OSPAR COMMISSION

Impacts of marine litter on biota in the OSPAR Maritime Area

A review of previous and current studies

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OSPAR Convention

The Convention for the Protection of the Marine Environment of the North-East Atlantic (the "OSPAR Convention") was opened for signature at the Ministerial Meeting of the former Oslo and Paris Commissions in Paris on 22 September 1992. The Convention entered into force on 25 March 1998. The Contracting Parties are Belgium, Denmark, the European Union, Finland, France, Germany, Iceland, Ireland, Luxembourg, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom.

Convention OSPAR

La Convention pour la protection du milieu marin de l´Atlantique du Nord-Est, dite Convention OSPAR, a été ouverte à la signature à la réunion ministérielle des anciennes Commissions d´Oslo et de Paris, à Paris le 22 septembre 1992. La Convention est entrée en vigueur le 25 mars 1998. Les Parties contractantes sont l´Allemagne, la Belgique, le Danemark, l´Espagne, la Finlande, la France, l´Irlande, l´Islande, le Luxembourg, la Norvège, les Pays-Bas, le Portugal, le Royaume- Uni de Grande Bretagne et d´Irlande du Nord, la Suède, la Suisse et l´Union européenne

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Executive Summary

Marine litter has become a major stressor of wildlife adding another severe impact to existing human pressures on the marine environment. Therefore, additional measures to combat litter pollution are necessary, which rely on monitoring and assessment programmes. This review collects available information from more than 147 studies on ingestion, entanglement and other impacts of marine litter on biota and habitats, for the geographical region of the OSPAR Convention. It gives an overview about available knowledge on harm to various species in the area of interest (the North-East-Atlantic) from different taxonomic classes. The authors intended to collate as much available literature as possible on the OSPAR region and to reflect on the most relevant studies until mid-2021.

Until present, two impact indicators on ingestion of litter by seabirds and turtles have been adopted with long-term goals (Threshold Values) being in place and under development. The rather small number of standardised protocols applied so far contrasts with numerous case studies on impacts of marine litter. The methods to detect and quantify the impacts of marine litter on biota are highly diverse, and partly, they lack reproducibility. Recently, a few new standardised monitoring and assessment protocols of ingestion and entanglement have been developed. Together with the studies available, they provide inspiration for new common OSPAR indicators and future agreed action. Furthermore, the monitoring guidance for marine litter of the EU MSFD Technical Group on Marine Litter (TG ML) is currently under revision offering a chance to agree on further harmonised/comparable monitoring approaches to be applied in European marine waters and elsewhere.

Increased efforts are needed to elucidate the bioavailability and effects of plastic on marine biota. In a next step, dose-response-relationships have to be established feeding into the determination of further threshold values. Available data for different species should be evaluated to assess the risk of ingestion of and entanglement in plastic marine litter by integrating inter-specific factors such as plastic exposure rates and life history traits.

Récapitulatif

Les déchets marins sont devenus un facteur de stress majeur pour la faune et la flore, ajoutant un autre impact sévère aux pressions humaines existantes sur l'environnement marin. C'est pourquoi des mesures supplémentaires sont nécessaires pour lutter contre la pollution par les déchets, qui reposent sur des programmes de surveillance et d'évaluation. Cette revue rassemble les informations disponibles de plus de 147 études sur l'ingestion, l'enchevêtrement et autres impacts des déchets marins sur le biote et les habitats, pour la région géographique de la Convention OSPAR. Elle donne une vue d'ensemble des connaissances disponibles sur les dommages causés à diverses espèces de la zone d'intérêt (l'Atlantique Nord-Est) appartenant à différentes classes taxonomiques. Les auteurs avaient l'intention de rassembler autant de littérature disponible que possible sur la région OSPAR et de réfléchir aux études les plus pertinentes jusqu'à la mi-2021.

Jusqu'à présent, deux indicateurs d'impact sur l'ingestion de déchets par les oiseaux de mer et les tortues ont été adoptés, avec des objectifs à long terme (valeurs seuils) en place et en cours de développement. Le nombre relativement faible de protocoles normalisés appliqués jusqu'à présent contraste avec les nombreuses études de cas sur les impacts des déchets marins. Les méthodes de détection et de quantification des impacts des déchets marins sur le biote sont très diverses et manquent en partie de reproductibilité. Récemment, quelques nouveaux protocoles standardisés de surveillance et d'évaluation de l'ingestion et de l'enchevêtrement ont été développés. Avec les études disponibles, ils constituent une source d'inspiration pour les nouveaux indicateurs communs OSPAR et les futures actions convenues. En outre, le guide de surveillance des déchets marins du groupe technique sur les déchets marins (TG ML)

de la Directive cadre stratégie pour le milieu marin de l'UE, est actuellement en cours de révision, ce qui offre la possibilité de convenir de nouvelles approches de surveillance harmonisées/comparables à appliquer dans les eaux marines européennes et ailleurs.

Des efforts accrus sont nécessaires pour élucider la biodisponibilité et les effets du plastique sur le biote marin. Dans une prochaine étape, il faudra établir des relations dose-réponse qui permettront de déterminer d'autres valeurs seuils. Les données disponibles pour différentes espèces doivent être évaluées afin de déterminer le risque d'ingestion et d'enchevêtrement dans des déchets marins en plastique en intégrant des facteurs interspécifiques tels que les taux d'exposition au plastique et les caractéristiques du cycle de vie.

1. Introduction

During the last decades, marine litter has become a major stressor of marine wildlife and ecosystems (Villarrubia-Gómez et al., 2018) adding another severe impact to existing human pressures on the marine environment such as global warming, ocean acidification, overfishing, bycatch, underwater noise and others. The numbers of animals affected from negative interactions with marine litter and the associated suffering that affects animal welfare in combination with the extent of encounters which in some represent a substantial proportion of a population, clearly show, that reductions in further input and of existing amounts of marine litter are urgently needed (Werner et al. 2016).

Marine litter mainly consists of plastics, which are very persistent and degrade slowly in time spans of centuries. As a consequence, the majority of reported encounters of individual marine organisms were with plastic litter (Werner et al., 2016). Breakdown of larger plastic particles leads to secondary generation of meso-, micro- and nanoplastics, the latter of which are discussed to pass tissues of intestines and stomachs or even cell membranes, once ingested by motile organisms (Anderson et al., 2016). In addition there are two ways in which plastics can act as a vector facilitating the transport of chemicals to organisms. Plastics contain and release potentially harmful chemicals that were incorporated during manufacture (so-called additives such as plasticisers, flame retardants and antimicrobials) and plastics are known to sorb persistent organic pollutants from water in a matter of days, concentrations on the surface of plastics can become order of magnitudes greater (Werner et al. 2016).

To summarize, known adverse effects on marine animals comprise:

- Ingestion of plastic particles via filter feeding, suspension feeding, and consumption of prey exposed to microplastics, or direct ingestion mistaken for food (Derraik, 2002). In turn, this might cause blockage or damage of the digestive tract, reduced nutritional value of food, and increased exposure to plastic-associated chemicals and particle toxicity (Cole et al., 2011, van Franeker et al., 2011). However, Koelmans et al. (2017) discussed that risk assessment should address all compounds, those absorbed by the plastic and those in ambient water and food, as well.
- Entanglement especially with litter items of a certain shape eligible to cause it, such as loops or tangled string shaped items, packaging bands, netlike structures, ropes, cable ties, plastic bags and other kinds of filamentous litter, leading to immobility or direct injury, and subsequently to death (Werner et al., 2016; Gregory, 2009). This review deals with entanglement in marine litter including so-called ghost nets, and not with entanglement through active fishing gear.
- Smothering of benthic habitats and generation of artificial hardgrounds, which alters the structures of benthic communities and leads to loss of biodiversity (Gregory, 2009; Werner et al., 2016; Galgani et al., 2018).
- Furthermore, floating litter acts as a vector for transport of biota including microbes and thereby changes or modifies assemblages of species (Derraik, 2002; Gregory, 2009, Werner et al., 2016).

Wilcox et al. (2015) performed a spatial risk analysis using predicted debris distributions and ranges for 186 seabird species to model debris exposure. The model was fitted using literature data and applied to predict risk across seabird species at the global scale. These authors predict that plastics ingestion will increase in seabirds from 29 % nowadays to 99 % of all species by 2050. Wilcox et al. (2015) also state that effective waste management could significantly reduce ingestion. However, Diepens and Koelmans (2018) provided evidence for diverse patterns of biomagnification of additives and pollutants sorbed to ingested plastics.

In Europe, several regional and EU-wide treaties have been agreed to combat further increases in amounts of marine litter and to significantly reduce abundances of litter, especially where it represents harm to marine wildlife. One of these treaties is the Oslo-Paris-Convention (OSPAR, 1992) for the North-East Atlantic region including the North Sea. In turn, part of the OSPAR region is part of the European Union, which inaugurated the Marine Strategy Framework Directive in 2008 ((MSFD), EU, 2008, 2010). According to descriptor 10 ‘Marine Litter’ of the MSFD, “*the properties and quantities of marine litter should not cause harm to the coastal and marine environment*” which is in line with the OSPAR objective, as laid down in the North-East Atlantic Environment Strategy 2030 to “*prevent inputs of and significantly reduce marine litter, including microplastics, in the marine environment to reach levels that do not cause adverse effects to the marine and coastal environment with the ultimate aim of eliminating inputs litter.”* To fulfil this aim, measures need to be further implemented and new ones initiated to prevent the further input of litter into and reduce existing amounts of litter in the marine environment. One way to assess the success of these measures is by means of monitoring and assessment programmes of relevant indicators of marine litter.

