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Perspectives on using marine species as bioindicators of plastic pollution

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ABSTRACT

The ever-increasing level of marine pollution due to plastic debris is a globally recognized threat that needs effective actions of control and mitigation. Using marine organisms as bioindicators of plastic pollution can provide crucial information that would better integrate the spatial and temporal presence of plastic debris in the sea. Given their long and frequent migrations, numerous marine species that ingest plastics can provide information on the presence of plastic debris but only on large spatial and temporal scales, thus making it difficult to identify quantitative correlations of ingested plastics within well-defined spatio-temporal patterns. Given the complex dynamics of plastics in the sea, the biomonitoring of marine plastic debris should rely on the combination of several bioindicator species with different characteristics that complement each other. Other critical aspects include the standardization of sampling protocols, analytical detection methods and metrics to evaluate the effects of ingested plastics in marine species.

1. Introduction

Bioindicators are living organisms like plants, animals and microbes, which provide information on the quality of the environment, from deep marine ecosystems to terrestrial habitats of high altitude (Burger, 2006; Holt and Miller, 2011). The rationale for using bioindicators relies on the hypothesis that cumulative effects of environmental changes are integrated over, or reflected by, the current status or trends in the diversity, abundance, or accumulation of pollutants by one or more species living in that environment (Bartell, 2006; Zukal et al., 2015; Bonanno and Vymazal, 2017). Bioindicators are important tools for detecting changes in the environment and have the potential for assessing the health of ecosystems before their functionality is compromised, by providing biological responses that can guide policy makers and environmental managers (Khatri and Tyagi, 2015; Bonanno and Orlando-Bonaca, 2017). Using bioindicators as sentinels of the health of the environment is nowadays a well-established biotechnology able to provide qualitative and quantitative information on the impact of numerous pollutants and stressors (Bonanno and Pavone, 2015; Siddig et al., 2016). Any good bioindicator, in particular, should have some basic properties, including natural occurrence, abundance, ease of identification and sampling, moderate tolerance to disturbances and stresses, and wide distribution corresponding to a range of exposures to a certain pollutant or stressor (Carignan and Villard, 2002; Caro, 2010; Urban et al., 2012).

The marine environment is ever increasingly subject to manifold and diverse pollutants that threaten the integrity of numerous habitats and their associated biota, from coastal to pelagic environments, and from benthonic to surface ecosystems (Cesar-Ribeiro et al., 2017; Anbuselvan et al., 2018; Bonsignore et al., 2018; Urban-Malinga et al., 2018). Given the great ecological and economic importance of the oceans, the need to monitor the state of the marine environment has increased dramatically in the last few decades (Ofiara and Seneca, 2006; Fox et al., 2016; Avila et al., 2018). As a result, the use of species as bioindicators of marine pollution has become an established practice to assess the effects that various kinds of pollutants have on marine ecosystems (D'Costa et al., 2017; Márquez et al., 2017; Zalewska and Danowska, 2017). To date, numerous species of different taxonomic groups have been used as bioindicators of diverse marine pollutants such as: molluscs (Dirrigl et al., 2018), turtles (Santos Fraga et al., 2018), fish (Caçador et al., 2012), sponges (Orani et al., 2018), macroalgae and seagrasses (Bonanno and Raccuia, 2018; García-Seoane et al., 2018) for heavy metals; polychaetes (Maranho et al., 2014) and molluscs (Cunha et al., 2017) for pharmaceuticals; fish (Smalling et al., 2016) and molluscs (Viñas et al., 2018) for organic pollutants; macroalgae and seagrasses for nutrients (Yamamuro et al., 2003; Alquezar et al., 2013); and seahorses for hydrocarbons (Cariello Delunardo et al., 2015).

Marine pollution due to plastic litter is a widely recognized global threat not only by policy makers and scientific community but also by

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an ever-increasing number of citizens (Bergmann et al., 2017; Borrelle et al., 2017). Although the numerous issues associated with marine plastic debris are addressed on different stages, e.g. legislative, scientific, social, etc. (Law, 2017; Rist et al., 2018), worldwide, many policy makers, scientists and environmental managers are still striving to find cost-effective management solutions to the urgent global environmental issues due to marine plastics (Jambeck et al., 2015; Geyer et al., 2017), whose impact has been recently associated also to disease on coral reefs (Hoeksema and Hermanto, 2018; Lamb et al., 2018). Therefore, the biomonitoring of plastic pollution should be considered as an additional tool to assess the state of the marine environment (Avio et al., 2017; Avery-Gomm et al., 2018), prompting appropriate and tailored actions of prevention and mitigation for a better protection of the sea ecosystems. However, the use of organisms as bioindicators of plastic pollution is still at a preliminary stage, with few documented monitoring campaigns in the marine environment (van Franeker et al., 2011, 2017). The need to identify potential useful bioindicators is thus urgent, given the ever-increasing impact of plastic debris on the sea. In particular, this article aimed to provide insights into the potentials and limits of using marine species as bioindicators of plastic pollution. This article aimed also to identify the current knowledge gaps in order to consolidate the bases for future research.

