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Reporting Marine Microplastics Data: the Need for a Standardized Protocol

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Abstract

Marine microplastics have become an issue of great concern at the global level. The attention towards the issue of marine microplastics, highly recognized by international policy and scientific research, has increased considerably over the last decades. At the European level, several initiatives have been promoted addressing the reduction of plastic pollution as a high priority target, among which the *Marine Strategy Framework Objective (DSO)* and the *European Strategy for Plastics in a Circular Economy*. In addition, researchers have explored many strategies to optimize the detection and monitoring of microplastics in sediments, seawater, and organisms and to effectively demonstrate their potential ecological harm. However, since pollution dynamics, the functioning of natural ecosystems, and their relationships are very complex, there still lacks a comprehensive understanding of the impacts of microplastics on marine ecosystems. This lack of knowledge may impact the effectiveness of decision-making processes in terms of plastic reduction and waste management. In this study, we present the results of a literature review which focuses on particularly impactful marine microplastic methodological and analytical articles from 2004 to 2017 to identify possible gaps or inconsistencies in the reported data. Based on this review, a framework for a general reporting protocol (GRP) is outlined to encourage increased collaborative research efforts to harmonize the reporting of microplastics data in scientific studies. The proposed GRP outline could be useful in addressing data needs for effective ecological risk assessment.

Keywords

Plastic pollution
Marine ecosystems
General reporting protocol
Microplastics
Marine litter

1 Introduction

Marine microplastics (MPs) have become a global environmental issue, posing serious threats on ecological and human health (Sharma and Chatterjee, 2017). The Mediterranean Sea is considered one of the greatest plastic

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accumulation zones in the world along with the 5 gyres (Suaria et al., 2018). There are roughly 320 million inhabitants along the coast of the Mediterranean Sea and their activities lead to tons of plastic polluting the sea each year. While several initiatives have been promoted to address the reduction of plastic pollution, such as the *Marine Strategy Framework Objective (D10)*, *European Strategy for Plastics in a Circular Economy*, and banning of single use plastic in Europe, plastic continues to accumulate in marine ecosystems.

The attention towards this environmental issue is clearly increased in the scientific research (Pauna et al., 2019). In recent years, researchers have explored many ways to optimize the detection and monitoring of microplastics in sediments, seawater, and organisms to effectively demonstrate their potential ecological harm. However, there still lacks a comprehensive understanding of how microplastics are transferred towards marine trophic webs, affecting natural capital stocks and their capacity to provide ecosystem services on which human well-being relies (Buonocore et al., 2018, 2019; Pauna et al., 2018; Renzi et al., 2018).

Pollution, the functioning of natural ecosystems, and their relationships are very complex issues. Nonetheless, several tools exist to support scientists and decision makers in identifying and predicting the potential future impacts of plastics on marine ecosystems.

1.1 Research efforts for quantifying anthropogenic pressure on marine ecosystems

The Intergovernmental Panel on Climate Change (IPCC) provides decision makers with prediction models to show the potential impacts of greenhouse gas (GHG) emissions. These prediction models are based on high-quality data collected at the global scale. However, gathering this data requires strong collaboration among numerous scientists involved in diverse fields of study. This type of global and interdisciplinary collaboration can be complicated, especially if there is a lack of clear guidelines for the contributing scientists.

Meanwhile, the Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP), established in 1969, provides the United Nations (UN) with scientific information on marine environmental protection. GESAMP WG40 consists of a group of experts who come from a wide range of relevant disciplines and continue to contribute to the scientific research on marine litter and microplastics.

The International Union for Conservation of Nature (IUCN), a membership Union composed by both government and civil society organizations, works to provide information about the status of the natural world and measures for its protection. The IUCN has contributed extremely valuable reports to the scientific community and decision-makers including a review of plastic footprint methodologies “Laying the foundation for the development of a standardized plastic footprint measurement tool”. The IUCN recognizes that without a comprehensive understanding of the impacts of an anthropogenic pressure, we cannot know what to expect, given the current state of the marine environment. Also, it is not possible to predict how the state of the marine environment will change if we continue business as usual. This lack of knowledge may impact the effectiveness of decision-making processes in terms of plastic reduction and waste management. Meanwhile, as plastic production continues to grow, the Mediterranean Sea is filled with more and more plastic every day. In other words, the problem is growing at a concerning rate while scientists are forced to wait for more and better data.

While the IPCC has been able to quantify the impacts of GHG emissions, experts in the microplastic field have not yet been able to offer this kind of broad information. One of the main reasons could be that microplastic research is still relatively young as was demonstrated in a bibliometric analysis conducted by Pauna et al. (2019) which showed that significant research interest regarding MPs did not occur until 2013. In addition, there appears to be a problem related to the availability of the “right” data needed to understand the impacts of MPs on marine ecosystems. In particular, data which contains an adequate level of detail such that it can be compatible with other relevant analyses (Cowger et al., 2020). In this regard, future research efforts should be devoted to providing MPs data of a standardized level of detail.