In the OSPAR region, the Regional Action Plan for Marine Litter (RAP ML) refers to monitoring and assessment programmes including agreed common indicators of marine litter. Until present, OSPAR assesses beach litter, seabed litter, as well as plastic particles in fulmar stomachs and turtle digestive tracts. OSPAR is also working on the development of new indicators, such as ingestion of plastic particles by fish and microplastics in sediments. However, until present, no fish species eligible as common indicator has been found, because plastic does not accumulate in the digestive tract of most fish species (Foekema et al., 2013). Whereas the fulmar indicator is related to the North Sea and most of the North-East Atlantic, the turtle indicator, proposed first by France within RAP action 44 and developed with the support of INDICIT European project, is related to the Bay of Biscay, Iberian Coast and Macaronesia (OSPAR regions IV and V).

During the last couple of years, the number of species evidenced to be affected by marine litter has significantly increased (Kühn et al., 2015). Kühn and van Franeker (2020) counted numbers of entanglement and ingestion records for all species of marine megafauna in a total of 747 studies. Accordingly, marine litter affected 914 species through entanglement and/or ingestion. Ingestion was documented for 701 species, entanglement was recorded for 354 species. The total number of species encountered either entangled in or with ingested litter has increased from 267 in 1997 (Laist, 1997) and 557 in 2015 (Kühn et al., 2015) to 914 species in 2020 (Kühn and van Franeker, 2020). According to the online database “Litterbase” of the Alfred-Wegener Institute, even 2,788 marine species have encountered plastics to date (litterbase.awi.de). This increase correlates with increasing numbers of studies on harm of marine litter.

However, the large number of case studies carried out so far corresponds to a considerable lack of standardized monitoring protocols (Fossi et al., 2017; Claro et al., 2019). Until present, the monitoring protocols for the ingestion of plastic particles in Northern Fulmars (van Franeker et al., 2011) and for the ingestion of plastic particles by Loggerhead Turtles (Galgani et al., 2013; Mattidi et al., 2017; 2019) are the only agreed methods to quantify effects of ingestion of plastic particles. Fulmars found beached or accidentally killed on the coasts of the Greater North Sea are further investigated in laboratory. Birds are dissected, the extracted stomachs are rinsed and the stomach contents are examined. Non-food particles are counted, weighed and classified according to shape, colour and origin (user plastics and industrial plastics). The Threshold Value (former EcoQO) based on this monitoring protocol relies on five-year running averages of the mass of plastic in each of the different litter categories. OSPAR has a long-term of less than 10% of fulmars exceeding a level of 0.1 g of plastic in their stomachs. Building on protocol published by the EU MSFD Technical Group on Marine Litter (TG ML) in 2013 (Matiddi et al., 2011; Galgani et al., 2013), a protocol and a video tutorial were developed for measuring the ingestion of plastic particles by loggerhead turtles *C. caretta* (Matiddi et al., 2017; 2019), applicable to both the Mediterranean and part of the OSPAR region. These authors and INDICIT (2019) proposed two indicator scenarios with associated approaches to set threshold values, which are currently further developed within INDICIT II in collaboration with the TG ML.

For entanglement of seabirds in breeding colonies in the North Sea, according to a proposal on an experimental basis by the TG ML (Galgani et al. 2013), a new protocol has been developed by the University of Kiel (Germany), and applied to the breeding colonies on the rocks of Helgoland (Dürselen et al., 2016). This protocol relies on observations of entanglement victims and marine litter as nesting material. For the categorization of litter types, the marine litter master list from the Monitoring Guidance report of the EU Technical Group on Marine Litter (Galgani et al., 2013) is used. To classify the amount of plastic per nest a four-step system based on the number of items is employed. Additionally, the colour of the different litter types is identified in each nest to investigate if e.g. Northern Gannets preferred certain colours.

Johnson (2008) presented a framework for biodiversity monitoring and assessment for OSPAR. He requires that biological indicators should be:

- scientifically sound,
- easily understood,
- variable over time,
- sensitive to the change that they are intended to measure,
- measurable and capable of being updated regularly,
- and based on readily available data and information.

He states that relevant marine-litter indicators should be typical of its source, relatively common in the survey area, easy to identify, easy to find, and easy to count. It should be differentiated between acute and chronic effects on biota, and the spatial extension should be documented. Consideration of the costs of monitoring is desirable, as well.

Overall and as elsewhere, in the OSPAR region, the number of standardised monitoring procedures of impacts of marine litter on biota is small. In contrary, there are numerous case studies on encounters of biota with marine litter (Gall and Thompson, 2015). Many direct and indirect consequences have been recorded, with the potential for sublethal effects. In the recent past, the percentage of encounters of biota with marine litter has increased for all taxonomic groups including endangered species. The Leatherback Turtle (all OSPAR regions) and the Loggerhead Turtle (Region IV and V) are listed as OSPAR's Threatened and Declining Species. Data are still limited, but nevertheless show, that both species are still in decline and are significantly impacted by by-catch and marine litter. Evidence for ecosystem or population effects is available but limited, which is likely due to the fact that such effects are difficult to quantify especially in combination with other anthropogenic pressures.

This review intends to collate information on impacts of marine litter on biota, which is given for the OSPAR region. The focus was on field studies, but laboratory and mesocosm studies on species occurring in the OSPAR region were also included. Finally, the most important conclusions and recommendations for future actions are extracted from the screened scientific literature.

2. Ingestion

In a literature review, Kühn & Franeker (2020) identified 701 marine species, which have been reported to ingest marine litter. The TG ML (Galgani et al., 2013) discussed and proposed standardized protocols, approaches and metrics for reporting litter ingestion in seabirds, turtles and fish. In case of the Northern Fulmar the TG ML and Provencher et al. (2016) recommend documenting user plastics and industrial plastics, as well as abundance, size class, colour, and weight. In addition, recommendations of standardized metrics for reporting ingested plastic are provided, to harmonize the data. For reporting, the mean, standard deviation, median, and range of all plastic metrics (number of pieces, total mass of litter, pieces by litter category) should be given. Moreover, absence of plastic items should be documented. While Vandermeersch et al. (2015) stated that there is no further need to improve existing microplastic analyses, Dehaut et al. (2016) recommended digestion with KOH as the most reliable method to prepare sample of dead marine biota for analyses of ingested plastics. In contrary, Claessens et al. (2013) developed a digestion protocol with nitric acid, hydrogen peroxide and sodium hydroxide.

3.1 Marine mammals

Some marine mammal species are more sensitive to adverse effects of marine litter than others (Haelters et al., 2018). According to these authors, seals do not seem to be negatively affected by plastic in their stomachs, while entanglement of whales in ropes or floating fishing nets could be a growing problem in the southern North Sea.

Unger et al. (2016) reported large amounts of marine litter in stranded sperm whales along the coasts of the North Sea between January and February 2016. The gastrointestinal tracts of 22 of the carcasses were investigated. Remains of plastic and other marine litter were found in nine of the 22 individuals. However, none of the items was responsible for the death of the animals, but these findings highlight the risk of marine litter for large predators (Unger et al, 2016).

After a sperm whale mortality event in the North Sea, IJsseldijk et al. (2018) performed necropsies of 30 carcasses. In nine of the sperm whales, diverse marine litter was found. However, ingestion of litter was likely not the primary cause of the stranding event.

During 2015, 115 cetacean stranding comprising 13 species were examined by CSIP (2015) using standardised protocols. The most common causes of mortality of the 53 harbour porpoises examined were entanglement in fishing gear (by-catch, n=10), infectious disease (n=10, primarily pneumonias due to parasitic infestations or diseases of the gastrointestinal tracts), starvation (n=9, including seven neonates) and attack by one or more bottlenose dolphins (n=8). Noteworthy, ingestion of plastics could not be identified as primary cause of death in any case. In a stranded sperm whale, large piece of plastic sheeting amongst other marine debris was found in parts of it stomach, but again, the ingested items did not cause death though.

In harbour seals stranded at the Dutch North Sea coast, the incidence of plastic was 11% for stomachs, 1% for intestines, and 0% for scats (Bravo-Rebolledo et al., 2013). Younger animals, up to three years of age, were most affected. These authors could not recommend seals as indicator for monitoring spatial and temporal patterns of marine litter.

In a review study, Baulch and Perry (2014) found that ingestion of marine litter has been documented in 48 (56% of) cetacean species, with rates of ingestion up to 31% in some populations. Mortality rates of 0–22% of stranded animals due to marine litter were documented, suggesting that marine litter could be a threat to some cetacean populations.

Nelms (2019) and Nelms et al. (2018) investigated trophic transfer of microplastic ingestion in marine top predators analysing faeces from captive grey seals and the wild-caught fish they were fed upon. The extent to which wild marine mammals ingest microplastics was examined by analyses of digestive tracts of 50 marine mammals from ten species that stranded around the British coast. Microplastic was found to be ubiquitous within the digestive tracts of wild marine mammals, but the overall low abundance indicated substantial egestion rates. Nonetheless, Nelms et al. (2018) discuss trophic transfer of plastics as an indirect, but potentially major pathway of microplastic ingestion for predators.

Nelms et al. (2019) analysed entire digestive tracts of 50 individuals from ten marine mammal species stranded at the coast of UK. Microplastics were detected in every individual examined. Microplastic numbers per animal were as low as a mean of 5.5 items, suggesting that plastics are transitory. Stomachs contained a greater number of microplastics than intestines. The majority of particles were fibres (84%) while the remaining 16% was fragments. Animals died of infectious diseases had a slightly higher number of particles than those that died of trauma and other drivers of mortality.

Lusher et al. (2015) developed a method for identifying microplastics ingested by marine megafauna. Microplastics were identified throughout the digestive tract of a whale that was examined for the presence of microplastics. It was not possible to ascertain whether prey were the source of microplastics.