2. Materials and methods

A set of scientific articles on the interactions between marine biota and plastics has been analysed. To identify these articles, two on-line scientific databases, “Scopus” and “Web of Science”, were consulted. The following keywords were used in the search, appropriately combined: marine plastic pollution, contamination, debris, litter, microplastics, impact, ingestion, bioindicators, biomonitoring, oceans, Mediterranean Sea, mussels, seabirds, turtles, fish, cetaceans, molluscs, crustaceans, plankton, fauna. The information obtained from the bibliographic material was arranged into four tables according to these groups of species: seabirds, sea turtles, mussels and other marine organisms. These tables contain five categories of data: pollutant types (e.g. microplastics), marine species, kind of exposure (e.g. ingestion), geographical location, and references. Only peer-reviewed articles were considered, avoiding references from gray literature (e.g., congress proceedings, local reports). The obtained data were used to discuss the current state of knowledge on marine plastics biomonitoring, and to highlight advantages and drawbacks of the species currently used as bioindicators of marine plastic pollution.

3. Results and discussion

The bibliographic research showed that the studies on the interaction between marine biota and plastics are covering a period of thirty years, but with a significant increase in publications in the last decade. Seabirds are the most studied group of species used as bioindicators of marine plastic debris (Table 1). The majority of studies investigated northern fulmars (*Fulmarus glacialis* Linnaeus, 1761), while other publications included albatrosses, auklets, cormorants and kittiwakes. Sea turtles are another group of widely investigated marine species, with most articles focusing on loggerhead sea turtles (*Caretta caretta* Linnaeus, 1758), followed by green sea turtles (*Chelonia mydas* Linnaeus, 1758) (Table 2). A third group of quite investigated species, but mainly in laboratory experiments, included mussels, in particular the blue mussel (*Mytilus edulis* Linnaeus, 1758) and the Mediterranean mussel (*Mytilus galloprovincialis* Lamarck, 1819) (Table 3). Other investigated taxonomic groups included fish, mammals, polychaetes, bryozoans, holothurians, and also bacterial communities (Table 4).

3.1. Selection of species as bioindicators of marine plastic pollution

Our analysis found that current studies on plastics and marine organisms focused mainly on the kind of interactions (predominantly ingestion) and on the categories of plastics (predominantly microplastics). Several studies, in particular, investigated the harmful effects of ingested plastics in single species (e.g., von Moos et al., 2012; Besseling et al., 2013; de Sá et al., 2015; Martínez-Gómez et al., 2017), rather than showing the biological response of organisms over time across a geographical gradient (e.g., Dantas et al., 2012; Devriese et al., 2015). The current few studies on the spatio-temporal correlations between plastic debris and ingested plastics by marine species suggest that the possibility of using bioindicators of marine plastic pollution is still at a preliminary stage (e.g., Avery-Gomm et al., 2012; Bellas et al., 2016). However, the selection of bioindicator species follows general criteria that can be applied also to plastics in the sea, therefore many more species than those so far investigated could act as potential bioindicators of marine plastics. In particular, given the pervasive nature of marine plastics, cosmopolitan species should be considered as primary sentinels of environmental impact because greater ecological niche allows organisms to detect the same disturbances or stressors in different habitats (Bartell, 2006; Urban et al., 2012). Wide distribution is, indeed, a prominent aspect for candidate bioindicator species because it is based on the rationale that organisms with a widespread geographical presence allow to: set large-scale monitoring networks, facilitate multi-scale comparisons between different territories, and carry out meta-analysis studies (Caro, 2010; Lindenmayer and Likens, 2011). Specific studies testing the suitability of cosmopolitan marine organisms as bioindicators of plastics are generally scarce. The most investigated case studies include four marine organisms that fit the main features of bioindicator species not only in terms of wide distribution but also for their relative tolerance to pollutants, ease of identification and sampling: northern fulmar, loggerhead sea turtle, and the blue and Mediterranean mussels.

As already mentioned, numerous studies focused on seabirds as biomonitor species of marine plastic debris (e.g., Hammer et al., 2016; O'Hanlon et al., 2017; Nicastro et al., 2018). Several scholars, in particular, showed that northern fulmars (*F. glacialis*) act as suitable bioindicators of trends in marine plastic pollution because, like many petrels, fulmars forage exclusively at sea and are prone to ingest anthropogenic debris because of their non-selective feeding at the sea surface (van Franeker and Law, 2015; Acampora et al., 2016). Although age and breeding status may bias the amounts of ingested plastic in this species (Avery-Gomm et al., 2012), in beached birds the condition, sex and cause of death were not found to affect the amount of ingested plastic (van Franeker and Meijboom, 2002; van Franeker et al., 2005). This suggests that beached northern fulmars are ideal biomonitors for plastic pollution in coastal areas, where they are prone to being washed up on beaches in sufficient numbers (e.g. $n > 40$; van Franeker and Meijboom, 2002). Together with their high abundance and wide distribution (Hatch and Nettleship, 1998), all these features make fulmars promising candidates for the ecological monitoring of plastic litter in the marine environment. Where northern fulmars are not available, other petrel species may be suitable, since many of the key characteristics are common to other procellariids (Avery-Gomm et al., 2012). Moreover, the content of debris in the stomach of northern fulmars is used as an indicator of regional plastic pollution, by the Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR convention) (van Franeker et al., 2011). This indicator, called “EcoQO” and standing for “Ecological Quality Objectives for the North Sea”, states that acceptable ecological conditions are defined as “less than 10% of northern fulmars having 0.1 g or more plastic in the stomach in samples of 50–100 beached fulmars, from each of 5 different regions of the North Sea, over a period of at least 5 years” (OSPAR, 2010a, b). However, fulmars could act as good bioindicators only for monitoring on large geographical and temporal scales. Indeed, the migratory capacity of fulmars allow them to travel across much or all of the North Sea in a single or very few days, thus implying that local differences of plastic pollution within the North Sea are unlikely to be