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The impact of plastic on cetaceans with consideration of plastics generated by the COVID19 pandemic

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Abstract

The implications of plastic pollution on marine wildlife, in particular cetaceans, are being wildly discussed in several fora, including the recent IWC workshop on marine debris held in December, 2019. Following on from previous work, we present the most recent cases from the scientific literature and worldwide news on the interactions between cetaceans and marine debris, with particular reference to ocean plastic. Eighty percent of cetacean species have interacted with marine debris, either by ingestion or entanglement. We present and discuss the conservation and welfare consequences at individual and population level and provide an initial overview of the environmental implications of the ongoing COVID19 pandemic. High volumes of pandemic-related debris have reached the oceans in the past 14 months with the potential to heavily affect cetacean populations. We argue that the pandemic not only adds further threats to cetacean populations, but that it also offers a unique opportunity to recognise the link between the production, consumption and discardment of plastic in general. The understanding of this specific "COVID19 litter cycle" could in fact aid to inform the industrial, social and management sectors and clarify their dynamics towards effective mitigation and conservation efforts.

Introduction

Plastics pose a serious threat to marine wildlife with an ever-increasing list of species linked to negative effects from interactions with debris (Laist 1987; Thompson et al. 2014; Gall and Thompson 2015). As such, it is included in several national and international regulations[1] (Thompson et al. 2009; Löhr et al. 2017). In 2020, 914 marine species have been documented either entangled in human trash or with it lodged in their gastro-intestinal tracts (Kühn and van Franeker 2020).

Between 19 and 23 million metric tonnes[2] of plastic are estimated to have entered the marine environment in 2016 (Borrelle et al. 2020). Because of its durability, low-recycling rates,

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[1] These include the EU Marine Strategy Framework Directive (MSFD 2008/56/EC), with Descriptor 10 specifically focussing on marine litter, amongst other legal measures e.g. Marine Litter Legislation: A Toolkit for Policymakers (https://goo.gl/Zc588N); Marine plastic debris and microplastics – Global lessons and research to inspire action and guide policy change (https://goo.gl/nSMzxw); International Law and Marine Plastic Pollution - Holding Offenders Accountable (https://goo.gl/484U2w)

[2] This figure was estimated as between 4.8 and 12.7 million metric tonnes for 2010 by (Jambeck et al. 2015).

poor waste management and maritime use, a significant portion of the plastic produced worldwide enters and persists in marine ecosystems (Barnes et al. 2009). Plastics account for 60 - 80% of marine litter (Galgani et al. 2000; Barnes et al. 2009; Law et al. 2010; Thiel et al. 2013; Law 2017) and are ubiquitous across the entire ocean, including remote areas (Waller et al. 2017). The accumulated number of microplastics (see Info Box 1) in the Ocean in 2014 is estimated to range from 15 to 51 trillion particles, weighing between 93 and 236 thousand metric tons, which is only approximately 1% of global plastic waste, estimated to have entered the ocean in the year 2010 (van Sebille et al. 2015).

A significant increase in macroplastics in the world oceans from 1957 to 2016 (Ostle et al. 2019) has been related to the exponential increase in total plastic production worldwide (Worm et al. 2017). A similar exponential growth of research output concerning plastic pollution in the environment, in particular in the world oceans, has been reported (e.g. Borja and Elliott 2019; Pauna et al. 2019; Qin et al. 2020; Zhang et al. 2020; Sorensen and Jovanović 2021).

Info Box 1: Plastic size classification (GESAMP 2019):

Plastic debris is classified based on size into megaplastic (>1m), macroplastics (size 25 - 1000mm), mesoplastics (between 5 - 25mm), microplastics (< 5mm) and nanoplastics (size < 1µm).
Bigger items of plastic can break down into smaller size items due to weathering (Barnes et al. 2009) and generate the so called ‘secondary microplastics’ (and smaller particles). Microplastic pieces are also produced by industry directly and used in personal care products and in other industrial applications; these are called ‘primary microplastics’.

Scientific research on the impact of marine plastic on cetaceans suggests a more than sevenfold rise in the number of cases of cetaceans interacting with marine debris during the last 50 years (Baulch and Perry 2014) with a concurrent increase in the number of cetacean species reported to have ingested or been entangled in marine debris (Denuncio et al. 2011; Poeta et al. 2017; Pierantonio et al. 2018).

Filter-feeding cetaceans seem to be particularly prone to microplastic ingestion and contamination by plastic-associated toxins because of the large volumes of water they process during feeding and trophic transfer (Fossi et al. 2014, 2016; Alava 2020), but microplastic particles have also been found in several non-suspension feeding species (Xiong et al. 2018; Hernandez-Gonzalez et al. 2018; Nelms et al. 2019; Zhu et al. 2019; Moore et al. 2020; Novillo et al. 2020). The ingestion of larger items of plastics has been reported more often for toothed cetaceans where evidence suggests that the species feeding and diving behaviour rather than the availability of plastic in the water correlates to the rate of ingestion (Di Beneditto and Oliveira 2019). Although the ingestion of plastic is in most cases a concurrent cause to the death of a cetacean, several extreme cases exist where the ingestion of very large amounts of debris, including plastic, has been the cause of death (Secchi and Zarzur 1999; de Stephanis et al. 2013; Alexiadou et al. 2019).

Entanglement in marine plastic has been reported for both mysticetes and odontocetes (e.g. Laist 1997; Butterworth et al. 2012; Baulch and Perry 2014). While it is important to underline how most of entanglement cases involve fishery related items (e.g. Cassoff et al. 2011), it is crucial to stress out that it is very difficult to distinguish between actual entanglement in abandoned, lost or discarded fishing gear (ALDFG) and by-batch (Stelfox et al. 2016; Asmutis-Silvia et al. 2017; Stelfox 2017). Reported numbers should be therefore considered with caution.

There is an open debate on the actual hazards and risks posed by marine plastic (Zhang et al. 2020) and given the inherent difficulties in studying this aspect in cetaceans, the severity of this global problem may have been underestimated so far (Puskic et al. 2020). While the direct effects of ingestion of and entanglement in marine debris are relatively well documented and understood, the more subtle consequences of exposure to microplastics are not clear. For both ingestion of and entanglement in marine plastic the potential long-term population consequences on cetaceans have not been assessed in the past 50 years (Senko et al. 2020).

The proliferation of plastic pollution in the marine environment has been driven by rapid growth in plastic production and use combined with linear economic models that ignore the externalities of waste (Geyer et al. 2017; Lebreton and Andrady 2019; Lau et al. 2020). A sharp rise in single-use plastic consumption and an expanding "throw-away" culture have exacerbated the problem. Waste management systems do not have sufficient capacity at the global level to safely dispose of or recycle waste plastic (Wilson and Velis 2015; Velis et al. 2017), resulting in an inevitable increase in plastic pollution into the environment.

A vast majority of marine plastic pollution derives from land-based sources (Jambeck et al. 2015; Schmidt et al. 2017), so a sole focus on marine oriented solutions is insufficient (Haward 2018). Marine plastic pollution is a global societal issue with strong ecological, social and economic impacts (Beaumont et al. 2019). While suitable solutions to this issue have been proposed (e.g. Lau et al. 2020), given the complexity and urgency of the global plastic crisis, ongoing scientific work must continue to understand the scale and scope of the problem. In this context, a crucial step is linking business and industry as well as social behaviours to the issue of marine plastic pollution.

The recent and ongoing COVID-19 pandemic has altered the pace, fabric and nature of our lives (Hiscott et al. 2020; Nicola et al. 2020) and, since its beginning, several elements of environmental concern have risen, alongside its more direct devastating impacts on communities across the world. In fact, since the first COVID-19 cases were reported, plastic has gained substantial attention. Its importance for hospital devices and personal protective equipment (PPE) is unquestionable, but the same material that protects, becomes a polluter when inadequately disposed of (de Sousa 2020). COVID-19 triggered an estimated global use of 129 billion face masks and 65 billion gloves every month (Prata et al. 2020). The UK alone throws away 53 million disposable face masks every day[3]. Furthermore, more subtle consumption changes like switching to single-use products for hygiene and convenience, using disposable wipes for disinfecting surfaces or carrying small bottles of hand sanitiser have happened worldwide (Kalina and Tilley 2020). Where countries had started to make changes by adopting some form of legislation to regulate plastic bags, either through a ban, levi (tax) or extended producer responsibility (United Nations Environment Programme 2018), the coronavirus spread reverted these with some places choosing to ban reusable shopping bags in an attempt to protect both customers and supermarket employees from spreading the virus[4]. In the UK, a much heralded charge on plastic bags has been suspended, while retailers including Starbucks have banned reusable products to protect against the spread of COVID-19.

While the effects of the drastic increase in the production, use and disposal of PPE and other Covid-19-associated single-use plastic items on the marine environment are just beginning to emerge, and while the worldwide effects of the COVID-19 pandemic are still tangible, the pandemic also offers a unique opportunity to explore the direct link between industry, human behaviours and their effects on cetaceans.

Building on previous work and newly available information, this report presents updated information on the issue of interactions between cetaceans and plastic debris in terms of both ingestion and entanglement. The most relevant types of debris affecting cetaceans are discussed in an effort to provide a comprehensive overview on the issue and inform appropriate mitigation and conservation decisions. The effects of the COVID19 pandemic and the potential for further impacts on cetaceans due to the rise in use of plastics during the pandemic are also discussed.

Methodology

Through a content review of available scientific and other grey literature we gathered information on the cetacean species interacting with marine debris, the type of interaction (ingestion and/or entanglement) and size of litter (micro-, meso-, macro- and mega litter). We also included worldwide news articles to account for a number of stranding events that would have otherwise been missed, because they were not yet included in available literature. Some of these events are specifically referred to in the Findings section below.