Besseling et al. (2015) detected plastics in the intestines of a baleen whale (*Megaptera novaeangliae*). Several polymer types were found in varying particle shapes and sizes. This diversity was interpreted as representative of marine plastics and the unselective way of ingestion.

In Ireland, bycaught and stranded cetaceans were analysed for both, ingestion of plastics and entanglement, by Lusher et al. (2018). Two hundred and forty-one of the stranded cetaceans presented signs of possible entanglement or interactions with fisheries. Necropsies on a total of 528 stranded and bycaught individuals revealed that 45 (8.5%) had marine debris in their digestive tracts. Forty percent of the ingested debris were fisheries-related items. The occurrence of plastic ingestion was highest for deep-diving species, but this fact could not be attributed to habitat characteristics.

3.2 Birds

While large cetaceans mainly ingest macroplastic or even megaplastic items, the size range of plastics ingested by birds ranges from microplastics to macroplastics, and mainly peaks in the mesoplastic fraction (5 mm – 25 mm). Northern Fulmars are amongst others a common indicator of marine litter. In the OSPAR region, Fulmars nearly all ingest plastics on a regular basis. Approximately 95% of all individuals have plastics in their stomachs. Plastics are likely processed in the stomach and passed on to the gut rather quickly. Loss rates are estimated to approximately 75% per month on mass basis (Van Franeker et al., 2011). Therefore, physical sublethal effects from the accumulation of litter in gizzards, and chemical sublethal effects from a constant grinding of plastic litter, probably take place in almost every adult Fulmar. During a mass mortality of Fulmars in the North Sea in 2004, several indicators suggested a background of hormonal disturbance. These effects could well be related to persistent high levels of chemicals, some of which may have been leached from plastics. These chemicals are supposed to circulate in Fulmar bodies, thus interacting with prolonged food shortage (Van Franeker et al., 2011). After a long period of population growth, the trend apparently has stopped or reversed since the late 1990s. At present, reproductive success is often poor. Cumulative stressors are interacting in these developments, leading to reduced adult survival and reduced reproductive output as a consequence of plastic ingestion. In turn, this is supposed to have adverse effects on a population level. Kühn and van Franeker (2012) showed that plastic pollution levels in the North Atlantic tend to decrease towards higher latitudes. Therefore, levels of pollution seemingly are linked to regions of intense human coastal and marine activities.

In an early long-term study, Harris and Wanless (1994) analysed elastics and artificial polymers in Puffins in Britain. Between 1969 and 1992, artifacts were found in 42 (13.3%) of the stomachs from 315 North Sea birds but in none of the stomachs from 43 Atlantic coast birds. The abundances of ingested artifacts per individual were generally low. A gradual decrease in the occurrence of ingested artifatcs was found, but this trend was not significant.

Another long-term study by Ferns and Mudge (2000) focussed on the ingestion of litter by gulls in sewage outfalls in southern Wales and England. However, this study was done to relate the abundance of gulls to organic litter recycling rather than to provide information on ingestions of plastic litter.

In correspondence to their earlier manuscript on best practices for monitoring ingestion by marine megafauna, Provencher et al. (2018) developed a monitoring concept for ingestion by seabirds, which is nearly identical to the former concept. Again, the EcoQO Northern Fulmar was used as example how to monitor and document litter ingestion.

A study on Cory's Shearwaters revealed that 83% of birds were affected by ingestion of plastic, with on average 8.0 plastic pieces per bird (Rodríguez et al., 2012). The average plastic weight per bird was 2.97 ± 3.97 mg, a low value compared with other petrel species. There were no significant relationships between plastic loads and body condition or body size.

Bond and Lavers (2013) studied the effectiveness of emetics as indicator of plastic ingestion by Leach's Storm-petrels. Almost half the storm-petrels sampled had ingested plastic, ranging from 0 to 17 pieces, and weighing 0.2–16.9 mg. The authors state that many adult seabirds egest plastic to their offspring. Thus, storm-petrel chicks likely experience a higher plastic burden than their parents.

Acampora et al. (2016) performed surveys of beached seabirds in Ireland and analysed their intestinal tracts for plastics. Of 121 collected individuals, 27.3% comprising 12 different species were found to ingest litter, mainly plastics. The mean mass of ingested litter amounted to 0.141 g. Among 14 sampled Northern Fulmars, 13 (93%) had ingested plastic litter, all of them over the 0.1 g threshold used in OSPAR and MSFD policy target definitions.

Acampora et al. (2017a) monitored plastic litter in pellets from Great Cormorant (*Phalacrocorax carbo*) in Ireland. Plastic prevalence was consistently 3.2%. Opportunistic sampling of regurgitates of seabirds was conducted by Acampora et al. (2017b) again at the coast of Ireland. Regurgitates were collected from nestlings of Black-legged Kittiwake (*Rissa tridactyla*), Northern Fulmar (*Fulmarus glacialis*) and Great Cormorant (*Phalacrocorax carbo*). Plastic was found in all species, with the highest occurrence in Northern Fulmar chicks (28.6%), followed by Black-legged Kittiwakes (7.9%) and Great Cormorants (7.1%).

The latter specie was also subject of a monitoring of pellets performed by Álvarez et al. (2017) at the coast of Spain. Microplastics were found in 63% of pellets, suggesting severe plastic pollution in the study area. Nylon fibers were most abundant, followed by polyester. The presence of microplastics was linked to pellets containing remains of benthic fish, evidencing selective feeding of plastics mistaken for prey.

In a case study at the coast of Portugal, plastic in stomach contents of stranded aquatic birds was examined (Basto et al., 2019). Out of the 288 individuals, 12.9% ingested plastics. Six of 16 species ingested plastics. Lesser Black-backed Gulls (18.7%) had the highest incidence, while Northern Gannets (4.8%) had the lowest. User plastic was the most common plastic type ingested, whereas microplastic was the dominant size fraction.

An additional baseline study by Nicastro et al. (2018) at the Portuguese coast exhibited that 22.5% of all individuals had ingested plastic debris. Plastic particles were found in *Ciconia ciconia*, *Larus fuscus* and *L. michahellis*, where *Ciconia ciconia* was the most affected specie by number of items and total mass of plastic debris.

Franco et al. (2019) performed a screening of plastic ingestion by 15 seabird species in the Bay of Biscay. From 159 individuals, 26 had ingested plastics corresponding to 16% of the total. The occurrence of plastic ingestion ranged from 0% (Razorbill) to 100% (species of the family Procellariidae). According to the occurrence of plastic ingestion, species abundances and stranding occurrence, Common Guillemots and Atlantic Puffins were envisaged as sentinel species.

Procellariiformes were found to be the group with the highest frequency of marine litter ingestion by Roman et al. (2019). Data on death from 1733 seabirds of 51 species were analysed by these authors. There was a significant dose-response relationship. A 20.4% chance of lifetime mortality from ingesting a single litter item increased to 100% after consuming 93 items. Obstruction of the gastro-intestinal tract was the major reason of mortality. Balloons revealed the highest risk with 32 times higher probability of death than ingesting hard plastic. The cause of death of 1265 (73%) of the seabirds was not debris ingestion (KND). A statistical model on the relationship between the number of litter items in the gut and the cause of death included significant effects for species and species weight. This model can be used to simulate population impacts on Procellariiform seabirds, because of a low level of uncertainty derived from Monte Carlo simulations.

A study by Amelineau et al. (2016) in remote Arctic regions on Greenland investigated both, microplastics in zooplankton and in Little Auks (*Alle alle*). All birds had eaten plastic filaments. Biomagnification was observed, as Little Auks collected high levels of microplastics compared to background levels with 9.99 and 8.99 pieces per chick meal. Little Auks preferred light coloured microplastics, rather than darker ones, which hints at active contamination mistaking microplastics for natural prey.

Tanaka et al. (2019) not only provided abundances of ingested plastics in seabirds, namely Northern Fulmars from the Faroe Islands, and Laysan Albatross and Blackfooted Albatross from Mukojima Island, but also highlighted the role of ingested plastics as carriers of additives, such as UV stabilizers, brominated flame retardants, and styrene oligomers.

Lourenço et al. (2017) spatially analysed plastic ingestion by seabirds and invertebrates in three wetland sites located in the Eastern Atlantic, one of which belongs to the OSPAR region (Portugal). The scope of the study not only comprised the intertidal food web, but also factors that could explain the distribution of microplastics. Microfibers were present in a large portion of sediments (91%), macroinvertebrates (60%) and shorebird faeces (49%). Microfiber concentrations in faeces of shorebirds with different foraging behaviour correlated with the composition of fibres collected from invertebrates hinting at microfiber transfer along intertidal food webs.

In a most recent study, Thompson et al. (2020) investigated the prevalence and source of plastic incorporated into nests on a small Scottish island. Plastic was found in 24.5% to 80% of all nests. Moreover, pellets of regurgitated material were analysed. Applying and evaluating digital photographs of herring gull nests, 35.6% of all nests were found partly to consist of plastic items, the majority of which was sheet plastic and off-white/clear in colour. Plastic items in nests most likely originated from consumer waste rather than from accidentally ingested litter that is then regurgitated at the nest site.

3.3 Reptiles

The digestion of litter items by turtles considerably differs from that of the seabird species. Passage through the stomach seems rapid. Most litter has been found not in the stomachs but in the intestines. Camedda et al. (2014) report that in studies of necropsied specimens, 70% of the litter was found in the intestines, whereas only 30% were detected in the stomach. This was confirmed by Nicolau et al. (2016) and Matiddi et al. (2017), suggesting potential excretion of plastic items. In turn, this provides evidence for substantial passage of plastics through turtles. However, long residence times in the intestinal tract cannot be excluded, because in rehabilitation centres, defecation of plastic items has been observed two weeks to a month after arrival in the centre (Mascarenhas et al., 2004; Stamper et al., 2009). Litter items can become stuck in intestines, causing damage different from that observed in seabirds. Balloon fragments were experimentally shown to conglomerate to balls in the intestines of freshwater turtles (Irwin, 2012), probably impeding the passage of food.

