Henderson (2001); Boland and Donohue (2003); Donohue and Foley (2007); Good et al. (2007)
Pagophilus groenlandicus (Erxleben, 1777)		●			●	Fowler (1988); Ólafsdóttir (2010)
Phoca vitulina (Linnaeus, 1758)	●	●		●	●	Stewart and Yochem (1987); Fowler (1988); Hanni and Pyle (2000); Good et al. (2007); Dau et al. (2009); Moore et al. (2009); Ólafsdóttir (2010); Rebolledo et al. (2013)
Phoca largha (Pallas, 1811)		●			●	Artukhin et al. (2010)
Pusa hispida (Schreber, 1775)		●			●	Artukhin et al. (2010); Ólafsdóttir (2010)
Pusa caspica (Gmelin, 1788)		●			●	Dmitrieva et al. (2011)
Family Mustelidae						
Enhydra lutris (Linnaeus, 1758)		●			●	Degange and Newby (1980); Moore et al. (2009)
Order Cetartiodactyla						
Cetacea						
Sub-Order Mysticeti						
Family Balaenidae						
Balaena mysticetus Linnaeus, 1758	●	●			●	Philo et al. (1992); Lowry (1993)
Eubalaena glacialis (Müller, 1776)	●	●			●	Kraus (1990); Knowlton and Kraus (2001); Johnson et al. (2005); Cole et al. (2006); Good et al. (2007); Nelson et al. (2007); Cassoff et al. (2011); Henry et al. (2012); Knowlton et al. (2012); Van Der Hoop et al. (2014); Kraus et al. (2016)
Eubalaena australis (Desmoulins, 1822)	●	●			●	Cawthorn (1984); Kemper et al. (2008); Ceccarelli (2009)
Family Neobalaenidae						
Caperea marginata (Gray, 1846)		●			●	Ceccarelli (2009); Australian antarctic division in Baulch and Perry (2014)
Family Eschrichtiidae						
Eschrichtius robustus (Lilljeborg, 1861)	●	●			●	Mate (1984); Hare and Mead (1987); Heyning and Lewis (1990); Bradford et al. (2009); Cascadia Research (2010); Barboza (2012)
Family Balaenopteridae						
Balaenoptera acutorostrata Lacépède, 1804	●	●		●	●	Cawthorn (1984); Mate (1984); Hare and Mead (1987); Reyes and Van Waerebeek (1991); Tarpley and Marwitz (1993); Fontaine et al. (1994); Barlow et al. (1997); Gill et al. (2000); Mauger et al. (2002); De Pierrepont et al. (2005); Cole et al. (2006); Good et al. (2007); Nelson et al. (2007); Ceccarelli (2009); Artukhin et al. (2010); Cassoff et al. (2011); Henry et al. (2012); Van Der Hoop et al. (2012); Arbelo and Fernandez in Baulch and Perry (2014); Smithsonian Research Institute in Baulch and Perry (2014)
Balaenoptera borealis Lesson, 1828		●			●	Lyman (2012); Van Der Hoop et al. (2012)
Balaenoptera edeni Anderson, 1879	●	●			●	Haines and Limpus (2000); Cole et al. (2006); Ceccarelli (2009); Cassoff et al. (2011); Van Der Hoop et al. (2012)

Table 1 – *(continued)* “Black list” of impacted marine mammal species by anthropogenic marine litter.