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[3] This equated to 371 million per week or 1.6 billion per month which will weigh 20,000 tonnes in total. In one year, the UK alone will use 19.2 billion face masks which weight as much as 5.5 Eiffel towers. https://www.tradewaste.co.uk/20000-tonnes-of-single-use-face-masks-will-be-dumped-in-landfill-by-march/

[4] https://www.independent.co.uk/life-style/coronavirus-reusable-shopping-bags-safe-plastic-supermarket-online-delivery-a9449836.html

Findings

Overall 72 (80%) of the 90 cetacean species officially recognised by the Society for Marine Mammalogy (SMM)[5] are affected by marine plastic pollution – either by ingestion or entanglement (Figure 1 and Table 1). While sixty species have been impacted by entanglement (66.7%, Figure 2), 53 species have been reported to have ingested plastic (58.9%, Figure 3) with macroplastics being the main issue for all. Members of the *Balaenopteridae* family seem to be most affected by microplastics (Figure 4) whilst members of the *Delphinidae* seem to be particularly affected by meso- (Figure 5) and macroplastic (Figure 6). This can probably best be explained by the different feeding behaviours. To date, the only two cetacean families not reported to be affected by plastics are the *Lipotidae* (only member is the functionally extinct Baiji, *Lipotes vexillifer*) and the *Platanistidae*[6] (only member is the South Asian river dolphin, *Platanista gangetica gangetica*).

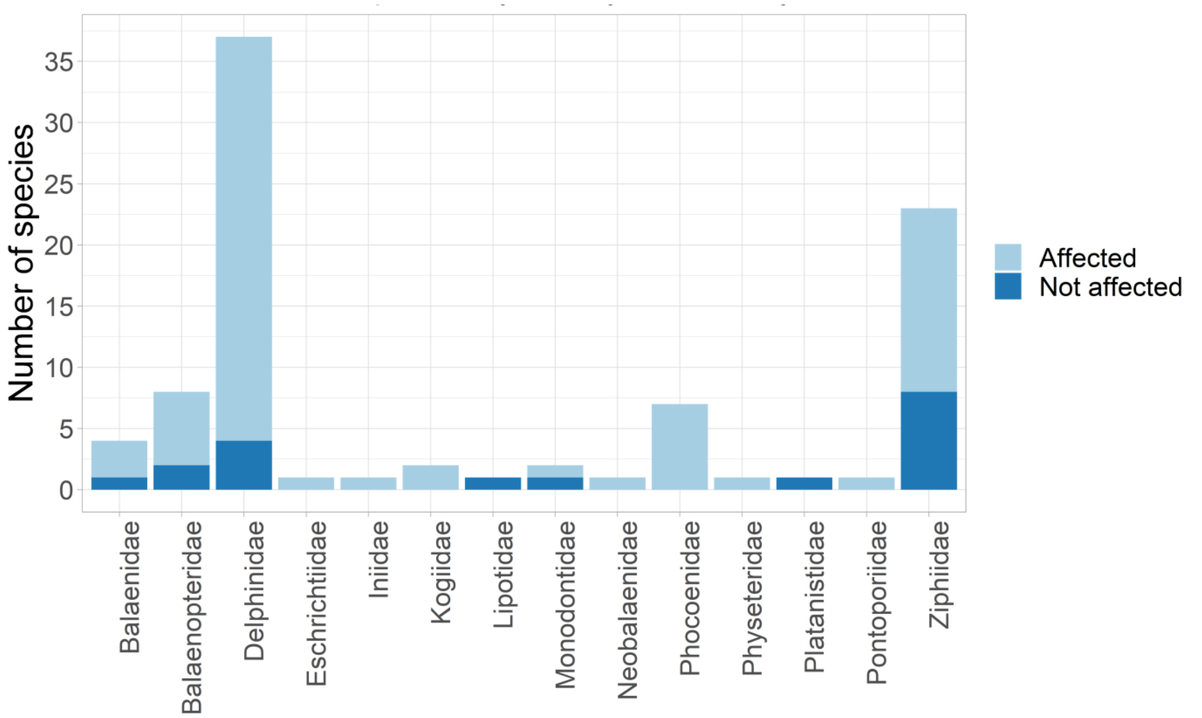

Figure 1: Number of species affected/not affected by marine debris within all 14 Cetacean families (either by entanglement or ingestion).

[5] Currently, the SMM list is the most recently updated species list (May 2020), therefore our choice for the analysis done in this report. However, in January 2021, a new species of whale, the Rice's whale, *Balaenoptera ricei sp. nov.*, has been described by Rosel et al. (2021) which has already been recorded as having ingested plastic in a strandings event in 2019, but has not yet officially been added to any list, so cannot be included in the analysis at this point in time, but we will discuss implications for this species. Equally, a taxonomic revision of the South Asian River dolphin by Braulik et al. (2021) has led to two separate species, the Indus River dolphin (*Platanista minor*) and Ganges River dolphin (*Platanista gangetica*).

[6] See footnote 5 above.

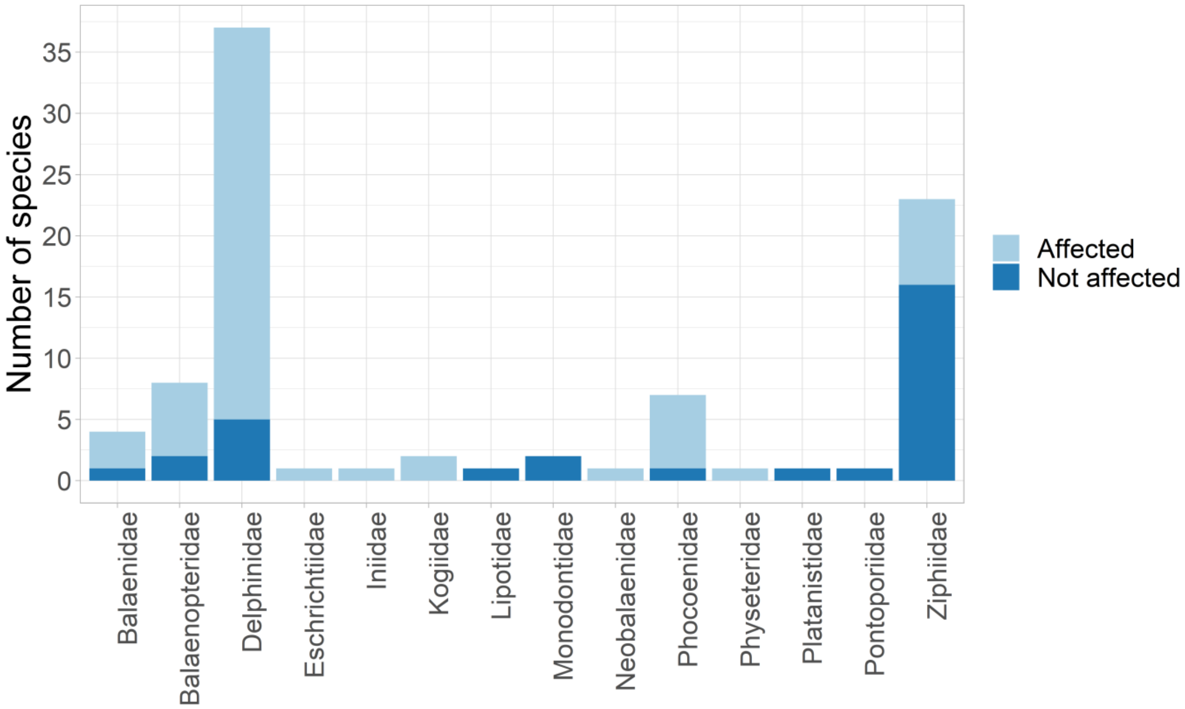

Figure 2: Number of species affected/not affected by entanglement within all 14 cetacean families.

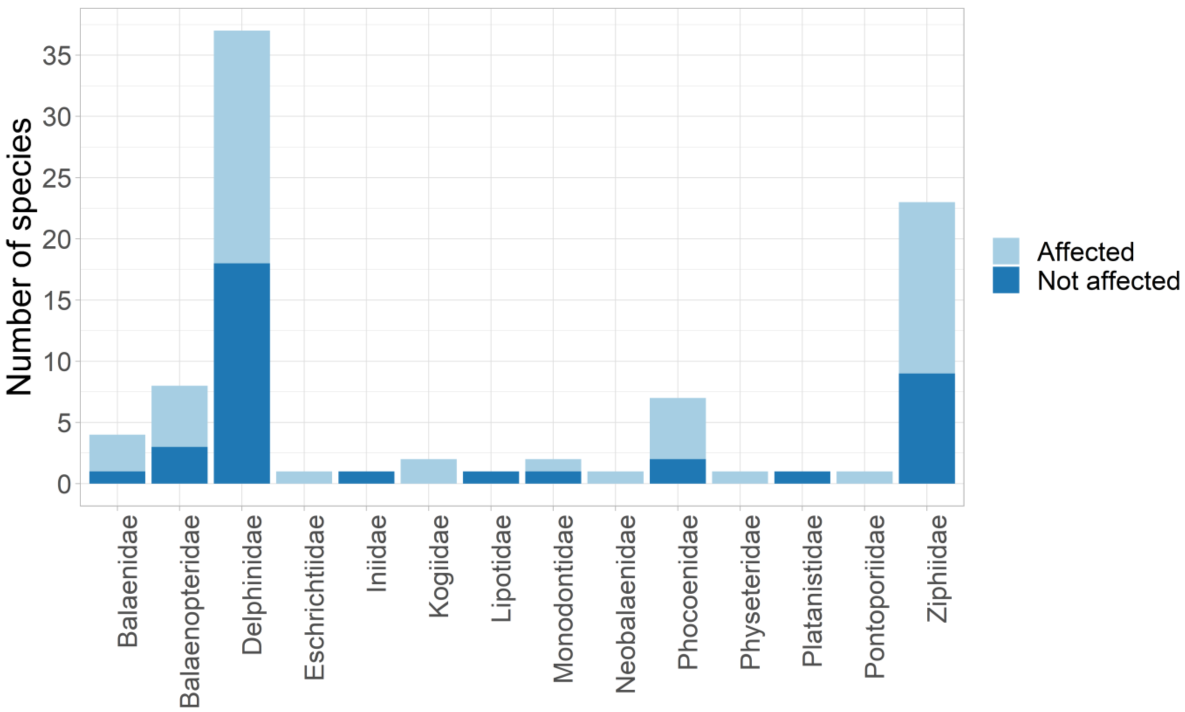

Figure 3: Number of species affected/not affected by marine debris ingestion within all 14 cetacean families.