An early study assessed the anthropogenic reasons for mortality of turtles in the Bay of Biscay (Duguy et al., 1998). Four species were investigated: Leatherback (*Dermochelys coriacea*), Loggerhead (*Caretta caretta*), Ridley's Turtle (*Lepidochelys kempii*) and Green Turtle (*Chelonia mydas*). Entanglement of Leatherbacks in fishing gear led to drowning, but the main stressor for all species was found to be the ingestion of floating waste. Plastic bags were observed to induce occlusion or lesions in the stomach and subsequent death, providing direct evidence for the harm of marine litter.

Leatherback turtles feed exclusively on jellyfish and other gelatinous organisms, so they are at high risk of both lethal and sublethal effects from ingested marine debris such as plastic bags (Hardesty et al., 2016). Leatherback turtles could be included as indicator species in the Atlantic European waters, due to their very wide range of distribution and their specific feeding behaviour (INDICIT, 2018).

Staffieri et al. (2019) developed a blacklist of reptiles endangered by ingestion and entanglement of marine litter, also for the OSPAR region. These authors identified eleven species impacted by marine litter, which belong to the orders Testudines, Squamata, and Crocodilia. There was evidence of highest impact of macrolitter and the lowest of microlitter.

In a review paper on litter ingestion by sea turtles, Nelms et al. (2016) found that of seven species considered, all are known to ingest or become entangled in marine litter. Ingestion was evidenced to cause intestinal blockage and internal injury, dietary dilution, malnutrition, and increased buoyancy which in turn can result in poor health, reduced growth rates and reproductive output, or death. The majority of research was carried out in the Atlantic Ocean basin.

Nicolau et al. (2015) presented results of a study on litter in stomachs of stranded Loggerhead turtles found along the Portuguese continental coast. Litter was present in 56 individuals of 95 individuals investigated. Most individuals had less than 10 litter items and less than 5 g in their stomachs. Potential biasing variables, such as loggerhead stranding season, cause of stranding or size of individuals had no significant influence on the amount of litter ingested.

In another case study, Pham et al. (2017) analysed the gastrointestinal tracts of 24 juvenile oceanic-stage loggerheads captured off the North Atlantic subtropical gyre, in the Azores region. Twenty individuals had ingested marine litter, consisting of plastic items. Large microplastics (1–5 mm) amounted to 25% of the total number of litters and occurred in 58% of the individuals sampled. The arithmetic mean of the abundance of ingested items was 15.8 ± 6.0 per individual, corresponding to a mean dry mass of 1.07 ± 0.41 g.

Darmon et al. (2017) used aerial surveys in the Channel, the Atlantic and the Mediterranean in winter and summer seasons, to identify areas of high exposure of turtles to floating plastic items. Spatial overlap, encounter probability and density of surrounding debris at various spatial scales were assessed in this study. Overlapping areas were found in the Atlantic and Mediterranean fronts, concerning mainly the leatherback and loggerhead turtles. Comparison of the observed mean litter density with a random distribution hint at turtles selecting areas with high litter densities. This can be due to drift of both, litter and turtles, to turtles meeting litter accidentally by selecting high food concentration areas, and/or to turtles actively selecting litter items mistaken for prey.

3.4 Fish

From the logistic point of view, existing scientific fishing programs makes many fish species convenient and appropriate sentinels of microplastic ingestion (ICES, 2018), but ethical reasons might stand against using fish as common indicators. Most fish species ingest microplastics rather than larger size fractions (de Sa et al., 2018). ICES (2018) analyses microplastics in stomachs of fish apart from other marine compartments. Data from this monitoring are available in the online database DATRAS.

For some fish species, including demersal and pelagic fish, such as flounder and herring, there is clear evidence that in some populations, a large proportion of individuals contain plastic litter (Scholz-Böttcher et al., in press). These authors systematically investigated demersal and pelagic species for ingested microplastic and developed an elaborate monitoring protocol. The number of fish species potentially affected by ingestion is high (de Sa et al., 2018), but mostly, microplastics are not accumulated in the digestive tracts of fish (Foekema et al., 2013).

Lusher et al. (2013) documented microplastics in ten species of fish from the English Channel. Plastics were found in the gastrointestinal tracts of 36.5% of 504 individuals. Of the 184 fish that had ingested plastic, the average number of pieces per fish was 1.90 ± 0.10. Abundances of plastic ingested by pelagic and demersal fish were not significantly different. The authors conclude that microplastic ingestion by fish is common in relatively small quantities irrespective of feeding habitat.

Lenz et al. (2015) analysed microplastic in the stomachs of herring and cod from the North Sea and Baltic Sea. The focus of this study was on comparing distributions in coastal and offshore waters. Cod contained plastic more often and also in higher numbers than herring, but the latter species showed higher numbers of microplastic items per gram of stomach analysed. Stable coastal populations in close proximity to urban areas were found to be ideal for comparison against a reference group unaffected by direct land-based microplastic input. The widespread distribution and differing feeding strategies of both species are advantageous for their development into indicator species for microplastic ingestion by fish. These authors highlight the necessity of studies on seasonal patterns of microplastic uptake. Cod and herring are potential indicator species for microplastic in demersal/benthopelagic and pelagic fish species, respectively. Inclusion of a population remote from continental coasts, such as the open North Atlantic, could be used as reference.

In addition to baseline values of microplastic ingestion by fish larvae in the English Channel, Steer et al. (2017) were able to correlate microplastic loads negatively to the distance to the coast and thus to densities of microplastics in fish larvae. This was enabled by sampling both, water and fish larvae and water samples across three sites in the western English Channel. The occurrence of microplastic ingestion amounted to 2.9%.

Smith (2018) gave the first evidence of plastic ingestion by the elasmobranch specie *Scyliorhinus canicula* trawl captured in the North Sea. However, the occurrence plastics ingested was low and was based on three individuals only.

Kühn et al. (2018) investigated juvenile polar cod for the presence of plastics in their stomachs. Sampling was performed in open waters around Svalbard. Two of a total of 72 stomachs contained nonfibrous microplastic particles. The incidence of the two non-fibrous objects shows that ingestion of microplastic particles by polar cod is possible. However, the authors state that for complete assessment of the significance of ingestion of microplastics, secondary pollution with microplastics during sampling and analyses has to be avoided.

In a comprehensive study comprising a combined dataset of 4389 individuals from 15 species, Kühn et al. (2020) analysed the spatial distribution and temporal variability of plastic uptake by fish. Airborne fibre contamination was observed to strongly bias numbers of fibres in the samples. Therefore, all fibres were omitted from further analyses. The incidence and the average number of plastics in fish was low and amounted on average to 1.8% and 0.022 pieces per organism, respectively. Only cod had a higher prevalence (12.3%). Geographical latitude was found to influence plastic uptake, while the distance to the coast had no significant effect. In winter, less plastics were ingested than in other seasons. The authors conclude that the observed low ingestion of plastics does not make fish an ideal impact indicator.

A spatially more restricted field study by Neves et al. (2015) examined the digestive tract contents of 263 individuals from 26 species of commercial fish for microplastics in Portuguese coastal waters. The occurrence of plastic ingestion was 19.8%, where 63.5% of all affected species were benthic and 36.5% pelagic. The mean of ingested microplastics amounted to 0.27 ± 0.63 per fish, (n = 263). Pelagic fish preferred particles, while benthic fish ingested more fibres, but differences were not significant. Ingestion rates were high near potential sources of microplastic, as was found in close vicinity to the mouth of the Tagus River.

In Scottish coastal and offshore waters, three demersal flatfish species sampled near the coast, as well as five pelagic species and four demersal species collected from the Northeast Atlantic revealed an occurrence of macroplastic and microplastic of 47.7% (Murphy et al., 2017). The mean of plastic items found per fish from all locations that had ingested plastic was 1.8 (± 1.7) with polyamide (65.3%), polyethylene terephthalate (14.4%) and acrylic (14.4%) being the three most commonly found polymers.

A case study by Gago et al. (2020) was performed to evaluate the ingestion of micro- and macroplastic by the piscivorous predator *Alepisaurus ferox*. A total of 27 specimens were captured in 2015 and 2016 in the North Atlantic. Their stomachs were dissected and inspected for plastic items. Pieces of macroplastic were found in 37% of samples, with an average weight of 0.46 ± 1.14 g. Microplastics were found in 74% of the samples, with abundances per individual on average of 4.7 ± 4.8 items per stomach. Microfibers and fragments were the only litter types observed. The authors assume trophic transfer to be the main mechanism for microplastic ingestion by this species.

Barboza et al. (2019) investigated microplastic ingestion and effect biomarkers in three fish species from the North East Atlantic, namely *Dicentrachus labrax*, *Trachurus*, and *Scomber colias*. From 150 analysed individuals, 49 % had microplastics in the gastrointestinal tract, gills and dorsal muscle. Fish with microplastics had significantly higher lipid peroxidation levels in the brain, gills and dorsal muscle, and increased brain acetylcholinesterase activity than non-contaminated fish. These effects were attributed to microplastic ingestion and plastic-associated pollutants.