	Impact		Pressure			
Taxa	**Ingestion**	**Entanglement**	**Micro litter**	**Meso litter**	**Macro litter**	**References**
Family Balaenopteridae *(continued)*						
Balaenoptera musculus (Linnaeus, 1758)	●	●			●	Cole et al. (2006); Baxter (2009)
Balaenoptera physalus (Linnaeus, 1758)	●	●	●		●	Sadove and Morreale (1989); Cole et al. (2006); Fossi et al. (2012); Henry et al. (2012); Van Der Hoop et al. (2012); Fossi et al. (2014); Arbelo and Fernandez in Baulch and Perry (2014)
Megaptera novaeangliae (Borowski, 1781)	●	●	●	●	●	Mate (1984); Humpback Whale Recovery Team (1991); Volgenau et al. (1995); Barlow et al. (1997); Mazzuca et al. (1998); Zerbini and Kotas (1998); Robbins and Mattila (2004); Johnson et al. (2005); Cole et al. (2006); Mattila and Lyman (2006); Good et al. (2007); Nelson et al. (2007); Ceccarelli (2009); Moore et al. (2009); Artukhin et al. (2010); Cassoff et al. (2011); Núñez et al. (2011); Henry et al. (2012); Lyman (2012); Van Der Hoop et al. (2012); Besseling et al. (2015); Marcondes in Baulch and Perry (2014)
Sub-Order Odontoceti						
Family Physeteridae						
Physeter macrocephalus Linnaeus, 1758	●	●	●	●	●	Mate (1984); Martin and Clarke (1986); Lambertsen and Kohn (1987); Sadove and Morreale (1989); Lambertsen (1990); Walker and Coe (1990); Viale et al. (1992); Spence (1995); Laist (1997); Zerbini and Kotas (1998); Roberts (2003); Evans and Hindell (2004); Katsanevakis (2008); International Whaling Commission (2008); Pace et al. (2008); NMES (2009b); Fernandez et al. (2009); Moore et al. (2009); Artukhin et al. (2010); Jacobsen et al. (2010); Mazzariol et al. (2011); Lyman (2012); Van Der Hoop et al. (2012); de Stephanis et al. (2013); Byrd et al. (2014); Arbelo and Fernandez in Baulch and Perry (2014); Smithsonian Research Institute in Baulch and Perry (2014); Unger et al. (2016)
Family Kogiidae						
Kogia breviceps (Blainville, 1838)	●	●		●	●	Sadove and Morreale (1989); Barros et al. (1990); Walker and Coe (1990); Tarpley and Marwitz (1993); Laist et al. (1999); Stamper et al. (2006); Fernandez et al. (2009); Jacobsen et al. (2010); Marcondes in Baulch and Perry (2014); Smithsonian Research Institute in Baulch and Perry (2014); Unger et al. (2016); Australian Anctarctic Division in Baulch and Perry (2014)
Kogia sima (Owen, 1866)	●	●			●	Barros et al. (1990); Walker and Coe (1990); Zerbini and Kotas (1998)
Family Ziphiidae						
Berardius bairdii Stejneger, 1883	●			●	●	Walker and Coe (1990); Smithsonian Research Institute in Baulch and Perry (2014)
Hyperoodon ampullatus (Forster, 1770)	●	●		●	●	Baird and Hooker (2000); Gowans et al. (2000); Deaville and Jepson (2011)
Indopacetus pacificus (Longman, 1926)	●	●			●	Dayaratne and Joseph (1993); Yamada et al. (2012b)
Mesoplodon bidens (Sowerby, 1804)	●			●	●	Deaville and Jepson (2011)
Mesoplodon carlhubbsi Moore, 1963	●	●			●	Barlow et al. (1997); Yamada et al. (2012a)