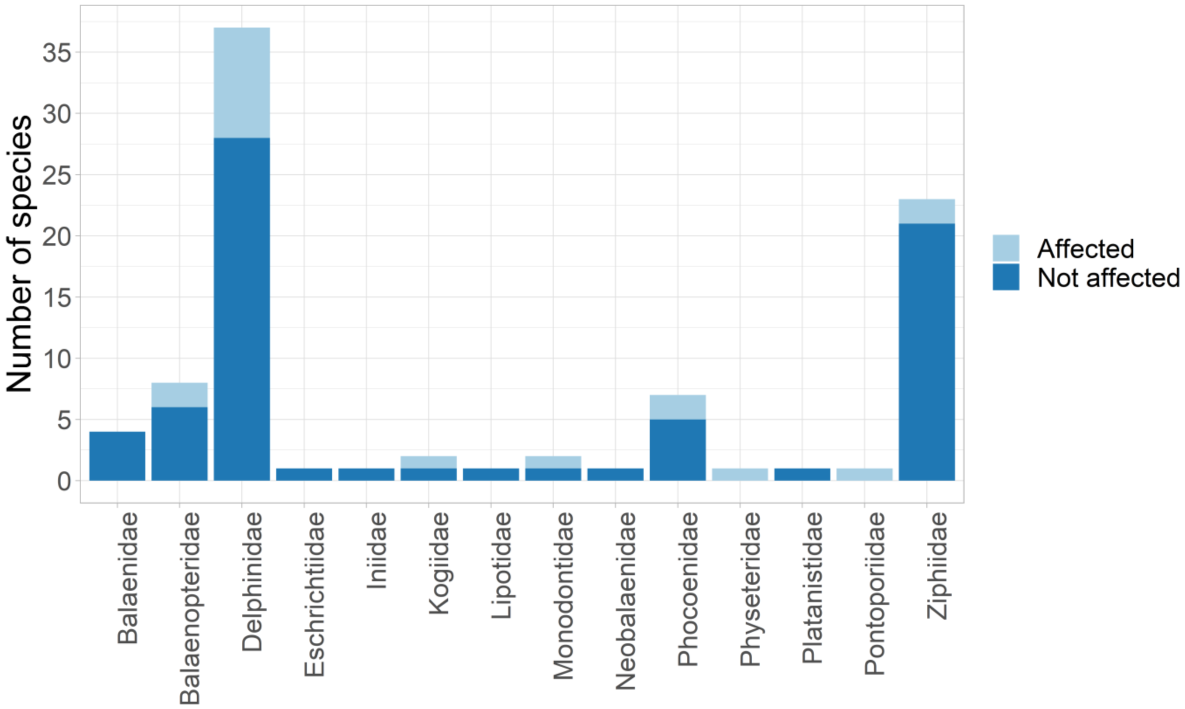

Figure 4: Number of species affected/not affected by microplastic within all 14 cetacean families.

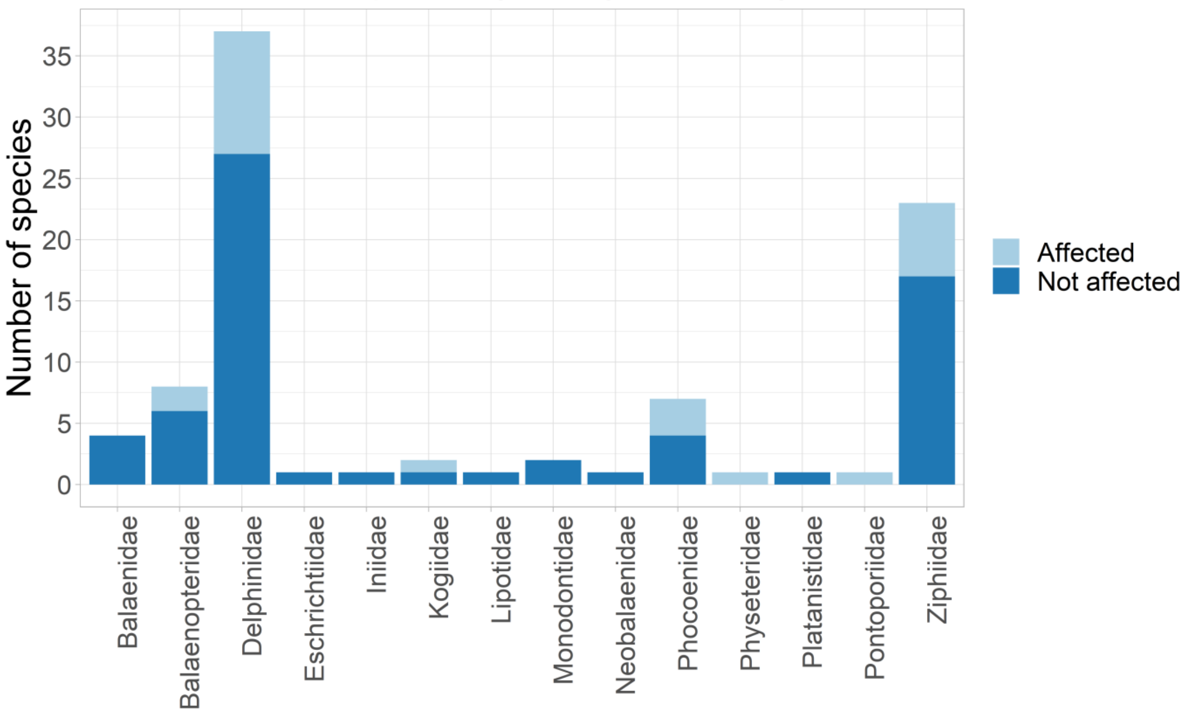

Figure 5: Number of species affected/not affected by mesoplastic within all 14 cetacean families.

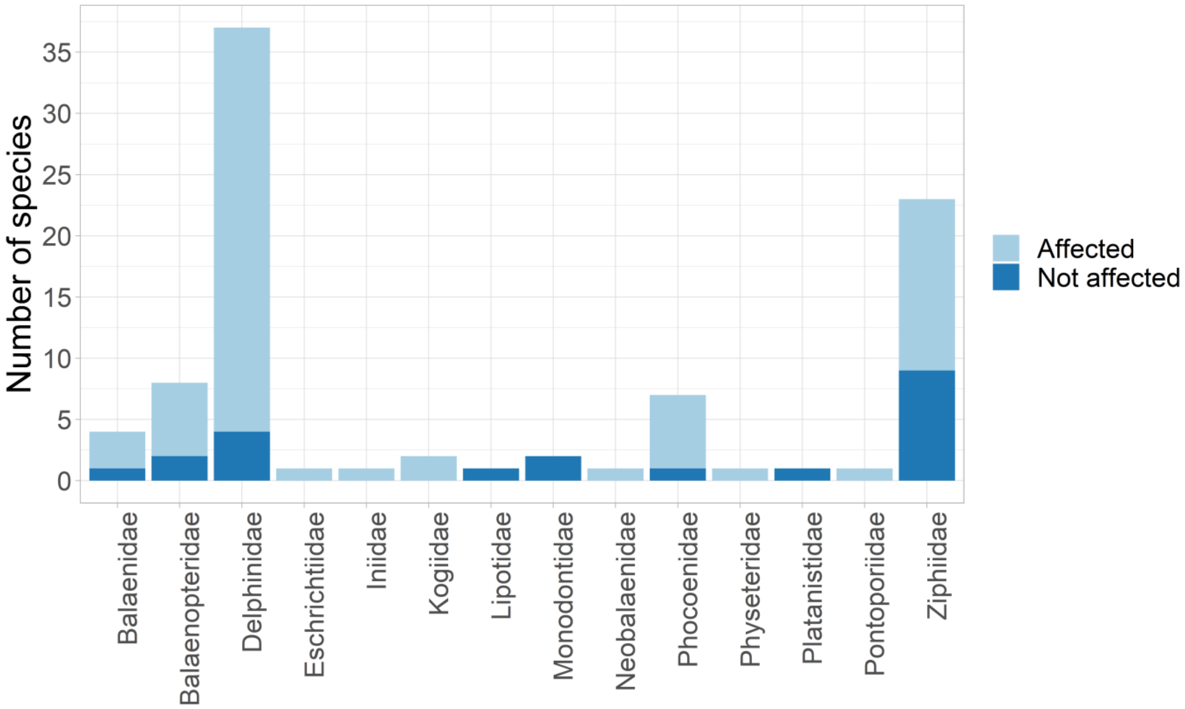

Figure 6: Number of species affected/not affected by macroplastic within all 14 cetacean families.

A summary of the collated information presented per Family is shown in Table 1 while the complete list of species along with the source of information used in the review process is presented in Annex I.