Foekema et al. (2013) analysed 1203 individual fish of seven common North Sea species for ingestion of microplastics: herring, grey gurnard, whiting, horse mackerel, haddock, Atlantic mackerel, and cod. Plastic particles were found in 2.6 % of the examined fish and in five species. No plastics were found in grey gurnard and mackerel. In most cases only one particle was found per fish. The frequency of ingestion was spatially significantly different with highest values in the Channel. Microplastics obviously did not accumulate inside the digestive tract. Therefore, the authors state that it is unlikely that the small abundances found affected the condition of the fish.

In a more recent study, Rummel et al. (2019) compared plastic ingestion by pelagic and demersal fish from the North Sea and Baltic Sea. Cod, dab and flounder, as well as herring and mackerel were selected as demersal and pelagic fish species, respectively. The overall occurrence of plastic ingestion amounted to 5.5%, where 74% of all ingested plastics belonged to the microplastic fraction. Pelagic feeders revealed a significantly higher ingestion frequency than demersal fish. Based on the condition factor K, no significant effect of plastic ingestion on the health status was found.

McGoran et al. (2017, 2018) monitored the Thames Estuary and the Firth of Clyde for plastic ingestion by pelagic and demersal fish species. Nearly 75% of sampled European flounder had plastic fibres in the gut compared with only 20% of smelt. Flatfish (38%) ingested more plastics than other benthic species (17%). In the Thames, more plastic was ingested by pelagic species and flatfish than by shrimps. However, spatial difference were not significant. Differences among species were attributed to different feeding behaviours.

Benthic habitats were in the focus of long-term monitoring conducted by López-López et al. (2018). These authors examined ingestion of plastics by 39 species belonging to teleosts and elasmobranchs. Plastic consumption seemed to be incidental rather than systematic and occurred only in 7 of the 39 species, where the portion of affected individuals was as low as < 0.3%. High ingestion rates were documented for benthic feeding elasmobranchs, including *Leucoraja naevus*, *Scyliorhinus canicula* and *Galeus spp.*

Collard et al. (2017a) related the morphology of the filtration apparatus of three planktivorous fishes (i.e. *Sardina pilchardus*, *Clupea harengus* and *Engraulis encrasicolus*) to amounts of litter in their intestines. Sardines displayed the highest filtration area and the closest gill rakers. Therefore, sardines filtered more microplastics than the other species, which makes sardines to a potential sentinel specie. The same species were studies by Collard et al. (2017b) who examined microplastics in the liver of fish. Mainly polyethylene was found to be translocated into the livers of the three species. In anchovy, 80 per cent of livers contained microplastics ranging from 124 µm to 438 µm in length. Large particles found in the liver were discussed to result from the agglomeration of smaller pieces, which in turn pass through the intestinal barrier.

In a regional study, Bråte et al. (2016) analysed the stomach contents of Atlantic Cod caught at six locations near the Norwegian coast. At average, only 3% of all sampled individuals had plastics in their stomach, where the harbour of Bergen City was a hot spot with an occurrence of 27%. The authors deduced from their results plastic gut clearance rates to be similar to those of the ingested food. Therefore, they discussed stomach fullness as an important metric assessing the levels of microplastic contamination of fish.

In a case study in the Mondego Estuary (Portugal), Bessa et al. (2018) analysed the intestines of commercial fish species for microplastics, namely Sea Bass (*Dicentrarchus labrax*), Seabream (*Diplodus vulgaris*), and Flounder (*Platichthys flesus*). A total of 157 particles were detected in 38% of all sampled fish, with 1.67 ± 0.27 microplastics per fish. Highest abundances of ingested microplastics were recorded for *D. vulgaris* (73%).

Bellas et al. (2016) conducted a baseline study on microplastic ingestion in Spanish Atlantic and Mediterranean waters on the Lesser Spotted Dogfish *Scyliorhinus canicula*, the European Hake *Merluccius merluccius* and the Red Mullet *Mullus barbatus*. The occurrence of microplastics was at average 17.5% (15.3% Dogfish, 18.8% Red Mullets and 16.7% Hakes), with an arithmetic mean of 1.56±0.5 items per fish.

The size of the microplastics ranged from 0.38 to 3.1mm. The authors highlight the role of the three fish species examined as sentinels within the monitoring programme of the MSFD.

Fischer (2019) analysed twelve marine species at four sites along the Wadden Sea coast of Schleswig-Holstein (Germany), including demersal and pelagic fish (Atlantic Herring, Viviparous Eelpout, European Plaice, and Common Sole) as well as benthic invertebrate species (soft-shell clam (Sand Gaper), Common Cockle, Lugworm, Green Shore Crab, and Brown Shrimp). In two monitoring campaigns, 16 to 66 individuals were sampled and examined for microplastics. All investigated species except for common sole were found to be affected by microplastic contamination. The proportion of affected individuals ranged from 38.9% (demersal chordates) to 88.2% of all invertebrates. In invertebrates, microplastic particles were most frequently found in individuals of molluscs (96.6% of all individuals), followed by polychaetes (92.7%) and arthropods (64.8%). Microplastics ingested were mostly fragments of larger items. The number of particles recorded correlated negatively to particle size. Atlantic herring showed a distinct size distribution pattern of microplastics. Based on these results, Fischer recommended several species as suitable biological indicators for future monitoring programs, namely soft-shell clams and lugworms. Seasonal differences in microplastic concentrations were detected. Differences between sampling locations were found, as well. A significant correlation between microplastic concentrations in marine species and weight of tissue highlights the urgent need to standardize reporting values. Benthic species had significantly higher amounts of plastic particles than demersal and pelagic species. Grazing feeders revealed higher median microplastic concentrations than deposit feeders, filter feeders and predators. Finally, Fischer (2019) identified the following criteria for indicator species: Feasibility of sampling, seasonal and spatial representativeness, statistical representativeness, sampling numbers and replicates, habitat induced limitations, morphologically induced limitations and detection limits.

3.5 Invertebrates

Similar to fish, invertebrates usually ingest microplastic rather than larger size fractions of plastic (Fischer, 2019). Van Cauwenberghe et al. (2015) studied the uptake of microplastics by marine invertebrates under field conditions. At six locations along the southern North Sea coast, two species representing different feeding strategies were investigated, the blue mussel *Mytilus edulis* (filter feeder) and the lugworm *Arenicola marina* (deposit feeder). Additional laboratory experiments were performed to assess possible adverse effects of ingestion. Microplastics were found in all organisms collected in the field: on average 0.2 ± 0.3 g^{-1} (*M. edulis*) and 1.2 ± 2.8 g^{-1} (*A. marina*). Both species showed no significant adverse effect in terms of the overall energy budget.

This is in line with a study of Catarino et al. (2018), who studied microplastics in wild mussels around the coast of Scotland (UK). Caged mussels were deployed in an urbanised estuary to assess seasonal patterns. In addition, samples of mussels were taken from eight sampling stations around Scotland to analyse spatial patterns of contamination. In Mytilus spp, the mean number of microplastics was 3.0 ± 0.9 g^{-1} and 3.2 ± 0.52 per mussel.

Phuong et al. (2018) presented microplastic contamination of two bivalves from the French Atlantic coasts: the blue mussel (*Mytilus edulis*) and the Pacific oyster (*Magellana gigas*). Three potential drivers of contamination were investigated, collecting at different sampling sites and different seasons, both wild and cultivated organisms. Microplastic abundances were measured to 0.61 ± 0.56 and 2.1 ± 1.7 items per individual, respectively for mussels and oysters. Most microplastics were fragments; with the size ranging from 50 to 100 µm for both studied species. There were inter-specific differences, but sampling site, season or mode of life had no significant influence on microplastic ingestion.

Li et al. (2018) sampled and analysed blue mussels (*Mytilus edulis*) from coastal waters of the U.K. for ingested microplastics. Seawater samples were taken in parallel in adjacent waters. At eight locations, the number of total microlitter items varied from 0.7 to 2.9 items/g of tissue and from 1.1 to 6.4 items/individual. Micro-FT-IR spectroscopy identified 50% of these litter items as microplastic.

Similarly, in a case study, Van Cauwenberghe and Janssen (2014) provided baseline values of microplastic ingestion by commercially grown specimen of *Mytilus edulis* and *Crassostrea gigas*. *M. edulis* was found to contain on average 0.36 ± 0.07 particles g^{-1} wet weight (ww), while mean values in individuals of *C. gigas* amounted to 0.47 ± 0.16 particles g^{-1} ww. The authors concluded that a European shellfish consumer can ingest 11,000 microplastic particles per year.

Sediment samples, overlying seawater and mussels (*M. edulis*) from intertidal locations in the South West of England were analysed for abundance and type of microplastic by Scott et al. (2019). 88.5% of all sampled individuals contained micro- and mesoplastics, ranging from 1.43 to 7.64 items per mussel. Mussel microplastic abundance correlated significantly well with that of their surrounding sediment, but not with sea-surface microplastic concentrations. Relative abundances of polymer types and particle sizes between seawater, sediment, and mussels were significantly different. Apparently, mussels selectively filtered polymer types, such as modified-cellulose fibres.

De Witte et al. (2014) stressed the importance of an integrated monitoring including microplastic analyses of Blue Mussels from commercial aquacultures and from wild populations near Zeebrugge. The abundance of microplastics varied from 2.6 to 5.1 fibres/10 g of mussel. A higher prevalence of orange fibres at quaysides was attributed to fisheries.

In French waters of the Channel, Blue Mussels (*Mytilus edulis*) and Common Cockles (*Cerastoderma edule*) were sampled and analysed for microplastics and additives by Hermabessiere et al. (2019). The occurrence of affected mussels ranged from 34 to 58%. Blue Mussels and Common Cockles showed 0.76 ± 0.40 and 2.46 ± 1.16 microplastics/individual and between 0.15 ± 0.06 and 0.74 ± 0.35 microplastics/g of tissue wet weight, respectively. However, only few additives were detected, probably because of rapid leaching in seawater prior to ingestion.