Mesoplodon europaeus (Gervais, 1855)	●				●	Walker and Coe (1990); Fernandez et al. (2009); Byrd et al. (2014); Arbelo and Fernandez in Baulch and Perry (2014); Smithsonian Research Institute in Baulch and Perry (2014)
Mesoplodon ginkgodens Nishiwaki and Kamiya, 1958	●					International Whaling Commission (2012)
Mesoplodon grayi von Haast, 1876	●	●			●	Donoghue (1994); Mayorga in Baulch and Perry (2014)
Mesoplodon mirus True, 1913	●		●		●	Smithsonian Research Institute in Baulch and Perry (2014); Lusher et al. (2015)
Mesoplodon peruvianus Reyes, Mead and Van Waerebeek, 1991		●			●	Reyes and Van Waerebeek (1991)
Mesoplodon stejnegeri True, 1885	●	●		●	●	Barlow et al. (1997); Walker and Hanson (1999); Yamada et al. (2012a)
Mesoplodon densirostris (Blainville, 1817)	●			●	●	Walker and Coe (1990); Secchi and Zarzur (1999); Byrd et al. (2014); Smithsonian Research Institute in Baulch and Perry (2014)
Tasmacetus shepherdi Oliver, 1937	●			●		Goodall et al. (2008); Smithsonian Research Institute in Baulch and Perry (2014)
Ziphius cavirostris G. Cuvier, 1823	●	●			●	Foster and Hare (1990); Walker and Coe (1990); Barlow et al. (1997); Fertl et al. (1997); Poncelet et al. (2000); Santos et al. (2001); Gomerčić et al. (2006); Santos et al. (2007); Artukhin et al. (2010); Arbelo and Fernandez in Baulch and Perry (2014); Kerem in Baulch and Perry (2014); Smithsonian Research institute in Baulch and Perry (2014); Bortolotto et al. (2016)
Family Iniidae						
Inia geoffrensis		●			●	da Rocha and Andriolo (2005)
Family Pontoporiidae						
Pontoporia blainvillei (Gervais and d'Orbigny, 1844)	●		●	●	●	Pinedo (1982); Bassoi (1997); Bastida et al. (2000); Denuncio et al. (2011); Di Beneditto and Awabdi (2014); Di Beneditto and Ramos (2014)
Family Delphinidae						
Cephalorhynchus commersonii (Lacépède, 1804)		●			●	Crespo et al. (1997); Goodall et al. (1997)
Cephalorhynchus eutropia (Gray, 1846)		●			●	Torres et al. (1992)
Cephalorhynchus heavisidii (Gray, 1828)		●			●	Barlow et al. (1997); Ofori-Danson et al. (2003)
Delphinus delphis Linnaeus, 1758	●	●		●	●	Walker and Coe (1990); Romano et al. (2002); Ceccarelli (2009); Deaville and Jepson (2011); Nicolau in Baulch and Perry (2014)
Feresa attenuata Gray, 1874		●			●	Dayaratne and Joseph (1993)
Globicephala macrorhynchus Gray, 1846	●	●			●	Walker and Coe (1990); Barros et al. (1997); Reyes and Van Waerebeek (1991); Ceccarelli (2009); Byrd et al. (2014); Carillo in Baulch and Perry (2014)
Globicephala melas (Traill, 1809)	●	●		●	●	Sadove and Morreale (1989); Donoghue (1994); Laist (1997); Zerbini and Kotas (1998); Ceccarelli (2009); Núñez et al. (2011)
Grampus griseus (G. Cuvier, 1812)	●	●			●	Walker and Coe (1990); Dayaratne and Joseph (1993); Barlow et al. (1997); Shoham-frider et al. (2002); Frantzis (2007); Bermudez Villapol et al. (2008); Arbelo and Fernandez in (Baulch and Perry, 2014)
Lagenodelphis hosei Fraser, 1956	●	●		●	●	Dayaratne and Joseph (1993); Ofori-Danson et al. (2003); Fernandez et al. (2009)