Table1: Summary of the number of cetacean families and the number of species per family impacted by marine debris. Ing. = Ingestion, Ent. = Entanglement, Micro. = Microplastic, Meso. = Mesoplastic, Macro. = Macro- and Megaplastic

Family (Species per Family)	**Affected (%)**	**Ing. (%)**	**Ent. (%)**	**Micro. (%)**	**Meso. (%)**	**Macro. (%)**
***Balaenidae* (4)**	3 (75)	3 (75)	3 (75)	0 (0)	0 (0)	3 (75)
***Balaenopteridae* (8)**	6 (75)	5 (62.5)	6 (75)	2 (25)	2 (25)	6 (75)
***Delphinidae* (37)**	33 (89.2)	19 (51.4)	32 (86.5)	9 (24.3)	10 (27)	33 (89.2)
***Eschrichtiidae* (1)**	1 (100)	1 (100)	1 (100)	0 (0)	0 (0)	1 (100)
***Iniidae* (1)**	1 (100)	0 (0)	1 (100)	0 (0)	0 (0)	1 (100)
***Kogiidae* (2)**	2 (100)	2 (100)	2 (100)	1 (50)	1 (50)	2 (100)
***Lipotidae* (1)**	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
***Monodontidae* (2)**	1 (50)	1 (50)	0 (0)	1 (50)	0 (0)	0 (0)
***Neobalaenidae* (1)**	1 (100)	1 (100)	1 (100)	0 (0)	0 (0)	1 (100)
***Phocoenidae* (7)**	7 (100)	5 (71.4)	6 (85.7)	2 (28.6)	3 (42.9)	6 (85.7)
***Physeteridae* (1)**	1 (100)	1 (100)	1 (100)	1 (100)	1 (100)	1 (100)
***Platanistidae* (1)**	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
***Pontoporiidae* (1)**	1 (100)	1 (100)	0 (0)	1 (100)	1 (100)	1 (100)
***Ziphiidae* (23)**	15 (65.2)	14 (60.9)	7 (30.4)	2 (8.7)	6 (26.1)	14 (60.9)

Grand Total (90)	**72 (80)**	**53 (58.9)**	**60 (66.7)**	**19 (21.1)**	**24 (26.7)**	**69 (76.7)**

There has been a marked increase in the number of cases reported, as well as an increase in the number of cetacean species recorded to have ingested marine plastic. In one of the earliest reviews on this subject, (Laist 1997) reported 28 species of cetacean (37%, n = 75) as affected by either ingestion or entanglement or both. Since then the proportion of affected species has more than doubled and the absolute number of affected species is almost three times higher.

Ingestion

While ingestion of plastics is mostly considered a contributing cause of death, lethal cases, where plastic bags fully occluded gastrointestinal passages or filled up stomach cavities, are reported worldwide (Secchi and Zarzur 1999; de Stephanis et al. 2013; Alexiadou et al. 2019). Sperm whales are the species with the highest reported number of ingested items (Alexiadou et al. 2019). As recently noted by Alexiadou et al. (2019), as half of ship-struck cetaceans had plastic in their guts, the ingestion of plastics could affect the swimming and diving behaviour of cetaceans, increasing the risk of ship strikes. For this reason, mortality resulting from plastic may be more common than direct mortalities from confirmed gastric obstructions or perforations would suggest (Roman et al. 2020).

Plastics, especially plastic bags, wrappers, plastic sheets, fragments of large plastic containers and, to a lesser extent, plastic bottles, represent the type of plastic item most frequently ingested by cetaceans. Items linked to fishing activities, such as portions of ropes, nets, lines and hooks also constitute a large portion of ingested material (Simmonds 2012, 2017; Baulch and Perry 2014; Poeta et al. 2017; Lusher et al. 2018; Roman et al. 2020).

The ingestion of plastic is reported to have a variety of detrimental health effects (see Info Box 2).

Info Box 2: Reported health effects of plastic ingestion (Gregory 1991; Laist 1997; Secchi and Zarzur 1999; Derraik 2002; Stamper et al. 2006; Jacobsen et al. 2010; de Stephanis et al. 2013; Alexiadou et al. 2019)

- laceration or ulceration of the gastrointestinal tract, leading to infection and internal bleeding;
- direct blockage of the digestive tract, reducing or preventing nutrient uptake;
- satiation (i.e. reducing the urge to feed);
- failure of digestive tract compartmentalization, allowing highly acidic gastric secretions into areas not adequately shielded;
- retention leading to an increasing amount of debris in the digestive system of the organism.

In December 2019, following on from Pierantonio et al. (2018), Eisfeld-Pierantonio et al. (2019) listed 16 new cases of ingestion events mentioned in the world media in the previous 12 months. Table 2 summarises the data presented by Eisfeld-Pierantonio et al. (2019), as well as the newest cases since then.

Table 2: Ingestion cases in the news between December 2018 and the present. * = pregnant, M = male, F = female, A = adult, J = juvenile, C = calf, SA = subadult

Species	Sex	Age	Length	Date	Location	Amount of debris (kg)	Type of debris	Cause of death	Reference
Franciscana	M			01/12/18	Sao Paulo, Brazil		Plastic ring around beak and pieces of plastic in stomach	starved to death	https://bit.ly/3mfpMjt
Sperm whale	M		8m	24/12/18	Ischia, Italy		plastic bags, nylon thread		https://bit.ly/3203GYZ
Roughtoothed dolphin	M			22/01/19	Pangasinan, Philippines		polyvinyl chloride wire, a lighter, a filter bag and empty plastic pouches of vinegar and soy sauce		https://bit.ly/2PO7v0q
Sei whale		C	5m	26/01/19	North Carolina, USA		bundles of plastic bag remnants and sea grass caught in the whale's throat	Euthanised	https://bit.ly/31zKL7g
Bryde's whale/ Rice whale			11.6m	31/01/19	Florida, USA		3-inch-square piece of sharp plastic in one of the whale's stomach chambers	The plastic caused haemorrhaging and acute gastric necrosis in the second stomach chamber. The ingestion of the plastic led to the stranding and subsequent death of this whale (Rosel et al. 2021)	https://bit.ly/3meDsvk
Cuvier's beaked whale	M	J		18/03/19	Philippines	40	plastic bags, including 16 rice sacks. 4 banana plantation style bags and multiple shopping bags	gastric shock	https://bit.ly/39yDV6t
Sperm whale	F	A*	8m	28/03/19	Sardinia, Italy	22	shopping bags, tangled fishing lines, corrogated tube for electrical works,plastic plates, the bag of a washing machine liquid still identifiable, with brand and barcode, and other objects no longer identifiable		https://cnn.it/39wABbM
Pygmy sperm whale	F		2.6m	10/04/19	Batangas province, Philippines	0.5	food packs, foil wrappers and hard plastic pieces from furniture	Plastic impaction, severe parasitic infection, including roundworms	https://bit.ly/3rXPhak
Roughtoothed dolphin	F	C	1.8m	23/04/19	Florida, USA		two plastic bags and a piece of a balloon	Euthanised	https://bit.ly/2OfuKAk
Bottlenose dolphin	M		2.1m	10/05/19	Florida, USA		two-foot plastic shower hose in the oesophagus and forstomach		https://cnn.it/3sJBXrd
Sperm whale	F	J	6m	17/05/19	Sicily, Italy		several kg of plastic bags	The plastic probably created a block that didn't let the food in.	https://bit.ly/3cE13lR
Sperm whale	M	J		20/05/19	Sicily, Italy		Plastic	not enough plastic to cause the death	https://bit.ly/2PtW3au
Roughtoothed dolphin	M	A	2.35m	20/05/19	Pangasinan, Philippines	0.2	plastic bags & wrappers	Severe pneumonia, but plastic, parasitism and gastric ulcers likely contributed to the death.	https://bit.ly/3whZsKf
Gray whale	M	A	12m	28/05/19	Washington, USA		2 small pieces of plastic	starved to death, but not because of plastic	https://bit.ly/31EIaJi
Sperm whale	M	SA	13.3m	11/10/19	Northumber-land, UK	1 plastic bag	1 plastic bag	N/A	https://bit.ly/3wtb6Ce
Sperm whale	M	J	6.7m	29/10/19	Gwynedd, Wales, UK		large piece of blue plastic sheeting & a relatively large mass of ropes, fragments of monofilament line & other plastic fragments	The ingested debris is considered to be an incidental finding and not necessarily the most significant factor in the whale's death, it may have had some impact on the animal's ability to digest any ingested prey.	https://bit.ly/3dqt8fx
Sperm whale	M		14m	28/11/19	Isle of Harris, Scotland, UK	100	sections of net, bundles of rope, plastic cups, bags, gloves, packing straps and tubing; a scrap of net that was 3m long and 2m wide, a stack of plastic cups & flat packing straps, three bundles of fishing rope, fragments of rubber gloves & rubber tubing	no evidence that this had impacted or obstructed the intestines, but could have caused acute cholic or similar discomfort; unclear if the rubbish was a direct cause of the whale's stranding	https://bbc.in/2PhUkVZ
Orca	M	J	4.6m	30/12/19	Lincolnshire, UK		large fragment of plastic material	Plastic incidental finding and not a causal factor in the animals death	https://bit.ly/3ur8uD9
Sowerby's beaked whale	M	J	4.3m	04/07/20	Wicklow Harbour, Ireland		10x3 cm piece of plastic lodged with fish bones partially blocking the whale's rectum	inconclusive	https://bit.ly/31DqoWK
Sperm whale			13-14m	14/08/20	Antalya Kumluca Beach, Turkey		plastic litter in the stomach, including a plastic jar for milk or yogurt	n/a	https://bit.ly/3uclZpZ

Microplastic is ubiquitous not only amongst large filter feeding cetaceans (Baulch and Perry, 2014; Besseling et al. 2015; Fossi et al. 2012, 2014, 2016, 2017), but also in smaller odontocete species (Puig-Lozano et al. 2018; Hernandez-Gonzalez et al. 2018; Nelms et al. 2019). Filter feeding species are reported to be mostly affected by the unintentional ingestion of microplastics through lunge feeding in surface waters or possibly as a result of trophic transfer through their prey (Fossi et al. 2014). In contrast, (Lusher et al. 2016) estimated that one striped dolphin (*Stenella coeruleoalba*) in the Irish Sea could ingest close to 463 million microplastic pieces annually through the consumption of contaminated prey[7].