Leslie et al. (2017) sampled potential sources and pathways of microplastics from wastewater treatment plants via canals and estuaries to sediments and benthic filter feeders (oysters and mussels) in Dutch coastal waters. Concentrations in tissues varied from 10 to 100 particles g^{-1} dry weight. However, it remained unclear whether the microplastic particles found in macroinvertebrates actually originated from the sampled sources and transport routes.

A comprehensive study on plastic ingestion by fish and invertebrates in Swedish coastal waters was performed by Karlsson et al. (2017). Biota, water and sediments were sampled in parallel, and a sediment extraction method was refined. Thus, the authors were enabled to quantify biomagnifications of microplastic in benthic filter feeders. Based on the number of plastic particles per kg dry weight, microplastic concentrations found in mussels were approximately a thousand-fold higher compared to those in sediment and surface water samples from the same location.

Bråte et al. (2018) monitored the ingestion of microplastics by Blue Mussels along the Norwegian coastline. Astonishingly, highest ingestion rates were found in areas remote from potential sources (i.e. Finnmark). At average, 1.5 (±2.3) particles per individual and 0.97 (±2.61) particles wet weight g^{-1} were found, where fibers were the dominant fraction. Mussel size and depuration were discussed as factors potentially biasing the monitoring results.

Bour et al. (2018a) conducted a laboratory study feeding individuals of the sediment-dwelling bivalve species *Ennucula tenuis* and *Abra nitida* with microplastics and analysing their physiological response. As main findings, microplastic exposure at three levels did not affect survival, condition index or burrowing behaviour in both bivalve species. However, significant changes in energy reserves were detected. Concentration and particle size were two factors significantly altering the observed effects. The authors concluded that long-term exposure to microplastics at ambient concentrations can adversely impact benthic filtration feeders.

In a laboratory study, Hämer et al. (2015) showed that individuals of an isopod specie did not distinguish between food with and food without microplastics during feeding experiments. After ingestion, microplastics were present in the stomach and in the gut but not in the tubules of the midgut gland. The faeces had the same concentration of microplastics as the food, indicative of no accumulation of microplastics during gut passage. No long-term effects of continuous microplastic consumption on mortality, growth, and intermolt duration were detected.

Porter (2018) studied ingestion of plastics by Zooplankton in the North Sea. He calculated the likelihood of encounter and therefore risk of plastics to plankton. For every plastic particle, there were between 500 and 1000 plankton individuals, suggesting very low risk of uptake. Marine snow mainly consisting of aggregated plankton was found to act as transport vector of microplastics from the surface to the seafloor. In addition, sea urchins were exhibited to be effective bioeroders of plastic. Urchins generated on average 172.9 ± 62.38 plastic pieces per urchin over 10 days; creating microplastics from a macroplastic tray.

Historic surveys and benthic samples from a cold water reef at the Scottish coast were analysed by La Beur et al. (2019), to obtain baseline levels of marine litter and microplastic ingestion. Most litter identified was fisheries-related. A total of 11% of benthic macrofauna had ingested microplastics, but there was no significant effect of feeding guild, or location on ingestion rates. Ingestion rate was highest at a location, where microparticles were entrapped by currents and hydromorphometry. The rapid tidal cycling currents at the reefs might have led to low ingestion rates. The authors recommend suspension feeders and the zoanthid *Parazoanthus anguicomus* as indicator species.

Ingestion of microplastics by deep-sea benthic invertebrates (*Ophiomusium lyma*ni and *Hymenaster pellucidus*) was investigated by Courtene-Jones et al. (2019) from 1976 to 2015. The sampling location was deep in the Rockall Trough, North East Atlantic. Microplastics were identified throughout the monitoring period. Data suggest the occurrence of microplastics within the deep sea starting in the 1950s. Of 153 individuals examined, 45% had ingested microplastics. Fibres were most prevalent, accounting for 95% of all microplastic particles. Eight different polymer types were determined. There were no significant trends in ingested abundances or polymer abundances.

Courtene-Jones et al. (2017) examined macrozoobenthic species with different feeding strategies (i.e. *Ophiomusium lymani*, *Hymenaster pellucidus* and *Colus jeffreysianus*) in deep areas of the North Atlantic. 48% of all individuals ingested microplastics with abundances comparable to those of coastal species. The number of ingested microplastics differed between species rather than between feeding behaviours. Moreover, the size and mass of individuals had no influence on the ingestion of microplastics.

In a mesocosm study, Welden and Cowie (2016a) analysed metabolism and catabolism of the langoustine, *Nephrops norvegicus*, where one group of individuals was exposed to increased microplastic concentrations over eight months. A control group served to quantify the impacts of increased microplastic ingestions compared to background contamination. Individuals fed on microplastic revealed a reduction in feeding rate, body mass, and metabolic rate as well as catabolism of stored lipids. The authors discuss potential adverse effects on langoustine populations exposed to high concentrations of microplastics. However, their discussion is speculative, because clear evidence for effects on a higher level than individuals was missing. Amending their mesocosm study, the same authors examined the ingestion and fate of microplastic in langoustines in populations from the Clyde Sea Area, North Minch and North Sea (Welden and Cowie, 2016b). Males, larger individuals, and animals that had recently moulted contained lower levels of microplastic. Large aggregations observed in wild-caught animals were discussed to accumulate over extended periods as a result of the complex gut structure of *N. norvegicus*.

Some years earlier, Murray and Cowie (2011) determined the extent Nephrops norvegicus consumes plastics in the Clyde Sea. Plastic contamination of the stomach was found to be as high as 83% of all animals sampled. Tightly tangled balls of plastic strands were found in 62% of all animals studied. No significant difference in plastic load was observed between males and females. N. norvegicus was supposed to accumulate plastic particles, because egestion could not be detected. Thus, it might be a potential sentinel specie for long-term monitoring.

Wójcik-Fudalewska et al. (2016) studied the ingestion of plastic by the invasive crab *Eriocheir sinensis* from coastal waters of the Baltic Sea and the Tagus Estuary (Portugal). However, results were descriptive rather than highlighting causal relationships. The authors provided a level of microplastic occurrence of 13%, where the microplastic particles were mainly aggregated to microplastic strands and balls in the crabs' stomachs.

In addition to the native crab *Carcinus maenas, Eriocheir sinensis* was also subject of a local case study of McGoran et al. (2020) in the Thames Estuary. Crabs were sampled every three months. Overall, 71.3% and 100% of *C. maenas* and *E. sinensis*, respectively, contained at least one item in the gill chamber, gastric mill or gastrointestinal tract. Fibres and tangles of fibers were the predominant items found in the gastrointestinal tract.

Hodgson (2019) investigated the ingestion of microplastics and its impact on the marine benthic dwelling polychaete worms *Hediste diversicolor* and *Ophryotrocha labronica* in three estuaries in South Devon, UK. 58.6% of *H. diversicolor* individuals ingested plastic particles, with fibres accounting for 86.8 % of all plastics ingested. There were no significant differences in the amount of plastics ingested between sampling sites. Additionally, the difference in toxicity between microplastic beads and fibres in *H. diversicolor* was investigated. Ingested fibres induced a greater oxidative stress response compared to that of microbeads. The impacts of microplastic exposure on the feeding and fitness of *O. labronica* were assessed, as well. *O. labronica* exposed to plastics produced less offspring and significantly smaller eggs than unexposed mating pairs. However, there was no difference in the offspring survival rate so that population effects could not be evidenced.

Hediste diversicolor was also selected by Muller-Karanassos et al. (2019) to investigate the uptake of antifouling paint particles (APP) in intertidal estuarine sediments from southwest England. A significant but heterogeneous metal contamination of local sediments corresponded to ingestion rates of APP by lugworms. The tissue of H. diversicolor was particularly enriched in Cu where ingested APPs were observed, probably reflecting the inability of the animal to regulate this metal. However, this significant correlation did not necessarily hint at adverse effects of APP ingestion on the health status of the animals.

Hodgson et al. (2018) conducted both, field and laboratory studies, to investigate the effect of shredding of plastic bags by the amphipod *Orchestia gammarellus*. Intense shredding was observed in the laboratory and in coastal waters adjacent to Plymouth (UK). The presence of a biofilm significantly increased the amount of shredding, but plastic type was found to have no influence on shredding rates. These results highlight the importance of benthic biota for the formation of microplastics.

An outdoor mesocosm experiment was performed to evaluate the effects of three different types of microplastic polymers on the health and biological activity of lugworms (*Arenicola marina*) by Green et al. (2016). Responses of the activities of the lugworms and of biomass of microphytbenthos were strongest to polyvinylchloride, but also biodegradable plastics had adverse effects on primary production and the animals' health.

In a case study at the western coast of Ireland, the gastropod *Littorina littorea* was analysed for mass and abundance of ingested microplastics (Doyle et al., 2019). Microplastics were found in 60.4% of the individuals and the average concentrations was 2.14 items/g. The authors discussed the prevailing flow regime as decisive factor leading to spatial differences of microplastics in water, sediments, and thus in the gastropods.

A comprehensive monitoring study by Bour et al. (2018b) investigated ten benthic species including fish, bivalves, echinoderms, crustaceans and polychaetes. Microplastics were present in all species with a frequency up to 65%. However, mostly, only one or two microplastics were found per individual, at a maximum of seven particles. The occurrence of microplastic ingestion was not influenced by habitat or trophic level, while characteristics and typology of polymers were partly significantly affected by feeding mode.

Jellyfish has been proposed as indicator of ingestion of plastic, ranging from micro- to macroplastic (Macali and Bergami, 2020). In this context, the authors discuss the trophic role of jellyfish making it a potential novel bioindicator for plastic pollution. As a common energy source in pelagic and deep-sea food webs, jellyfish may represent an invertebrate bioindicator to monitor plastic pollution in pelagic waters, along with their predators.