Table 1 – *(continued)* "Black list" of impacted marine mammal species by anthropogenic marine litter.

	Impact		Pressure			
Taxa	**Ingestion**	**Entanglement**	**Micro litter**	**Meso litter**	**Macro litter**	**References**
Family Delphinidae *(continued)*						
Lagenorhynchus acutus (Gray, 1828)		●			●	Fontaine et al. (1994)
Lagenorhynchus albirostris (Gray, 1846)	●	●			●	Fontaine et al. (1994); Baird and Hooker (2000)
Lagenorhynchus australis (Peale, 1848)		●			●	Goodall et al. (1997)
Lagenorhynchus obliquidens Gill, 1865	●	●		●	●	Caldwell et al. (1965); Cowan et al. (1986); Walker and Coe (1990); Barlow et al. (1997); Artukhin et al. (2010)
Lagenorhynchus obscurus (Gray, 1828)		●			●	Crespo et al. (1997)
Lissodelphis borealis (Peale, 1848)	●	●		●	●	Walker and Coe (1990); Barlow et al. (1997)
Lissodelphis peronii (Lacépède, 1804)		●			●	Reyes and Van Waerebeek (1991)
Orcaella brevirostris (Owen in Gray, 1866)	●	●			●	Baird and Mounsouphom (1997); Kreb in Baulch and Perry (2014)
Orcaella heinsohni Beasley, Robertson and Arnold, 2005		●			●	Ceccarelli (2009)
Orcinus orca (Linnaeus, 1758)	●	●			●	Cawthorn (1984); Baird and Hooker (2000); Ofori-Danson et al. (2003); Artukhin et al. (2010); Núñez et al. (2011); Smithsonian Research Institute in Baulch and Perry (2014); Australian Antarctic Division in Baulch and Perry (2014)
Peponocephala electra (Gray, 1846)		●			●	Dayaratne and Joseph (1993)
Pseudorca crassidens (Owen, 1846)	●	●		●	●	Barros et al. (1990); Dayaratne and Joseph (1993)
Sousa teuszii (Kükenthal, 1892)		●			●	Weir et al. (2011)
Sousa chinensis (Osbeck, 1765)		●			●	Razafindrakoto et al. (2008); Ceccarelli (2009)
Sotalia fluviatilis (Gervais and Deville in Gervais, 1853)	●			●	●	Geise and Gomes (1992); Laist (1997)
Sotalia guianensis (Van Bénedén, 1864)	●	●	●	●	●	Di Beneditto and Awabdi (2014); Geise and Gomes (1992); da Rocha and Andriolo (2005); Di Beneditto and Ramos (2014)
Stenella attenuata (Gray, 1846)	●	●			●	Dayaratne and Joseph (1993); Baird and Hooker (2000); Romano et al. (2002)
Stenella clymene (Gray, 1850)		●			●	Zerbini and Kotas (1998); da Rocha and Andriolo (2005)
Stenella coeruleoalba (Meyen, 1833)	●	●			●	Walker and Coe (1990); Dayaratne and Joseph (1993); Barros et al. (1997); Zerbini and Kotas (1998); Pribanic et al. (1999); Fernandez et al. (2009); Baulch and Perry (2014); Carillo in Baulch and Perry (2014)
Stenella frontalis (G. Cuvier, 1829)	●	●			●	Zerbini and Kotas (1998); Ofori-Danson et al. (2003); Arbelo and Fernandez in Baulch and Perry (2014)
Stenella longirostris (Gray, 1828)		●			●	Dayaratne and Joseph (1993); Zerbini and Kotas (1998); Romano et al. (2002); Razafindrakoto et al. (2008)
Steno bredanensis (G. Cuvier in Lesson, 1828)	●	●		●	●	Walker and Coe (1990); Dayaratne and Joseph (1993); Ofori-Danson et al. (2003); Meirelles and Barros (2007); Smithsonian Research Institute in Baulch and Perry (2014)
Tursiops aduncus (Ehrenberg, 1833)		●			●	Chatto and Warneke (2000); Bossley (2005); Ceccarelli (2009)
Tursiops truncatus (Montagu, 1821)	●	●		●	●	Barros et al. (1990); Walker and Coe (1990); Schwartz et al. (1991); Mann et al. (1995); Gorzelany (1998); Zerbini and Kotas (1998); McFee and Hopkins-Murphy (2002); Ofori-Danson et al. (2003); da Rocha and Andriolo (2005); McFee et al. (2006); Razafindrakoto et al. (2008); Ceccarelli (2009); Gomerčić et al. (2009); Levy et al. (2009); NMES (2009a); Deaville and Jepson (2011); FAU (2012); Lelis (2012); Stolen et al. (2013); Adimey et al. (2014); Baulch and Perry (2014); Byrd et al. (2014); Nicolau in Baulch and Perry (2014); Smithsonian Research Institute in Baulch and Perry (2014); Australian Antarctic Division in Baulch and Perry (2014)
Family Phocoenidae						
Neophocaena phocaenoides (G. Cuvier, 1829)	●	●		●	●	Baird and Hooker (2000); Hong et al. (2013)
Phocoena dioptrica Lahille, 1912		●			●	Goodall and Cameron (1980)
Phocoena phocoena (Linnaeus, 1758)	●	●		●	●	Hare and Mead (1987); Walker and Coe (1990); Kastelein and Lavaleije (1992); Fontaine et al. (1994); Baird and Hooker (2000); Radu et al. (2003); Tonay et al. (2007); Artukhin et al. (2010); Bogomolni et al. (2010); Deaville and Jepson (2011); Northwest Straits Initiative Project (2012)
Phocoena sinus Norris and McFarland, 1958		●			●	D'agrosa et al. (2000)
Phocoena spinipinnis Burmeister, 1865	●	●			●	Goodall and Cameron (1980); Reyes and Van Waerebeek (1991); Torres et al. (1992); Denuncio in Baulch and Perry (2014)
Phocoenoides dalli (True, 1885)	●	●		●	●	Degange and Newby (1980); Jones and Ferrero (1985); Walker and Coe (1990); Barlow et al. (1997); Artukhin et al. (2010)
Order Sirenia						
Family Trichechidae						
Trichechus inunguis (Natterer, 1883)	●	●			●	Reeves et al. (1996); Guterres-Pazin et al. (2012)
Trichechus manatus Linnaeus, 1758	●	●		●	●	Beck and Barros (1991); Bossart et al. (2004); Rodas-Trejo et al. (2008); Adimey et al. (2014); Attademo et al. (2015)
Trichechus senegalensis Link, 1795		●			●	Silva and Araújo (2001)
Family Dugongidae						
Dugong dugon (Müller, 1776)	●	●			●	Ceccarelli (2009); Gunn et al. (2010)