Evidence suggests (Lusher et al. 2015, 2018) that some species ingest debris more often than others due to their prey-capture strategy rather than the presence of higher amounts of debris in the water column or the species' habitat preferences and diving behaviour (e.g. Di Beneditto and Oliveira 2019). Recent studies also suggest that there is a strong correlation between the body size and the nature, frequency and size of plastic-biota interactions, with a size ratio of roughly 20:1 between animal body length and the largest ingested items (Jâms et al. 2020). However, this particular study only included a single specimen of a 10.34m humpback whale and therefore might not be representative for all cetacean species and the variability of their feeding strategies.

Entanglement

Entanglement in marine debris is a global concern that is known to affect a large number of marine species (Macfadyen et al. 2009), however, its identification is still difficult. Entanglement is defined as the process of being wrapped by a passive item, whilst bycatch defines the unwanted capture during fishing operations and implies that an animal is caught in nets or intentionally released from nets by fishers (Lusher et al. 2018).

Entanglement can cause decreased swimming ability, disruption in feeding, life-threatening injuries, and death (see Info Box 3).

Info Box 3: Reported effects of marine debris entanglement (Moore and van der Hoop 2012; Baulch and Perry 2014; van der Hoop et al. 2016).

- loops of material can embedded into the skin and flesh leading to
- abscess formation and infection
- amputation
- compromised or restricted movement
- disrupted feeding

[7] This number seems wrong, as this would mean that one single striped dolphin would consume > 1 million fish per day! In comparison, Mediterranean fin whales consume roughly 1 million pieces of plastic per year. We have written to Amy Lusher for clarification.

While the majority of entanglement records are in fact by-catch events, rather than entanglement in marine debris (Laist 1997; Butterworth et al. 2012; Baulch and Perry 2014), abandoned, lost or otherwise discarded fishing gear (ALDFGs) appear to pose a serious entanglement risk. Evidence suggests, some ALDFGs constitute the vast majority of baleen whale entanglements in marine debris (Laist 1997; Butterworth et al. 2012; Baulch and Perry 2014). However, the rate and number of entanglements in marine debris are generally difficult to decipher. Very high numbers of reports do not differentiate between ALDFGs, active fishing gear, or any other marine debris, and usually describe the cause of the entanglement as "Unknown" when clearly not attributable to active fishing gears (Johnson 1989; Johnson et al. 2005; Neilson et al. 2009).

Despite these difficulties, it is clear from the available literature that entanglement of cetaceans in marine debris has increased dramatically in recent decades (Laist 1997; Simmonds 2012; Baulch and Perry 2014). Since the last review by Pierantonio et al. (2018), no cases involving previously unlisted species were confirmed as entangled in marine debris. Nonetheless, within the worldwide news, there have been several cases of cetaceans apparently entangled. More recent entanglement cases found in the news are presented in Table 3 below. However, this list should be considered with care, as information are in part lacking to confirm entanglement as cause of death.

Table 3: Entanglement cases of cetaceans in the news between January 2019 and the present. *= pregnant, M = male, F = female, A = adult, J = juvenile, C = calf, SA = subadult

Species	Sex	Age	Length	Date	Location	Amount of debris (kg)	Type of debris	Cause of death	Reference
Common dolphin	F			22/01/19	Jersey, Channel Islands, UK		twine-like plastic	tightly bound her snout closed, starved to death, possibly bycatch	https://bit.ly/3mqg1iM
Sperm whale	F	A	6m	21/06/19	Pontian Archipelago, Tyrrhenian Sea, Italy	2m	driftnet	entanglement	https://bit.ly/3s0DjNm
Sperm whale	M	C		21/06/19	Pontian Archipelago, Tyrrhenian Sea, Italy	2m	driftnet	entanglement	https://bit.ly/3s0DjNm
Minke whale	F	A*		01/10/19	Sanday, Orkney, UK	netting	piece of discarded fishing net	drowned in surfline	https://bbc.in/3rOc2xq
Sowerby's beaked whale	F	A	4.5m	12/10/19	Gullane beach, East Lothian, UK		loop of thin, green cord	severe trauma to the right pectoral fin, large areas of skin loss from the flank, and a loop of thin, green cord embedded around its neck Unable to swim effectively, and most likely in a large amount of pain, the animal live stranded and died.	https://bbc.in/3ml2iJW
Sei Whale	F		12.1 m	23/10/19	Bridport, Tasmania		rope	died of starvation after rope became entangled around her upper jaw and restricted her ability to feed. Based on the level of emaciation and scarring, the whale has carried this entanglement for a significant length of time.	https://bit.ly/3cS6lu0
common dolphin	F	C		15/12/19	Tāwharanui beach, Auckland, New Zealand		braid from pelagic fishing	entanglement with deep cuts in the mouth, dorsal and tail fluke	https://bit.ly/3wwKi3W
minke whale				15/09/20	Whitby Pier, North Yorkshire, UK		fishing line around neck	n/a	https://bit.ly/2R2p7Gy
minke whale				15/09/20	Whitby Pier, North Yorkshire, UK		lobster pot wire	n/a	https://bit.ly/2R2p7Gy
minke whale	F	J	7.5m	06/10/20	Spurn, East Yorkshire, UK	4	mixture of rope, packaging "and other plastic material" around the fluke	the entanglement had inhibited the whale's ability to dive and feed, ultimately leading to starvation	https://bbc.in/2OonvWH
Common dolphin				15/01/21	Maenporth, Cornwall, UK		Ghostnet	drowned entangled in the net	https://bit.ly/2Q5hsHi

Discussion

Marine Debris Workshop

The International Whaling Commission (IWC) held its third international workshop on marine debris in December 2019 reviewing the latest evidence on interactions of marine debris with cetaceans (ingestion and entanglement) and considering evidence for associated toxicology, identifying protocols for gross pathology, including for microdebris, and highlighting the importance of long-term studies and the need for standardisation in post-mortem examinations (IWC 2020).

Based on the discussions during the workshop, a series of detailed recommendations were made in relation to the importance of long-term studies, the need for standardised approaches to post-mortems, the importance of strandings networks, the assessment of floating debris during aerial surveys and the integration of marine debris concerns into the IWC's Conservation Management Plans, where appropriate. The vulnerability of some species was highlighted and the potential of some to be used as indicator species. The IWC workshop noted that, skim feeders, like right and bowhead whales (*Balaenidae*), might be monitored for their potential susceptibility to microplastics ingestion and potential exposure to associated toxic compounds due to their feeding strategies and habitat overlap with microplastic hot spots, but species with a wider distribution might be better candidates as global indicators (IWC 2020). Humpback whales have also been recommended as possible candidates for indicators of interactions with marine debris, but are generally faithful to discrete feeding grounds, whereas fin whales are more wide-ranging in their foraging, except for some unique, segregated populations (for example in the Mediterranean and the Gulf of California). The gray whale (*Eschrichtius robustus*), feeding almost exclusively on the seabed, was noted to be a good candidate for monitoring microplastic impact from the benthos at appropriate depths (IWC 2020). Fossi et al. (2020) recommended sperm whales as indicators for macro litter at depth and fin whales for micro debris.

The potential impact of the COVID19 pandemic

While conservation and environmental issues related to marine debris/plastic pollution regularly made it to the worldwide news, during the pandemic, news specifically reporting on cases of plastic related cetacean deaths sharply decreased. A query of English language news in 2019 using the string ((plastic) AND (whales) AND (strandings))[8] resulted in 16 unique cases of cetaceans having died with plastic in their stomachs and in seven for having been entangled (see tables 2 and 3). In 2020, these numbers decreased to two cases of whales with plastic in their stomachs and four entanglement cases. This is generally in line with the proposed “finite pool of worry” hypothesis (Weber 2006, 2015) that environmental and climate concerns diminish as other worries rise in prominence. Whilst a recent study looking at the effect of the “finite pool of worry” and COVID19 on UK climate change perceptions show little evidence for diminishing climate change concern during the pandemic (Evensen et al. 2021), no such approach has been used specifically in relation to interactions between cetaceans and marine debris or ocean plastic. Using such an approach to evaluate the wider effect of the pandemic on the attitude of people towards marine plastic pollution and specifically on cetacean populations is strongly advised. Such studies will be particularly relevant in light of the enormous volume of COVID19 related litter.

The production of plastic waste has increased worldwide during the pandemic, either through an increase of plastic packaging or use of PPE with a concomitant rise in the presence of masks and gloves in oceans, seas, and rivers (CPRE 2020; Kalina and Tilley 2020; Okuku et al. 2020). Ignoring the use of PPE in hospitals, which we presume is predominantly, if not always, disposed of responsibly, this pollution largely comprises the public use of PPE, primarily in the form of single-use facemasks and gloves. Since March 1, 2020, according to customs statistics, China has exported 26.7 million N-95/KN-95 masks, 504.8 million surgical masks, 195.9 million gloves, 17.3 million surgical gowns and 873,000 goggles.

[8] While this string is very general and more efficient/selective combinations of words and operators could be used for deeper searches of the news, the results yielded still showed an imbalance in the amount of news in the different years.

Responding to evolving global needs, both national and international companies augmented their manufacturing and output of PPE products. For example, 3 M (USA) has multiplied its output of N95 masks to 95 million per month by May and the annual rate was projected from 1.1 billion to 2 billion masks by the end of 2020 (Gereffi 2020). Over the past 12 months, littering has occurred in new ways and different places – specifically in the UK, littering levels have fallen in town centres, but rocketed in parks and the countryside (CPRE 2020). A litter survey carried out in Essex, UK, found PPE litter in the 38% of sites inspected– with face masks being the most commonly found items (68%) followed by wipes (18%) and gloves (14%) (CPRE 2020). Similar figures were also reported during the Great British Beach Clean in September 2020[9].