Devriese et al. (2015) studied the ingestion of microplastics by brown shrimps (*Crangon crangon*) in the Channel and the southern North Sea. Synthetic fibers ranging from 200 µm up to 1000 µm in size were found in 63% of the total number of sampled individuals. Mean concentrations were calculated to 0.68 ± 0.55 microplastics/g wet weight and 1.23 ± 0.99 microplastics/shrimp. Spatial differences were not significant, but a significant seasonal trend was found. Microplastics were not found in the tissue of shrimps indicating absent or low translocation from the gut.

In a literature review, Botterell et al. (2019) showed that microplastics ingestion by zooplankton has been evidenced for 39 taxa from 28 taxonomic orders, with associated negative impacts on biological processes. Adverse effects were reported in ten studies including effects on feeding behaviour, growth, development, reproduction and lifespan. In contrary, only three studies reported no negative effects from microplastic ingestion. Microplastics used in experiments were found to be often different to those quantified in the marine environment, especially concerning concentration, shape, type and age. So far, no effects have been detected on a population level.

4 Entanglement

The most visible effect of pollution on marine organisms is entanglement of wildlife, often in abandoned, discarded or lost fishing gear or rope. Direct harm is in general more frequently reported for entanglement than for ingestion, since negative effects on individuals are more obvious to detect, with external injuries and death often observed. Although the data should be interpreted with caution since entanglement is much more visible and more often recorded in comparison to ingestion, which requires a post mortem examination to confirm, from species records it becomes clear that the problem is of substantial nature (Werner et al. 2016). Kühn & Franeker (2020) found in comparison to the comprehensive review by Laist (1997) the number of bird, turtle and mammal species with entanglement reports increased from 89 to 354. In 2013 TG ML (Galgani et al., 2013) discussed and proposed a first experimental protocols for entanglement in seabirds breeding colonies and associated mortalities due to strangulation.

4.1 Mammals

In an early study, Kirkwood et al. (1997) described and quantified the causes of death of marine mammals stranded on the coasts of England and Wales. The cause of death was diagnosed in 320 (76 per cent) of all cases. The most frequent cause of death of harbour porpoises and common dolphins was entanglement in fishing gear (bycatch), but no information was given whether the fishing gear was actively used or derelict.

Annual CSIP reports (e.g. 2015) regularly detail whether the cause of death of marine mammals stranded at the coast of UK was entanglement and gives information on the number of species affected by entanglement. For example, in 2015, 488 individuals were found stranded and dead, and 19 were dead cetaceans found at sea, two of which were found entangled in netting.

Minke Whales have been found to be prone to entanglement especially in hotspots, such as the North Sea (Werner et al., 2016). Deaville et al. (2010) documented entanglement rates of Minke Whales of 9 % in waters of the UK. However, the sample size of this investigation was very small (n = 11), and there is no standardized monitoring protocol of Minke Whale entanglement.

Butterworth et al. provided estimates of the average entanglement rate for pinnipeds of approximately 1% of the population. These estimates have been made for 13 species of which six are migratory, including the harbour and grey seals. World-wide, mortality rates range from 16% to 80 % (Butterworth et al., 2012).

Observations and a photo identification catalogue from a haul out site in southwest England were used to record entanglement of grey seals (Allen et al., 2012). Between 2004 and 2008, the annual mean entanglement rates varied from 3.6 % to 5%. The authors thereby assume adverse effects on the entire population. 64% of the 58 recorded entanglements caused physical injuries. Mostly, individuals were entangled in fisheries materials. Injuries are likely to impair feeding or lead to possible risk of infection (open wounds) as seals may grow with entanglement still in place.

Hazekamp et al. (2010) conducted a study on the Dutch coast between 1985 and 2010. Entanglement was more prevalent in grey seals than in harbour seals (39 versus 15 respectively). Among the entangled individuals, juveniles were most frequently recorded. Entanglement mainly occurred in fishing materials. Mortality due to entanglement was assumed to be underestimated because of the probable high rate of recovery of stranded animals in comparison to those that die at sea. Especially less fit individuals suffering sublethal effects sink to the seabed rather than being washed ashore. While Grey Seals often become victims of entanglement, there is less evidence for entanglement for Harbour Seals (Werner et al., 2016).

Entanglement has been recorded in 46 cetacean species worldwide, equivalent to 53% of all cetacean species (Marine Debris Working Group, 2013). The authors state that it is necessary to identify methods to determine whether there are population level effects of marine litter ingestion and entanglement for cetaceans. Until present, the number of studies on adverse effects of entanglement on cetaceans is small.

Moreover it was advised to create a standardized protocol for necropsies and to examine and collate data available from stranding networks.

Entanglement of marine mammals in marine litter has been documented for 27 species (Panti et al., 2019). 31.4% of marine mammal species exhibit at least one documented occurrence of entanglement. Therefore, Panti et al. (2019) suggest to harmonize/standardize protocols for the analysis of marine litter in stranded organisms, to simplify methods and thereby reduce the costs of these analyses. Furthermore, national stranding networks to collect samples should be reinforced, and the actual effect to organisms has to be quantified. Additional proposals tackle innovation of new methods, nanoplastics, and rising public awareness.

Moore et al. (2013) discuss entanglement of marine mammals as one potential cause of death of stranded whales and seals amongst others, such as parasitism, anthropogenic contaminants, biotoxins, subclinical microbial infections, competing habitat uses, prey depletion, elevated background and episodic noise. However, monitoring and quantifying these adverse effects is difficult on a species or population level, and even on individuals, also because these stressors act in concert and cumulatively.

4.2 Birds

Some bird species use marine litter as nesting material. The most common litter types found in seabird nests consists of remains of fishing nets, lines and ropes. Northern Gannets and Common Guillemots are amongst other species, such as spoonbills, European Shags, Kittiwakes, Cormorants, and Northern Fulmars, highly vulnerable to entanglement in their breeding colonies in the OSPAR region.

A study by Votier et al. (2010) investigated the use of plastics as nesting material by northern gannets in the periods 1996-1997 and 2005-2010. This study was conducted in a large gannet colony (Grassholm, Wales), where approximately 40.000 pairs of gannets breed. On average, gannet nests contained 470 g (range 0-1293 g) plastic. This corresponds to an estimated colony total of 18.46 tons (range 4.47- 42.34 tons). Mainly, synthetic rope (83%), synthetic netting (15%), and plastic packaging (2%) were used as nesting materials. The associated levels of mortality were estimated to on average 62.85 ± 26.84 (range 33-109) individuals a year. In total, mortality amounted to 525 individuals over eight years, the majority of which were nestlings.

A study by Bond et al. (2012) assessed the prevalence and composition of fishing gear in the nests of northern gannets. A significant correlation to fishing efforts in adjacent waters was found. Deformations of bills have been observed in entangled gannets, which probably impeded feeding (Rodriguez et al., 2013).

In a pilot monitoring, applying the protocol given by the MSFD GES TG ML (Galgani et al., 2013), observations of entangled birds and litter in nests were carried out on Helgoland, Germany. In the pre-breeding season in March/April, the entanglement victims from the previous year were counted. During the breeding peak in June and July, entanglement and litter in the nests was recorded, and in the past breeding season in September/October, only entanglements were recorded. In 2014, in 265 nests (40% of the entire gannet colony), the incidence of litter in nests amounted to 97%, in 2015 of 345 nests (50% of the entire gannet colony), 99% contained plastic litter. The litter types used were dominated by nets, net fragments, cords, strings and ropes, as well as packaging materials. In the 2015 breeding season, 33 Guillemots, twelve adult Gannets and 14 immature Gannets were found fatally entangled. The annual natural mortality rate of adult gannets has increased from annually 0.5% to 4-8%, due to entanglement.

Entanglement of Common Guillemots and litter used as nesting material were investigated in parallel to the entanglement study of Northern Gannets on the island of Helgoland in the North Sea (Dürselen et al., 2016). Based on a large number of replicates (2014: n = 2880, 2015: n = 3381) mortality rates of 1.1 % and 1.0 % were found in 2014 and 2015, respectively. For reasons of their wide spatial distribution, the observed lethal effects, and the standardized protocol applied for observations, Common Guillemots are an ideal indicator species of entanglement in addition to Northern Gannets.

Further suitable bird species breeding in colonies and being prone to entanglement are the following species, which occur in the North and Baltic Seas: European Shag, Cormorant, and Spoonbill.

4.3 Reptiles

A feasibility study of entanglement monitoring was conducted by France nationally with support of an European expert consultation (Claro, 2018a, 2018b). On the Atlantic Ocean and Channel North Sea facade, cases of entanglement, in particular of leatherback turtles, have often been documented. Available data can be extracted from stranding networks.

At the EU/ CMRs scale, a multispecies survey and literature review were performed by the INDICIT project in order to assess the feasibility of entanglement monitoring (Claro et al, 2018c). A standardized monitoring protocol, first drafted by INDICIT (2019) and merged with that of UNEP MAP (submitted), is currently under preparation for the revised D10 guidance (TGML, in prep). This protocol will support a harmonized data collection to accurately document litter types responsible for entanglement, as well as kinds and severity of impacts, information which is extensively needed in the perspective of the development of an indicator (Claro, 2018b; 2018c).

Nelms et al. (2016) summarized potential adverse effects of entanglement on seven reptile species. Accordingly, entanglement in plastic litter causes lacerations, increased drag, which reduces the ability to forage effectively or escape threats, and may evoke drowning or death by starvation.