Species citations, Scholar species recurrences and temporal trend

We obtained 431 species citations. Cerartiodactyla Cetacea showed the highest number of citations (n=321; Mysticeti n=82, Odontoceti n=239); followed by Carnivora (n=100) and Sirenia (n=10). Differences among the mean number of species in three Orders is not significant (χ^2=0.058, p=0.971, d.f.=2; Kruskal-Wallis test), also performing a paired comparison (Carnivora vs. Cetacea: Z=0.190, p=0.849; Odontoceti vs. Mysticeti: Z=1.371, p=0.170, Mann-Whitney U test).

At single species level, the species with highest number of citations (>10) were *Callhorinus ursinus* (n=11) among Carnivora, *Megaptera novaeangliae* (n=18), *Physeter macrocephalus* (n=18), *Tursiops truncatus* (n=15), *Eubalaena glacialis* (n=11) among Cetacea (see Tab. S1). The number of species recurrence ranged from 9 (*Mesoplodon grayi*) to 27900 (*Tursiops truncatus*) spanning along 4 log-orders. Interestingly, two species with high number of Scholar species recurrences (*Delphinapterus leucas*: 10400; *Ursus maritimus*: 10500) showed no species citations regarding the marine litter topic. We observed a direct correlation between Google Scholar recurrences and species citations on marine litter (r_s=0.613, p<0.001, n=128), also if data showed a high dispersion around the regression line (low coefficient of determination, R^2; Fig. 1). Considering the history of references, we observed a low number before 1986 with a progressive increasing trend in the Nineties: after the "2001–2005" period their number has been largely increased (Fig. 2). Data for the last period (starting from 2016) are obviously incomplete and only descriptive.

Table 2 – Total number of species and number of species impacted with their percentage frequency (%) subdivided for Orders and sub-orders of marine mammals.

Orders/suborders	Tot. no. of species	No. of impacted species	%
Carnivora	36	27	75.00
Cerartiodactyla Cetacea	88	70	79.55
Mysticeti	14	11	78.57
Odontoceti	74	59	79.73
Sirenia	4	4	100.00
Total	128	101	78.91

Table 3 – Total number of species and number of species impacted with their percentage frequency (%) subdivided for Orders and sub-orders of marine mammals.

	Tot. no. of species	No. of impacted species	%
Order Carnivora			
Otariidae	14	12	85.71
Odobenidae	1	0	0.00
Phocidae	18	14	77.78
Ursidae	1	0	0.00
Mustelidae	2	1	50.00
Order Cerartiodactyla: Cetacea			
Sub-order Mysticeti			
Balenidae	4	3	75.00
Neobalenidae	1	1	100.00
Eschrichtiidae	1	1	100.00
Balaenopteridae	8	6	75
Sub-order Odontoceti			
Physeteridae	1	1	100.00
Kogiidae	2	2	100.00
Ziphiidae	22	14	63.64
Platanistidae	1	1	100.00
Iniidae	1	1	100.00
Pontoporiidae	1	1	100.00
Monodontidae	2	0	0.00
Delphinidae	37	33	89.19
Phocoenidae	7	6	85.71
Order Sirenia			
Trichechidae	3	3	100.00
Dugongidae	1	1	100.00
Total	128	101	