At the start of the pandemic, news were filled with stories about animals and wildlife thriving with the absence of humans and pollution[10], but now across the world[11], single-use plastic gloves, masks and aprons have washed up on shores (e.g. De-la-Torre et al. 2021, p.; Alfonso et al. 2021) and first reports of wildlife found entangled in PPE[12] or with PPE parts in their stomachs are coming in. A green turtle necropsied in Queensland, Australia, revealed an assemblage of 'matter out of place' in its stomach contents, amongst them the remains of a disposable facemask (Schofield et al. 2021). While cases of ingestion of or entanglement of cetaceans in PPE are still lacking from scientific literature, it is just a question of time until the first cases will be reported alongside other potential effects of COVID19 on cetaceans (Audino et al. 2021).

While ingestion of or entanglement in PPE might seem to have a more imminent effect on cetaceans, it has been shown that facemasks are a significant source of microplastic fibres (Fadare and Okoffo 2020; Saliu et al. 2021). Preliminary results indicate that a single surgical mask, submitted to artificial weathering, could release up to 173,000 fibres a day (Saliu et al. 2021).

Another implication of face masks and other PPE reaching the marine environment is the possibility of acting as a medium for disease outbreak, as plastic particles are known to propagate invasive microbes (Reid et al. 2019) and further contribute to the potential pathogenic effects of marine debris on cetaceans (Fossi et al. 2020).

In this light, the pandemic offers a potential opportunity to investigate the direct link between industry, human behaviours and their effects on cetaceans. Knowing the time window, the rate of production, consumption and discardment of PPE and other COVID19 related litter

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9 https://www.mcsuk.org/news/gbbc_2020_results
10 https://www.bbc.co.uk/news/world-52459487 and https://www.theguardian.com/world/2020/mar/22/animals-cities-coronavirus-lockdowns-deer-raccoons
11 https://www.reuters.com/article/us-health-coronavirus-hongkong-environme-idUSKBN20Z0PP
12 https://www.independent.co.uk/climate-change/news/coronavirus-face-mask-bird-death-recycle-environment-conservation-a9475341.html and https://www.cbc.ca/news/canada/newfoundland-labrador/gull-tangled-by-medical-mask-covid-1.5935398 andhttps://www.bbc.co.uk/news/uk-england-essex-53474772 and https://www.birdsanddebris.com/

could help build a conceptual model of this specific "COVID19 litter cycle" that synthesizes sources, sinks and pathways. This in turn could help gain a holistic perspective on this specific issue; and, more in general, could be used to inform management, prevention efforts, describe knowledge gaps and to guide advancements in the research on the ecology of plastic litter and cetaceans.

In this context, it is strongly suggested that, in line with the latest IWC recommendations (IWC, 2020), findings of COVID19 related litter ingested by or entangling cetaceans should be reported during necropsies. Given the current projections for plastic production and associated mismanaged plastic waste (Lebreton and Andrady 2019), understanding how much of COVID19 related litter affects cetaceans would also provide an insight on the future effect of plastic pollution if no preventative actions are taken.

A problem at population level

Recent evidence suggest that no studies in the last 50 years have reported direct evidence of population level effects of plastic pollution despite increased interest in and awareness of the presence of plastic pollution throughout the world's oceans (Senko et al. 2020). While long-term population-level consequences of interaction with marine debris are unclear, life history traits, restricted geographic ranges and/or small population size of some species may amplify and quicken the more direct deleterious effects of plastic pollution and undermine the persistence of the species.

The IUCN Red list assesses 14 cetacean species as either Critically Endangered or Endangered as well as 42 subspecies or subpopulations[13]. Of these, some have been reported to have continuously and increasingly interacted with marine debris and ocean plastic. As an example, the Mediterranean subpopulation of sperm whales, currently classified as Endangered (Notarbartolo di Sciara et al. 2012) and with fewer than 5000 individuals (ACCOBAMS 2021), seems to be particularly susceptive to debris ingestion. Several reports exist where large amounts of plastic have been found in the GI tract of stranded individuals leading to their death (e.g. de Stephanis et al. 2013, Alexiadou et al. 2019). In the 12 months before the start of the pandemic alone, the news reported four sperm whales, including a pregnant female, in the Mediterranean with plastics in their stomachs likely contributing to their deaths (see Table 2). Whilst this sounds like a small number, we have to consider that the population is most likely declining due to the combined effects of ship strikes and entanglement in drift nets (Rendell and Frantzis 2016). In addition, stranded animals are only a portion of those who have died at sea, and as recently reported by Alexiadou et al. (2019), there is the possibility that ship-struck sperm whales in fact were impeded by ingested plastic. Thus, the number of reported sperm whales interacting with marine debris might be grossly underestimated. In light of these considerations, the mortality associated with ingestion of marine debris is clearly unsustainable and further threatens this subpopulation's survival in

[13] https://iucn-csg.org/3-updated-cetacean-red-list-assessments-published-in-2020-so-far/

the Mediterranean, particularly knowing that the Mediterranean is one of the most polluted areas in the world (e.g. Lambert et al. 2020).

Whilst the subpopulation of sperm whales in the Mediterranean seems relatively large and therefore the effects of marine debris might not be regarded as of immediate concern, the same consequences pose a serious threat to species numbering only a few tens of individuals.

In 2019, a whale stranded in the Everglades was found to have a sharp piece of intragastric plastic approximately 6.6 × 6.2 × 0.2 cm in dimension. The plastic caused haemorrhaging and acute gastric necrosis in the second stomach chamber. The whale was thin and because the necropsy identified no other infections or pathologies that could be attributed to the whale's death, it was concluded that the ingestion of the plastic led to his stranding and subsequent death (Rosel et al. 2021). This whale was initially thought to have been a Bryde's whale (see Table 2). However, detailed analyses showed that it was a separate species formerly categorised as a subpopulation of Bryde's-like whales inhabiting the Gulf of Mexico recently listed as Endangered under the U.S. Endangered Species Act of 1973 and as Critically Endangered on the IUCN Red List. This species has recently been described as Rice's whale, *Balaenoptera ricei sp. nov.* (Rosel et al. 2021), but has not yet officially been added to the SMM species list, so was not included in the analyses of this report. The current best estimate of its abundance is 33 (CV = 1.07; Waring et al. 2015).

The restricted distribution alone, along with the small population size and associated deleterious genetic effects of inbreeding depression, loss of potentially adaptive genetic diversity and accumulation of deleterious mutations place these whales at high risk of extinction (Rosel et al. 2021). Analyses of dive behaviour indicate that these whales may feed near the seafloor in a region where bottom longline fishing occurs, raising the risk of fishery interactions (Soldevilla et al. 2017). The same study suggests that these whales may spend a considerable time at night within the first 15m of the water column, raising the risk of ship strikes. The current PBR value for this species is 0.1 (Waring et al. 2015). Therefore the removal of one individual only due to the ingestion of plastic largely exceeds this value and is unsustainable.

The results of our review show that only two families of cetaceans have not yet been reported to have interacted with marine debris, the *Platanistidae* and the *Lipotidae.* This is in part surprising, given that the Yangtze and Ganges are amongst the top ten polluting rivers in terms of plastic in the world (Schmidt et al. 2017). Whilst *Lipotes vexillifer* has been declared functionally extinct and therefore not accessible for plastic interaction studies, the lack of information on South Asian river dolphin (*Platanista gangetica gangetica*[14]*)* – plastic interactions might not mean the actual absence of interactions.

[14] Here we use the former taxonomic name for the species despite the recent reclassification of South Asian river dolphin into Indus (*Platanista minor*) and Ganges (*Platanista gangetica*) river dolphin by Braulik et al. (2021). This is to insure consistency with the SMM list of cetacean species used in our review.

The dolphins' optimal habitat overlaps with heavily-used fishing areas, resulting in dolphin entanglement (Bashir et al. 2010). Because of demands for dolphin meat and oil for human consumption, medicinal use, and catfish bait, dolphins are often killed once entangled, and it is not uncommon for fishermen to deliberately set nets in areas where dolphins are likely to encounter them (Sinha 2002; Bashir et al. 2010; Kolipakam et al. 2020). In this context, a probable cause of the lack of reports on interactions with debris is likely due to the fact that stranded, killed or bycaught animals are inaccessible for analyses, as Nelms et al. (2020) assessed the Ganges River dolphin to have the second highest overall vulnerability score to entanglement in their recent study. They are threatened by habitat fragmentation, pollution, dam/irrigation canal construction, and accidental entanglement in fishing gear (Wakid 2009; Bashir et al. 2010; Braulik et al. 2021) and further efforts should be made to effectively evaluate the real volume of interactions with marine debris and associated consequences.

Welfare concerns

Human activities and anthropogenic environmental changes are having a profound effect on biodiversity and the sustainability and health of many populations and species of wild mammals. There has been less attention devoted to the impact of human activities on the welfare of individual wild mammals, although ethical reasoning suggests that the welfare of an individual is important regardless of species abundance or population health (Paquet and Darimont 2010; Sekar and Shiller 2020).

The individual-level effects of interactions with marine debris include drowning, starvation, gastrointestinal tract damage, malnutrition, physical injury, reduced mobility, and physiological stress, resulting in reduced energy acquisition and assimilation, compromised health, reproductive impairment and mortality. Evidence strongly suggests that cetaceans are in the highest category of animals on a scale of sensibility to pain and suffering (Porter 1992) and in cases like entanglement, the pain and stress has been described as presumably extreme (Cassoff et al. 2011; Moore and van der Hoop 2012). The embedded loops of material that affect a whale or dolphin who is entangled with fishing gear can compromise or restrict movement and eventually lead to severe wounding, infection, amputations and death, a process that can take months if not years, involving a lot of discomfort and pain. Therefore, from a welfare perspective, lethal entanglements of baleen whales are, arguably, one of the worst forms of human-caused mortality in any wild animal (Cassoff et al. 2011).

