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Bioindicators for monitoring marine litter ingestion and its impacts on Mediterranean biodiversity[☆]

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ABSTRACT

The Mediterranean Sea has been described as one of the most affected areas by marine litter in the world. Although effects on organisms from marine plastic litter ingestion have been investigated in several oceanic areas, there is still a lack of information from the Mediterranean Sea. The main objectives of this paper are to review current knowledge on the impact of marine litter on Mediterranean biodiversity, to define selection criteria for choosing marine organisms suitable for use as bioindicator species, and to propose a methodological approach to assessing the harm related to marine litter ingestion in several Mediterranean habitats and sub-regions. A new integrated monitoring tool that would provide the information necessary to design and implement future mitigation actions in the Mediterranean basin is proposed.

According to bibliographic research and statistical analysis on current knowledge of marine litter ingestion, the area of the Mediterranean most studied, in terms of number of species and papers in the Mediterranean Sea is the western sub-area as well as demersal (32.9%) and pelagic (27.7%) amongst habitats.

Applying ecological and biological criteria to the most threatened species obtained by statistical analysis, bioindicator species for different habitats and monitoring scale were selected. A threefold approach, simultaneously measuring the presence and effects of plastic, can provide the actual harm and sub-lethal effects to organisms caused by marine litter ingestion. The research revealed gaps in knowledge, and this paper suggests measures to close the gap. This and the selection of appropriate bioindicator species would represent a step forward for marine litter risk assessment, and the implementation of future actions and mitigation measures for specific Mediterranean areas, habitats and species affected by marine litter ingestion.

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1. Rationale

Concern about the occurrence, quantity and effects of marine litter in the world's ocean and seas has grown rapidly in recent years, attracting interest from a wide range of stakeholders: governments, environmental Non-Governmental Organization

(NGOs), the scientific community, the media and the general public. Mediterranean Sea, which is a crucial biodiversity hotspot and a critically polluted area, has been also described as one of the areas most affected by marine litter in the world (UNEP/MAP, 2015; Cózar et al., 2015). According to Suaria and Aliani (2014), 62 million macrolitter items were estimated to be floating on the surface of the Mediterranean basin. Marine litter has been detected on regional and local scales in the Mediterranean Sea: along the beaches, floating on the sea surface, in the water column and on the sea floor in (Aliani et al., 2003; Angiolillo et al., 2015; Bo et al., 2014; Cózar et al., 2015; Fabri et al., 2014; Fossi et al., 2016, 2017; Galgani et al., 2000; Ioakeimidis et al., 2014; Pham et al., 2014; Suaria and Aliani, 2014; UNEP, 2011; Vlachogianni and Kalampokis, 2014). Debris that enters marine environments, spreads and accumulates in habitats and compartments, and interacting with marine organisms including the occurrence inside biota following ingestion (Kühn et al., 2015).

Marine litter impacts and interactions on Mediterranean marine organisms were reviewed by Deudero and Alomar (2015) reporting almost 134 species were affected by marine litter at basin scale. This research gives scientific evidence that marine litter is a threat to Mediterranean marine organisms, which are historically exposed to a plethora of other environmental pollutants and other man-driven changes. Marine litter issue requires a series of mitigations actions or solutions.

In addition to National Action Plans at country level, management of marine litter in the Mediterranean Sea falls within the framework of two main regional drivers: the Regional Plan on Marine Litter Management in the Mediterranean (UN Environment/Mediterranean Action Plan), which covers the whole region and the Marine Strategy Framework Directive (MSFD; 2008/56/EC, Descriptor 10) only for European marine waters. Actions are also supported by the Union for the Mediterranean (UfM), through the labelled Plastic Busters project (<http://plasticbusters.unisi.it/>), led by Sustainable Development Solutions Network (SDSN) Mediterranean Regional Centre and the University of Siena (Italy).

Although the effects of plastic litter on the marine environment and organisms have been recently investigated in several oceanic areas, more information is needed for the Mediterranean Sea. In particular, plastic and microplastic inputs, their spatial and temporal distribution, potential accumulation areas, transport dynamics, and interactions with biota and trophic web, all need further investigation.

Recent studies in the different subregions of the Mediterranean basin have suggested that some areas are affected by high concentrations of marine litter, including microplastics and plastic additives (phthalates), representing a potential risk for biodiversity (Darmon et al., 2017; Fossi et al., 2017) and for endangered species (baleen whales, sea turtles, filter feeding sharks) in particular.