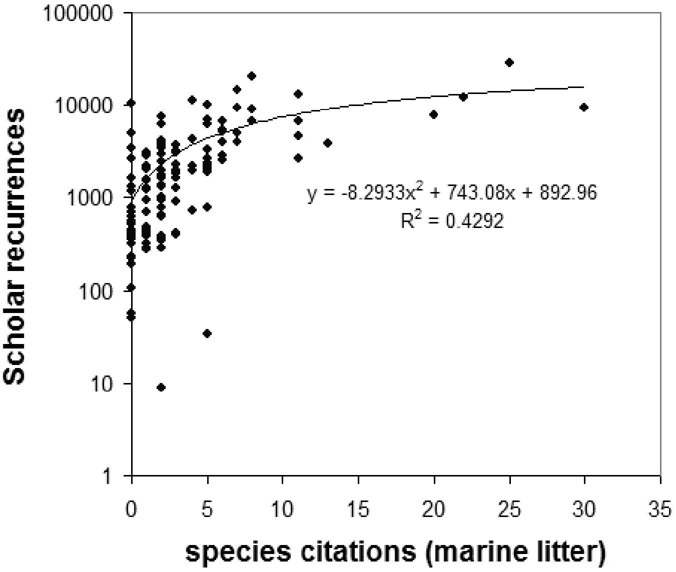

Figure 1 – Regression line between species citation on the topic "marine litter" and Google Scholar recurrences (n=128). The best-fit line (polynomial), the related equation and coefficient of determination (R^2) have been reported. Data on y-axis are log-transformed.

Type of impact

Regarding the type of impact, we have obtained evidence for 59 species impacted by ingestion (58.42% on the total) and for 91 species (90.1%) impacted by entanglement. Total is higher than the total number of impacted species (n=101) since for 50 species (49.5%) we have obtained evidence for both the impacts. Difference between these two percentage frequencies is significant (χ^2=24.887, p<0.001, 1 d.f.).

For ingestion, the percentage of species impacted ranged from 22 to 75%, while for entanglement ranged from 66 to 100%. Interestingly, a significant difference between the two type of impact occurs only in Carnivora (Tab. 4).

Type of pressure

Considering the type of pressure (criterion: size of litter), the highest number of species was observed for macro-litter (n=98, 97.03%) and, secondarily, for meso-litter (n=30; 29.70%) and micro-litter (n=9; 4.71%) with a significant difference (χ^2=173.017, p<0.001, 1 d.f.). Mysticeti showed the highest frequency of species impacted by micro-litter. From 75 and 100% of species was impacted in the different Order and sub-Orders by macro-litter. In each order and sub-Orders differences between the frequency of species impacted by the three types of pressure are significant (Tab. 5).

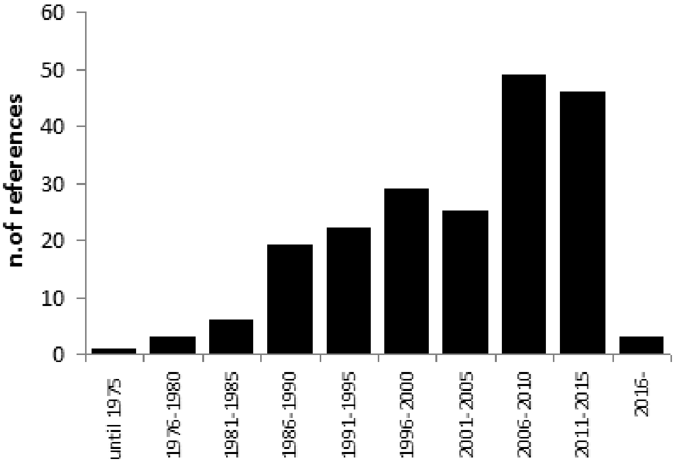

Figure 2 – Number of references subdivided for 5-year periods. Values for "2016–" period were possibly underestimated.

Table 4 – Number of species of different Orders and Sub-Orders subdivided for different type of impact (and percentage frequency). The χ^2 and p-values are reported below (for Sirenia, test has not been preformed).