It is widely accepted that wild animals can experience and suffer pain and stress, although there are difficulties in measuring the intensities of these states (Kirkwood et al. 1994). A Welfare Assessment tool for Wild Cetaceans (WATWC) including a pilot study on three hypothetical demonstration scenarios concerning the ingestion of marine debris by Cuvier's beaked whales (*Ziphius cavirostris*) and its results were presented at the plenary session of the IWC Scientific Committee meeting in Bled, Slovenia in April 2018 (Nicol et al. 2020). However, while it is understood that the tool, once the protocols have been fully developed, might be applied to the evaluation of a range of issues including comparing different welfare responses, the Scientific Committee Report SC67B (IWC 2018) and the associated ANNEX

N do not present any details on the above mentioned pilot study. Therefore there is only anecdotal evidence that cetaceans suffer after ingesting plastic[15]. Studies from other taxa, however show that ingestion of foreign objects likely causes discomfort, deep pain and can manifest in behavioural changes (e.g. Omidi et al. 2012; Priyanka and Dey 2018; Harne 2019; Eriksen et al. 2021). Recently Alexiadou et al. (2019) noted that sperm whales who stranded with copious amounts of plastic in their stomachs had changed their swimming and diving behaviour in the days prior to the stranding, highlighting how such changes could increase the risk of ship strikes to the species. Plastic bezoars, indigestible objects introduced in the gastro-intestinal tract, are considered a serious and painful threat also to humans (Verma 2013; Yaka et al. 2015; Tharayil et al. 2020).

Cetaceans are sentient, sapient individuals, many of whom form complex social bonds with their conspecifics (Marino 2013; Jones 2013). As a result interaction with plastic may deeply undermine their wellbeing and their ability to cope with normal life, including feeding, socialising and mating.

On a wider scale, the death of key individuals may cause breakdowns in social structure, leading to loss of social knowledge (lost wisdom) and fragmentation of social units (e.g. allomaternal care). As a result, this might have an impact on a whole group or even populations.

Clearly, marine debris is a pollution concern, but also an economic and social issue and all these aspects are currently taken into consideration when dealing with the plastic crisis worldwide. However, species' welfare and wellbeing at the individual and population level are crucial and should not be overlooked. Efforts should therefore be made to include welfare concerns relating to plastic pollution in conservation management plans.

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[15] https://newsinfo.inquirer.net/1105997/whale-dies-in-deep-pain-after-ingesting-plastic-trash

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ANNEX 1

Index	Family	Scientific Name	Common Name	Ingestion	Entanglement	Microlitter	Mesolitter	Macrolitter	Source
1	Balaenidae	Balaena mysticetus	bowhead whale	X	X	-	-	X	Philo et al. (1992); Lowry (1993); Laist (1997);
2	Balaenidae	Eubalaena australis	southern right whale	X	X	-	-	X	Cawthorn (1984); Kemper et al. (2008); Ceccarelli (2009); Laist (1997); Alzugaray et al. (2020)
3	Balaenidae	Eubalaena glacialis	North Atlantic right whale	X	X	-	-	X	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); Laist (1997)
4	Balaenidae	Eubalaena japonica	North Pacific right whale	-	-	-	-	-	
5	Balaenopteridae	Balaenoptera acutorostrata	Common minke whale	X	X	-	X	X	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)
6	Balaenopteridae	Balaenoptera bonaerensis	Antarctic minke whale	-	-	-	-	-	
7	Balaenopteridae	Balaenoptera borealis	sei whale	-	X	-	-	X	Lyman (2012); Van Der Hoop et al. (2012); Baulch and Perry (2014);
8	Balaenopteridae	Balaenoptera edeni	Bryde's whale	X	X	-	-	X	Haines and Limpus (2000); Cole et al. (2006); Ceccarelli (2009); Cassoff et al. (2011); Van Der Hoop et al. (2012)
9	Balaenopteridae	Balaenoptera musculus	blue whale	X	X	-	-	X	Cole et al. (2006); Baxter (2009)
10	Balaenopteridae	Balaenoptera omurai	Omura’s whale	-	-	-	-	-	
11	Balaenopteridae	Balaenoptera physalus	fin whale	X	X	X	-	X	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); Lusher et al. (2018)
12	Balaenopteridae	Megaptera novaeangliae	humpback whale	X	X	X	X	X	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); Nunezet al. (2011); Henry et al. (2012); Lyman (2012); Van Der Hoop et al. (2012); Besseling et al. (2015); Marcondes in Baulch and Perry (2014); Laist (1997); Lusher et al. (2018)
13	Delphinidae	Cephalorhynchus commersonii	Commerson's dolphin	-	X	-	-	X	Crespo et al. (1997); Goodall et al. (1997)
14	Delphinidae	Cephalorhynchus eutropia	Chilean dolphin	-	X	-	-	X	Torres et al. (1992)
15	Delphinidae	Cephalorhynchus heavisidii	Heaviside's dolphin	-	X	-	-	X	Barlow et al. (1997); Ofori-Danson et al. (2003)
16	Delphinidae	Cephalorhynchus hectori	Hector's dolphin	-	-	-	-	-	
17	Delphinidae	Delphinus delphis	common dolphin	X	X	X	X	X	Walker and Coe (1990); Romano et al. (2002); Ceccarelli (2009); Deaville and Jepson (2011); Nicolau in Baulch and Perry (2014); Simmonds (2012); Hernandez-Gonzalez et al. 2018; Lusher et al. (2018)
18	Delphinidae	Feresa attenuata	pygmy killer whale	-	X	-	-	X	Dayaratne and Joseph (1993)
19	Delphinidae	Globicephala	short-finned	X	X	-	-	X	Walker and Coe (1990); Barros

		macrorhynchus	pilot whale						et al. (1997); Reyes and Van Waerebeek (1991); Ceccarelli(2009); Byrd et al. (2014); Carillo in Baulch and Perry (2014); Simmonds (2012);
20	Delphinidae	Globicephala melas	long-finned pilot whale	X	X	-	X	X	Sadove and Morreale (1989); Donoghue (1994); Laist (1997); Zerbini and Kotas (1998); Ceccarelli (2009); Nunez et al. (2011)
21	Delphinidae	Grampus griseus	Risso's dolphin	X	X	X	-	X	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); Simmonds (2012); de Stephanis et al. 2013; Jacobsen et al. 2010; Puig-Lozano et al. 2018; Nelms et al. (2019)
22	Delphinidae	Lagenodelphis hosei	Fraser's dolphin	X	X	-	X	X	Dayaratne and Joseph (1993); Ofori-Danson et al. (2003); Fernandez et al. (2009); Baulch and Perry (2014);
23	Delphinidae	Lagenorhynchus acutus	Atlantic white-sided dolphin	-	X	X	-	X	Fontaine et al. (1994), Nelms et al. (2019)
24	Delphinidae	Lagenorhynchus albirostris	white-beaked dolphin	X	X	X	-	X	Fontaine et al. (1994); Baird and Hooker (2000); Baulch and Perry

									(2014); Nelms et al. (2019)
25	Delphinidae	Lagenorhynchus australis	Peale's dolphin	-	X	-	-	X	Goodall et al. (1997)
26	Delphinidae	Lagenorhynchus cruciger	hourglass dolphin	-	-	-	-	-	
27	Delphinidae	Lagenorhynchus obliquidens	Pacific white-sided dolphin	X	X	-	X	X	Caldwell et al. (1965); Cowan et al. (1986); Walker and Coe (1990); Barlow et al. (1997); Artukhin et al. (2010); Simmonds (2012);
28	Delphinidae	Lagenorhynchus obscurus	dusky dolphin	-	X	-	-	X	Crespo et al. (1997)
29	Delphinidae	Lissodelphis borealis	northern right whale dolphin	X	X	-	X	X	Walker and Coe (1990); Barlow et al. (1997); Simmonds (2012);
30	Delphinidae	Lissodelphis peronii	southern right whale dolphin	-	X	-	-	X	Reyes and Van Waerebeek (1991)
31	Delphinidae	Orcaella brevirostris	Irrawaddy dolphin	X	X	-	-	X	Baird and Mounsouphom (1997); Kreb in Baulch and Perry (2014)
32	Delphinidae	Orcaella heinsohni	Australian snubfin dolphin	-	X	-	-	X	Ceccarelli (2009)
33	Delphinidae	Orcinus orca	killer whale	X	X	X	-	X	Cawthorn (1984); Baird and Hooker (2000); Ofori-Danson et al. (2003); Artukhin et al. (2010); NÃºÃ±ez et al. (2011); Smithsonian Research Institute in Baulch and Perry (2014); Australian Ant arctic Division in Baulch and Perry (2014); Lusher et al. (2018)