4.4 Fish

Similar to ingestion, entanglement in ghost nets and derelict fishing gear has been documented for many fish species, including demersal and pelagic fish. There is strong support for adverse effects of entanglement on a species level. Therefore, fish species should be included in the development of thresholds of impact criteria also concerning entanglement, but again, the number of species potentially affected is high, and thus the choice of indicator species is difficult. Therefore in analogy to ingestion, it is proposed to select at least one pelagic, one demersal bonefish species, and one elasmobranch as indicator species as a good compromise. Primarily the focus could be on selecting demersal fish species. However, the MSFD distinguishes between pelagic, demersal, coastal and deep sea fish species as potential indicators.

In an early study, Sancho et al. (2003) deployed 27 fleets of tangled nets on soft bottoms in the Cantabrian Sea shelf to quantify the impact of ghost fishing on fish. Monkfish (*Lophius budegassa* and *Lophius piscatorius*) dominated the fish catches in abandoned tangled nets (81%). Partly, abandoned nets showed catch rates similar to those simultaneously recorded for commercial nets, however, after 224 days, ghost nets ceased to capture monkfish. Total monkfish catches by ghost fishing were simulated by means of a catch model. It was estimated that 18.1 t of monkfish are captured annually by abandoned nets, accounting for 1.46% of the commercial landings of monkfish in the Cantabrian Sea.

Lost gillnets were studied in the context of ghost fishing of Greenland halibut off the coast of mid-Norway by Humborstad et al. (2003), intentionally deploying fleets of nets. Most of the catch consisted of the target species. The proportions of different species did not change with time. The catching efficiency of gillnets decreased with soak time, which was attributed to the weight of the catch evoking the headline height to decrease. Nonetheless, lost gill nets were found to fish for long periods.

Baeta et al. (2009) investigated the impact of lost trammel nets in both sandy and rocky bottoms in the central area of the Portuguese coast. Catching efficiency of deployed nets decreased in a negative exponential way because of the nets' deterioration. The nets' effective fishing lifetime, when catching efficiency became lower than 1%, was 10–11 months on hardgrounds and eight months on sandy bottom.

Colmenero et al. (2017) documented entanglements of juvenile blue sharks *Prionace glauca* in pelagic longlines targeting tuna and swordfish in the Atlantic Ocean and the Mediterranean Sea. The plastic litter consisted of strapping bands and caused injuries on the dorsal musculature and pectoral fins. Additional obstructing of the gill slits very likely evoked breathing issues and subsequent death.

In a literature review, Parton et al. (2019) yielded 47 published elasmobranch entanglement events (N = 557 animals) in 26 scientific papers, with 16 different families and 34 species worldwide. The most common entangling items were ghost fishing gear (74% of animals) followed by strapping bands (11% of animals). Investigating Twitter, 74 cases of elasmobranch entanglement, representing 14 families and 26 species, were found. Here again, ghost fishing gear was the most common entangling item (94.9% of animals).

5 Smothering and invasive species

Sheehan et al. (2017) used stray finds on beaches and scuba dives to document gorgonians entangled in marine debris (sea fangles) across southwest England. Sea fangles were made up of a diverse range of litter from fishing and domestic sources, where the majority consisted of fishing gear. The authors highlight the remaining risks for coral reefs from ghost fishing pressure.

Garcia-Vazqueza et al. (2018) investigated effects of marine litter on the species composition in Tjärnö (Sweden), at the entry of the Baltic Sea. Benthic communities were monitored from eight sites of different ecological conditions. The taxonomic profiles of the communities supported by marine litter and hardgrounds were significantly different. More diverse communities were found on litter. Non-native species were attached mainly to non-plastic artificial materials. Overall, marine litter was found to be a shelter for both, invasive species and diverse natives.

Gerigny et al. (2019) proposed a new protocol for monitoring effects of marine litter on the epibenthic fauna in European marine waters. This protocol includes monitoring of smothering of benthic habitats by marine litter, using Remotely Operating Vehicles (ROVs) and video surveys.

Urra et al. (2021) quantified anthropogenic impacts at Gazul Mud Volcano in the Atlantic by means of underwater imagery and multibeam bathymetry. Slope and water depth were found to be the main factors explaining the distribution of six different benthic assemblages. ROV images showed abandoned or lost fishing gears and marine debris on the seafloor, probably adversely affecting the study site and adjacent areas.

6 Conclusions

Numerous case studies on impacts of marine litter on marine biota contrast with rather few existing standardized monitoring protocols. Further standardized protocols for sampling, necropsies, as well as plastics categorizations and analyses have to be derived and implemented. Many studies recommended potential indicator species of entanglement and ingestion. Among those, benthic invertebrates, such as mussels and lugworms are favourable, because as sessile organisms, they are easy to monitor, and as filter feeders, nearly all species of these orders contain microplastic particles. However, mussels are very resilient organism, which are able to ingest high loads of microplastic without notable physiological effect. In contrary to sessile filter feeders, fish species and marine mammals were found not to accumulate microplastics. Few bird species have been shown to be eligible indicators of entanglement, namely Common Guillemots, Northern Gannets, Spoonbills, Cormorants, European Shags, and Kittiwakes. Seals typically get entangled round the neck with it remaining for some time, so that their entanglement is easy to monitor. Ingestion in seabirds and turtles are agreed and adopted OSPAR impact indicators already with a long-term goal (threshold value) for assessment being in place for the fulmar indicator and one in development for the turtle indicator. The monitoring guidance for marine litter of the EU TG ML is currently under revision offering a chance to agree on further harmonized/comparable monitoring approaches to be applied in European marine waters and elsewhere.

The majority of ingested plastics consists of fragments. Mammals reveal a broad size spectrum of ingested plastics, while birds mostly ingest mesoplastics, and fish and invertebrates mainly eat microplastics. Targeted measures to avoid ingestions of plastics are difficult to develop, because fragments are non-identifiable litter types. In contrary, entanglements of all groups of species most often occur in filamentous litter, which in turn mainly consists of fishing-related litter types, such as remainders of nets, dolly ropes, and ropes. In addition, packaging (e.g. strapping bands) has been identified as cause of entanglement. As specific items related examples, it has been reported that strayfinds of Northern Gannets were often entangled with their beaks in plastic bags (Dürselen et al., 2016). Therefore, a reduction target on plastic bags as set by the EU Plastic Bag Directive is a measure easy to implement and effective in reducing mortalities of Northern Gannets. Another example are prohibitions of the use of dolly ropes. If applied widely preferably in the whole of the North-East Atlantic, this would lead to substantial decreases in the usage of strings as nesting material and associated mortalities in seabirds. Legislation is also challenged to find solutions against the loss of fishing gear, such as nets and parts of nets, which partly happens on purpose.

Plastic marine pollution is an increasing threat to marine diversity. However, marine litter is one ecological stressor amongst others, such as climate change, non-natives competition, impacts of fisheries in habitat and food availability and in terms of bycatches, as well as persistent organic pollutants. All these stressors together build up cumulative pressure on marine ecosystems, leading to their deterioration in terms of declines in species richness. DEFRA (2020) stresses that the degree of risk at population or species levels remains elusive. Until present, there is no agreed convention for hazard assessment of macro- and microplastics. Therefore, big efforts are needed to elucidate the bioavailability and effects of plastic on marine biota. In a next step, dose-response-relationships have to be established feeding into the definitions of additional threshold values and targeted measures.

Therefore, developments and of further standardized monitoring protocols are required to make observations comparable and to generate time series of impact variables. The latter serves to make the data ready for statistical analyses, which in turn allows for defining baselines and detecting trends. Both, baseline and trend analyses serve to implement targets and threshold values of ingestion of and entanglement in marine litter. In a next step, litter type-specific measures need to be implemented, and their success can again be controlled by time series analyses.

Thus, quantifying the effects of marine litter on biota is a complex task, especially when evaluating multiple species with different ecological requirements. This report gives an overview on available knowledge on harm to various species in the area of interest (the Northeast-Atlantic) from different taxonomic classes. As a next step the available data for the different species could be evaluated to assess the risk of ingestion of and entanglement in plastic marine litter by integrating inter-specific factors such as plastic exposure rates and life history traits (e.g., motility, habitat, and body size). This would require a modelling exercise to identify and estimate their exposure to plastic litter across the OSPAR region using literature data, species distribution maps and plastic dispersion models in order to identify hotspots for the risk of plastic ingestion and entanglement for the chosen species. Since coastal species seem to be at higher risk of ingesting plastic in the marine environment than open-sea species, a focus could be put on them. In addition, plastic exposure analyses indicated that species with larger home ranges were more at risk of marine litter interactions with increased distances while local species were more likely to be exposed to plastic closer to the center of their home range location. This could be another factor considered in such an exercise. This approach was tested in a study for the Mediterranean Sea (Compa et al., 2019). To support management and mitigation efforts and to minimize the impact of plastic pollution to the marine environment CPs could consider to apply this concept to the OSPAR region by means of a dedicated project, too.

Overall, in the OSPAR region, the identification of new sentinel species, eligible to exhibit adverse effects of marine litter, is in progress, whereas the development of suitable standardized monitoring protocols is partly still in its infancy. Such protocols can be based on strayfinds and active sampling, they can rely on remote sensing for the monitoring of entanglement or on necropsies of stranded carcasses for the monitoring of ingestion of plastics. There is a huge variety of monitoring methods for harmful effects of marine litter. Most of these methods will quantify effects on an individual level. However, there is a considerable gap concerning the quantification of effects on the levels of populations and species. Population models could bridge this gap, but in addition to effects of marine litter, they have to consider multiple stressors, to deliver realistic results. Thus, harmful effects of marine litter have to be set into the context of other anthropogenic factors, driving the deterioration of marine ecosystems in the OSPAR region.

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