		Cetacea			
	Carnivora	**Mysticeti**	**Odontoceti**	**Total**	**Sirenia**
Ingestion	8	9	39	49	3
	22.22%	64.29%	52.70%	55.68%	75.00%
Entanglement	27	11	49	60	4
	75.00%	78.57%	66.22%	68.18%	100.00%
Total impacted	36	14	74	88	4
χ^2	18.014	0.175	0.228	2.410	–
p	0.000	0.676	0.633	0.121	–

Table 5 – Number of species subdivided for different type of pressure and belonging to different Orders and Sub-Orders. The χ^2 test and p-values are reported below (for Sirenia, test has not been performed).

		Cetacea			
	Carnivora	**Mysticeti**	**Odontoceti**	**Total**	**Sirenia**
Micro–	3	2	4	6	0
	8.33%	14.29%	5.41%	6.82%	0.00%
Meso–	5	2	22	24	1
	13.89%	14.29%	29.73%	27.27%	25.00%
Macro–	27	11	56	67	4
	75.00%	78.57%	75.68%	76.14%	100.00%
Total impacted	36	14	74	88	4
χ^2	44.975	16.800	80.910	96.056	–
p	0.000	0.000	0.000	0.000	–

Discussion

Although research on marine litter is widespread worldwide at single species level, it has been highlighted that there is still a lack of evidence of effects at higher taxonomic level and for poor-studied target of litter (as microplastics; Laist, 1997; Derraik, 2002; Gall and Thompson, 2015). In our work, through a meticulous collection and analysis, we have arranged a comprehensive review of the state of knowledge on the effect of anthropogenic litter on marine mammals, assessing the impact at different taxonomic levels.

As observed in previous studies (e.g. Rochman et al., 2016), we confirmed that the number of scientific papers has extremely increased in the last years. The increase in the number of research on marine litter could be associated both with the increase of interest on the subject in the first years of new Century (2001–2005), due to an increase of awareness of the problem after the clamour for the discovery of the gyres occurring worldwide in the Oceans Moore et al. (2001) and could be not necessarily a consequence of an increase in the number of cases. Nevertheless, the increase in the use of the coastal and estuarine areas by anthropic activities and related greater pollution might explains the increase of the impact in the last years.

In this work we found a higher number of species than all the previous reviews (Wallace, 1985; Walker and Coe, 1990; Katsanevakis, 2008; Ceccarelli, 2009; Núñez et al., 2011; Hong et al., 2013; Baulch and Perry, 2014). A relevant frequency of species, in all the taxonomic groups, resulted impacted: about $\frac{3}{4}$ of the two main Orders (Carnivora and Cetacea) and Sub-Orders of Cetacea, and all the species of the less species-rich order (Sirenia).

Excluding a carnivore (*Callhorinus ursinus*), four cetaceans (*Megaptera novaeangliaee*, *Physeter macrocephalus*, *Tursiops truncatus*, *Eubalaena glacialis*) showed the highest number of species citations (>10). Nevertheless, cetacean are also the more studied marine mammals (among the nine species with >10000 Scholar recurrences, six belongs to cetaceans; see Tab. S1). Testing if the number of species citation is a consequence of the research effort or, at the contrary, an evidence of a specific sensitivity, we observed a strong correlation between Scholar recurrences (a proxy of research effort) and species citations: therefore, could be probable that increasing the research effort further impacted species will be added into the "black-list".

However, also intrinsic ecological and biogeographical characteristics traits of the different species could explain our data. For example, the differences between cetaceans and carnivores could be explained from differences in their habitat preferences (carnivores living also in terrestrial ecosystems), trophic niche and food catching behaviour. Species feeding near the coasts (e.g. some carnivores) show a different behaviour and catch different preys when compared to species feeding in the open seas (as cetaceans): this might be a further factor affecting their vulnerability to the impact from marine litter (Croxall et al., 1985; Piatt, 1992; Robinson et al., 2007; Kuhn et al., 2009). Moreover, the geographic context might be also important: interestingly, two species, inhabiting polar and sub-polar context (*Delphinapterus leucas* and *Ursus maritimus*), showed high numbers of Scholar species recurrences but no evidence of impacts due to marine litter. These species live in areas with low human density, low shipping traffic and a consequent low density of marine litter (although evidence of its increase has been recently reported for the Arctic sea; Bergmann and Klages, 2012). Moreover, polar bears have a different trophic behaviour (Gormezano and Rockwell, 2013; Rode et al., 2015) compared with others marine mammals, probably avoiding events of entanglement in marine water and/or direct ingestion of litter.