34	Delphinidae	Peponocephala electra	melon-headed whale	-	X	-	-	X	Dayaratne and Joseph (1993)
35	Delphinidae	Pseudorca crassidens	false killer whale	X	X	-	X	X	Barros et al. (1990); Dayaratne and Joseph (1993)
36	Delphinidae	Sotalia fluviatilis	tucuxi	X	-	-	X	X	Geise and Gomes (1992); Laist (1997)
37	Delphinidae	Sotalia guianensis	Guiana dolphin	X	X	X	X	X	Di Beneditto and Awabdi (2014); Geise and Gomes (1992); da Rocha and Andriolo (2005); Di Beneditto and Ramos (2014); Baulch and Perry (2014); Di Benedetto and Oliveira (2019)
38	Delphinidae	Sousa chinensis	Indo-Pacific humpbacked dolphin	X	X	X	-	X	Razafindrakoto et al. (2008); Ceccarelli (2009); Zhu et al. (2019)
39	Delphinidae	Sousa plumbea	Indian Ocean humpback dolphin	-	-	-	-	-	
40	Delphinidae	Sousa sahulensis	Australian humpback dolphin	-	-	-	-	-	
41	Delphinidae	Sousa teuszii	Atlantic humpback dolphin	-	X	-	-	X	Weir et al. (2011)
42	Delphinidae	Stenella attenuata	pantropical spotted dolphin	X	X	-	-	X	Dayaratne and Joseph (1993); Baird and Hooker (2000); Romano et al. (2002)
43	Delphinidae	Stenella clymene	clymene dolphin	-	X	-	-	X	Zerbini and Kotas (1998); da Rocha and Andriolo (2005)
44	Delphinidae	Stenella	striped dolphin	X	X	X	-	X	Walker and Coe (1990);

		coeruleoalba							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); Simmonds (2012); Lusher et al. (2018); Nelms et al. (2019), Novillo et al. (2020)
45	Delphinidae	Stenella frontalis	Atlantic spotted dolphin	X	X	-	-	X	Zerbini and Kotas (1998); Ofori-Danson et al. (2003); Arbelo and Fernandez in Baulch and Perry 2014
46	Delphinidae	Stenella longirostris	spinner dolphin	-	X	-	-	X	Dayaratne and Joseph (1993); Zerbini and Kotas (1998); Romano et al. (2002); Razafindrakoto et al. (2008)
47	Delphinidae	Steno bredanensis	rough-toothed dolphin	X	X	-	X	X	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); Simmonds (2012);
48	Delphinidae	Tursiops aduncus	Indo-Pacific bottlenose dolphin	-	X	-	-	X	Chatto and Warneke (2000); Bossley (2005); Ceccarelli (2009)
49	Delphinidae	Tursiops truncatus	Common bottlenose dolphin	X	X	X	X	X	Barros et al. (1990); Walker and Coe (1990); Schwartz et al. (1991); Mann et al. (1995);

									Gorzelany (1998); Zerbini andKotas (1998);McFee andHopkins-Murphy (2002); Ofori-Danson et al. (2003); da Rocha and Andriolo (2005); McFee et al. (2006); Razafindrakoto et al. (2008); Ceccarelli (2009); Gomercic 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);Quintana-Rizzo (2014); Simmonds (2012); Nelms et al. (2019)
50	Eschrichtiidae	Eschrichtius robustus	gray whale	X	X	-	-	X	Mate (1984); Hare andMead (1987); Heyning and Lewis (1990); Bradford et al. (2009); Cascadia Research (2010); Barboza (2012); ; Laist (1997);
51	Iniidae	Inia geoffrensis	boto	-	X	-	-	X	da Rocha and Andriolo (2005), Iriarte and Marmontel (2013)
52	Kogiidae	Kogia breviceps	pygmy sperm whale	X	X	X	X	X	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); Simmonds (2012); Nelms et al. 2019, Brentano & Petry 2020
53	Kogiidae	Kogia sima	dwarf sperm whale	X	X	-	-	X	Barros et al. (1990); Walker and Coe (1990); Zerbini and Kotas (1998); Baulch and Perry (2014); Simmonds (2012);
54	Lipotidae	Lipotes vexillifer	baiji	-	-	-	-	-	
55	Monodontidae	Delphinapterus leucas	white whale	X	-	X	-	-	Moore et al., (2020)
56	Monodontidae	Monodon monoceros	narwhal	-	-	-	-	-	
57	Neobalaenidae	Caperea marginata	pygmy right whale	X	X	-	-	X	Ceccarelli (2009); Australian antarctic division in Baulch and Perry (2014); Glenn Atkinson, DPIW Tasmania, pers. Comm in Ceccarelli (2009)
58	Phocoenidae	Neophocaena asiaeorientalis	Narrow-ridged finless porpoise	X	-	X	-	-	Xiong et al. 2018
59	Phocoenidae	Neophocaena phocaenoides	finless porpoise	X	X	-	X	X	Baird and Hooker (2000); Hong

									et al., (2013)
60	Phocoenidae	Phocoena dioptrica	spectacled porpoise	-	X	-	-	X	Goodall and Cameron (1980)
61	Phocoenidae	Phocoena phocoena	harbour porpoise	X	X	X	X	X	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); Good et al. (2010); Deaville and Jepson (2011); Northwest Straits Initiative Project (2012); Baulch and Perry (2014); Simmonds (2012); Lusher et al. (2018); Nelms et al. (2019)
62	Phocoenidae	Phocoena sinus	vaquita	-	X	-	-	X	D'agrosa et al. (2000)
63	Phocoenidae	Phocoena spinipinnis	Burmeister's porpoise	X	X	-	-	X	Goodall and Cameron (1980); Reyes and Van Waerebeek (1991); Torres et al. (1992); Denuncio in Baulch and Perry (2014)
64	Phocoenidae	Phocoenoides dalli	Dall's porpoise	X	X	-	X	X	Degange and Newby (1980); Jones and Ferrero (1985); Walker and Coe (1990); Barlow et al. (1997); Artukhin et al. (2010); Simmonds (2012);
65	Physeteridae	Physeter macrocephalus	sperm whale	X	X	X	X	X	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 (2009); 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); Mate (1985); Simmonds (2012);
66	Platanistidae	Platanista gangetica gangetica	South Asian river dolphin	-	-	-	-	-	
67	Pontoporiidae	Pontoporia blainvillei	franciscana	X	-	X	X	X	Pinedo (1982); Bassoi (1997); Bastida et al. (2000); Denuncio et al. (2011); Di Beneditto and Awabdi (2014); Di Beneditto and Ramos (2014); di Beneditto & Oliveira 2019

68	Ziphiidae	Berardius arnuxii	Arnoux's beaked whale	-	-	-	-	-	
69	Ziphiidae	Berardius bairdii	Baird's beaked whale	X	-	-	X	X	Walker and Coe (1990); Smithsonian Research Institute in Baulch and Perry (2014)
70	Ziphiidae	Hyperoodon ampullatus	northern bottlenose whale	X	X	-	X	X	Baird and Hooker (2000); Gowans et al. (2000); Deaville and Jepson (2011); Baulch and Perry (2014);
71	Ziphiidae	Hyperoodon planifrons	southern bottlenose whale	-	-	-	-	-	
72	Ziphiidae	Indopacetus pacificus	Longman's beaked whale	X	X	-	-	X	Dayaratne and Joseph (1993); Yamada et al. (2012b); Baulch and Perry (2014)
73	Ziphiidae	Mesoplodon bidens	Sowerby's beaked whale	X	-	-	X	X	Deaville and Jepson (2011); Baulch and Perry (2014); Lusher et al. (2018)
74	Ziphiidae	Mesoplodon bowdoini	Andrews' beaked whale	-	-	-	-	-	
75	Ziphiidae	Mesoplodon carlhubbsi	Hubbs' beaked whale	X	X	-	-	X	Barlow et al. (1997); Yamada et al. (2012a); Baulch and Perry (2014);
76	Ziphiidae	Mesoplodon densirostris	Blainville's beaked whale	X	-	-	X	X	Walker and Coe (1990); Secchi and Zarzur (1999); Byrd et al. (2014); Smithsonian Research Institute in Baulch and Perry (2014); IWC (2013); Simmonds (2012);
77	Ziphiidae	Mesoplodon	Gervais' beaked	X	-	-	-	X	Walker and Coe (1990);

		europaeus	whale						Fernandez et al. (2009); Byrd et al. (2014); Arbelo and Fernandez in Baulch and Perry (2014); Smithsonian Research Institute in Baulch and Perry (2014); Simmonds (2012);
78	Ziphiidae	Mesoplodon ginkgodens	ginkgo-toothed beaked whale	X	-	-	-	-	International Whaling Commission (2012); Baulch and Perry (2014)
79	Ziphiidae	Mesoplodon grayi	Gray's beaked whale	X	X	-	-	X	Donoghue (1994); Mayorga in Baulch and Perry (2014)
80	Ziphiidae	Mesoplodon hectori	Hector's beaked whale	-	-	-	-	-	
81	Ziphiidae	Mesoplodon layardii	strap-toothed whale	-	-	-	-	-	
82	Ziphiidae	Mesoplodon mirus	True's beaked whale	X	-	X	-	X	Smithsonian Research Institute in Baulch and Perry (2014); Lusher et al. (2015); Lusher et al. (2018)
83	Ziphiidae	Mesoplodon perrini	Perrin's beaked whale	-	-	-	-	-	
84	Ziphiidae	Mesoplodon peruvianus	pygmy beaked whale	-	X	-	-	X	Reyes and Van Waerebeek (1991)
85	Ziphiidae	Mesoplodon stejnegeri	Stejneger's beaked whale	X	X	-	X	X	Barlow et al. (1997); Walker and Hanson (1999); Yamada et al. (2012a)
86	Ziphiidae	Mesoplodon traversii	spade-toothed whale	-	-	-	-	-	
87	Ziphiidae	Tasmacetus shepherdi	Shepherd's beaked whale	X	-	-	X	-	Goodall et al. (2008); Smithsonian Research Institute

									in Baulch and Perry (2014)
88	Ziphiidae	Ziphius cavirostris	Cuvier's beaked whale	X	X	X	-	X	Foster and Hare (1990);Walker and Coe (1990); Barlow et al. (1997); Fertl et al. (1997); Poncelet et al. (2000); Santos et al. (2001); Gomercic 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); IWC (2013); Poeta et al., (2018); Simmonds (2012); Lusher et al. (2018)
89	Ziphiidae	Berardius minimus Yamada	Sato’s beaked whale	-	-	-	-	-	
90	Ziphiidae	Mesoplodon hotaula Deraniyagala	Deraniyagala’s beaked whale	X	-	-	-	X	Abreo et al. (2016)