In 2016, the UN Environment Integrated Monitoring and Assessment Programme of the Mediterranean Sea and Coast and Related Assessment Criteria (IMAP) adopted the Candidate Indicator 24 “Trends in the amount of litter ingested by or entangling marine organisms focusing on selected mammals, marine birds, and marine turtles” under Ecological Objective 10 (EO10) i.e. Marine Litter. Work is underway to define the most representative species to be used for this Indicator. Additionally, at a European level, the MSFD criteria D10C3 (Commission Decision 2017/848) states: “The amount of litter and micro-litter ingested by marine animals is at a level that does not adversely affect the health of the species concerned” and criteria D10C4 “The number of individuals of each species which are adversely affected due to litter, such as by entanglement, other types of injury or mortality, or health effects.” Specifically, the decision states that: “Member States shall establish that list of species to be assessed through regional or subregional cooperation. Litter and

micro-litter classified in the categories ‘artificial polymer materials’ and ‘other’, assessed in any species from the following groups: birds, mammals, reptiles, fish and invertebrates”.

For this reason, further research in this area which addresses multiple species with different ecological and biological importance is needed to decipher indicator species for marine litter ingestion. The quantification of marine litter in the environment (particularly floating macro- and micro litter) depends on several environmental factors (e.g. wind, currents, sea state, etc.) and may change according to multiple oceanographic features; and, in many cases, quantity alone cannot reflect the potential impact of litter on marine organisms and ecosystems. Information obtained from bioindicator species would better integrate spatial and temporal presence of marine litter in the marine environment. The choice and identification of representative bioindicator species for marine litter in the Mediterranean can allow measuring of not only the occurrence of marine litter within species and their environment but also the threat posed to the organisms by the evaluation of contaminants (associated/sorbed to plastic litter) accumulation and any related biological effect (Rochman et al., 2013).

1.1. Harm caused by marine litter ingestion

Marine litter ingestion is one of the main threats to biodiversity in the Mediterranean. Ingestion has been reported in various organisms ranging from invertebrates to vertebrates, including endangered species (Deudero and Alomar, 2015; Kühn et al., 2015; Werner et al., 2016; Wright et al., 2013). Marine organisms may deliberately ingest litter items because of their resemblance to prey (Campani et al., 2013; Cole et al., 2011; Romeo et al., 2016; Wright et al., 2013) or accidentally ingest litter while they are feeding on their prey, e.g. by filter feeding (Fossi et al., 2014) or hunting on shoals (Battaglia et al., 2016; Romeo et al., 2015) or as a result of secondary ingestion (debris already ingested by prey).

Depending on litter size and species, marine litter particles may be egested or accumulate in the gastrointestinal tract, and could cause physical and mechanical damage, such as abrasion, inflammation, blockage of feeding appendages or filters, obstruction of gastrointestinal tract (Cole et al., 2011; Li et al., 2016; Pedà et al., 2016; Wright et al., 2013) or may cause pseudo-satiation resulting in reduced food intake (Kühn et al., 2015). In some cases when gastrointestinal tracts become blocked or severely damaged, marine litter ingestion may lead to mortality of the organism (Werner et al., 2016).

Marine litter, in particular microplastics (<5 mm), also represents a direct and indirect vector for the introduction of chemical substances into the food-web, although information on this issue is still debated (Koelmans et al., 2016). Given the high biodiversity (Coll et al., 2010) and the widespread distribution of marine litter in the Mediterranean basin, many species may be directly impacted by ingestion. The sub-lethal and the chronic effects of litter ingestion could compromise the species and consequently ecosystems having long term implications. This document will particularly focus on the bioindicator organisms for marine litter ingestion.

The main objective of this paper is to review the current knowledge on marine litter ingestion by Mediterranean species and to propose a methodological approach for the assessment of litter in the Sea, using marine organisms as bioindicator species and applying a new integrated approach to monitoring. Selection criteria for the choice of bioindicators are suggested and harmonization of the approach to the study of Mediterranean marine litter is discussed. In particular, this study: (i) reviews the current knowledge of the impact of litter on Mediterranean marine organisms, (ii) defines selection criteria for the choice of sentinel (bioindicator) species, (iii) proposes a threefold monitoring

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