Regarding sirenians, all the species showed evidence for an impact by marine debris. Sirenians are large herbivorous aquatic mammals that have high energetic requirements relative to other marine herbivores (Aragones et al., 2012). Consequently, these species may involuntarily ingest debris while they are grazing large amount of seagrass (e.g. Beck and Barros, 1991). This behaviour might explain the fact that all the species belonging to this group evidenced an impact.

About the type of impact, a significant higher number of species have been impacted from entanglement but, as for the number of species citation, also this result could be biased. In fact, this type of impact is easier to detect just because it implies only an external observation. On the contrary, in most cases evidence for the ingestion of debris by marine mammals have been detected by post-mortem examination of collected, by-caught or stranded animals (Jacobsen et al., 2010). Moreover, entanglement of large marine mammals is also a health issue for humans who use the dead whales as "bush meat" and data on this impact are largely available, when compared to data on ingestion (>300000 cetaceans/year casually or voluntarily entangled in fishing gear; e.g. International Whaling Commission, 2014; Baker et al., 2006; Read et al., 2006). Marine mammals caught unintentionally in fishing gear have been increasingly utilized for consumption (Clapham and Van Waerebeek, 2007; Robards and Reeves, 2011; Moore, 2014; Porter and Lai, 2017). In this regard, many "accidental" events could be considered actively induced also considering the high economic value of dead whales (for Asian country, see Kang and Phipps, 2000; Ishihara and Yoshii, 2000; the high price of meat may be acting as an incentive for "deliberate by-catch"; MacMillan and Han, 2011).

The factor of pressure represented by macro-litter appears the more represented, especially in Cetacea. Also in this case, this result might be biased since large litters items are easier to detect. However, Mysticeti showed the higher frequency of citations for micro-litter; probably this result is not biased as the previous ones and an increase of research effort on micro-litter will confirm this result. The food behaviour (filtrators) of Mysticeti could explain this specific sensitivity toward a pressure represented by micro-litter (Fossi et al., 2014), while other marine mammals could ingest micro-litter only through predation on already contaminated organisms.

A recent systematic review found that evidence of ecological impacts, especially in relation to micro-litter, is lacking (Rochman et al., 2016): so more research focused on this size-specific litter are necessary.

Pressure and impact in marine mammals: a proposal for a standardization in literature

As stated before, the marine litter arena from occasional topic of research, assumed in the last decade a worldwide relevance. Nevertheless, the analyzed literature appeared extremely heterogeneous regarding the criteria adopted to analyze the type of impact and pressure and the number of animals detected. This fact implies a lost of information and consequently, making difficult or impossible perform standardized comparisons. For example, in this work we used only the size-based criterion to define the type of pressure just because it is widespread and well represented in literature, so allowing a balanced comparison among groups. Nevertheless other criteria (e.g. type and chemical composition, specific weight and density, shape, floatability, etc.) could be utilized to perform analyses on their impact. In this sense, we suggest the use of consolidated standardized nomenclature and characterization (see "Guidance on Monitoring of Marine Litter in European Seas" – GMML, Galgani et al., 2013). Moreover, the lack of standardization make impossible take in account both the different pressure induced from different categories of marine litter and the type of injuries suffered by animals (from non-serious to serious and irreversible; see Andersen et al., 2007).

However, starting form our arrangement, further analyses could be carried out on stratified sub-set of our data. For example, comparing the marine environments suitable by the species (e.g. estuarine, littoral and oceanic), verifying if the occurrences of impact are greater in areas with anthropic occupation or by fishing use. This information could address public policies for waste management in each environment.

As final recommendation, we think that the adoption of a logical causal chain (pressure-impact-change in state of target-conservation response; Salafsky et al., 2008) could help researchers and conservationists in define suitable indicators for each step of the process (e.g. DPSIR approach; Kristensen, 2004).

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Supplemental information

Additional Supplemental Information may be found in the online version of this article:

Table S1 Impact and pressures list.