According to the literature investigated in this review, most methodologies, standard operating procedures (SOPs), and experimentation in general have been focused on optimizing extraction of the MP particles from samples and assessing different aspects such as the overall % recovery and overall % digestion of organic matter. Meanwhile, recent studies already show that there is a potential for MPs to cause ecological harm and highlight

the key data needs for understanding potential consequences of MPs at the ecosystem scale (Galloway et al., 2017). The mentality that there could be a one-size-fits-all procedure for microplastic sampling and analysis does not appear to be effective in terms of understanding and addressing the impacts of MPs generated at the ecosystem level. This could be due to the complexity of MPs pollution, arguably on the same scale of complexity as GHG emissions (Borrelle et al., 2017). Similar to how the IPCC was aware that as emissions continued to increase, so would the potential for irreversible damage, MP researchers are becoming more aware that as populations grow and plastic waste continues to be mismanaged, marine ecosystems are expected to be exceedingly pressured.

Miller et al. (2017) conducted a review on methodologies for microplastic assessment with the aim of providing recommendations to establish reproducible microplastic methodologies. Lusher et al. (2017) reviewed existing methodologies to find the pros and cons of each methodology in terms of their potential to damage microplastics in the samples. Finally, Burns and Boxall (2018) conducted a literature review to highlight the urgent need for performing high quality and more holistic monitoring studies along with environmentally realistic effects studies.

In this study, based on these three reviews, a literature review of 48 recent methodological and analytical articles was conducted to determine possible gaps or inconsistencies in the reported information. Based on the findings of the literature review in this study, an outline for a general reporting protocol (GRP) was developed to encourage future research efforts to focus on the standardization or harmonization of the reporting of microplastics data. In addition, examples of methods used by the co-authors for currently unpublished microplastic sampling and analysis of Mediterranean organisms, sediment, and seawater are listed. The proposed outline is intended to support the development of effective models capable of predicting the impacts of microplastics on marine ecosystems.

2 A review of methodologies for microplastics assessment

The articles in the literature review were chosen based on a thorough review article published by Miller et al. (2017) which focused on best practices of microplastic extraction and assessment. Among the articles reviewed in Miller et al. (2017), only those related to field samples were considered for this study. These selected articles were then re-reviewed to explore how the researchers defined the term “microplastics”, what reporting units were used, and how or if shape, color, polymer type and size were specified. Finally, a lack of standardization in data reporting is demonstrated via statistical graphs which represent the diverse reporting units and various MP particle details found within the reviewed articles. The purpose of this approach was to ensure that the articles reviewed in this study are those which have contributed valuable information to microplastic extraction protocols and are already considered among the most used and accepted methods for extracting and analyzing microplastics in the marine environment.

Based on this literature review, it was found that existing publications on MPs show great variability in the information that is reported as well as the reporting units. This variability is not only the result of studies being focused on different samples (i.e., sediment vs. seawater vs. biota), but is also likely due to the lack of a standardization for the reporting units, which was clearly variable even within the sole investigation of marine individuals, sediment, and seawater (Figure 1).

The reporting units for the marine organisms ranged from being reported as the number of MP particles per individual, to the percent of individual that ingested at least one MP particle, or the number of particles per wet weight of individual. In the case of sediment, the number of particles per dry weight of sediment or per wet weight of sediment is reported, and in some studies the number of particles per volume of sediment and the number of particles per area of sediment is reported. Seawater studies also show variability in reporting units. Given the various reporting units found among the reviewed articles, it appears that there is lack of consistency in the reporting of microplastics data. Furthermore, given that some MP research studies did not specify units when reporting observed MP particles, it could be possible that it has not yet been made clear to the scientific

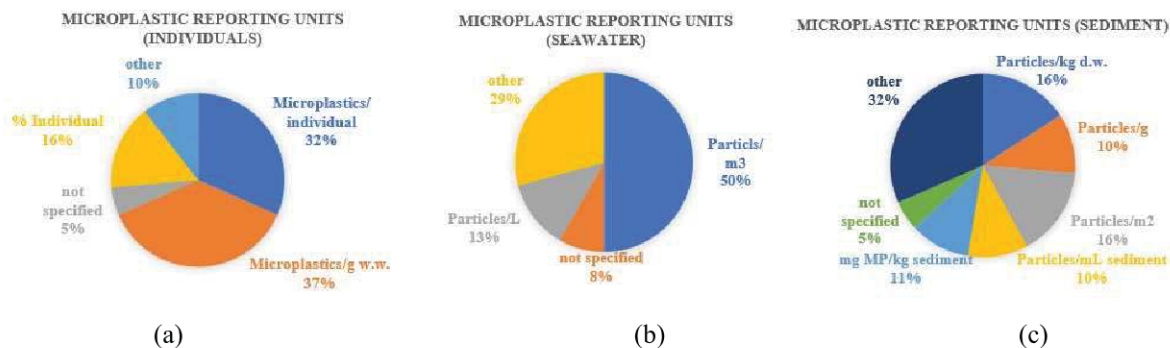


Fig. 1 Statistical graphs representing the various reporting units used in recent articles focusing on methodologies for microplastic extraction and analysis. The percentage of articles that did not specify reporting units are included in each chart. a) Reporting units used in studies focused on MPs found in individuals. b) Reporting units used in studies focused on MPs found in seawater. c) Reporting units used in studies focused on MPs found in sediment.

community the importance of this detail in ensuring that valuable findings can be used to foster the development of larger scale risk assessment of the presence of MPs in marine ecosystems.

Another crucial aspect to be considered in MP research is whether the results of a study discuss the morphology (size, shape), color, and polymer types found. The literature review showed that, in several cases, the shapes and colors of the microplastic particles were not specified (Figures 2 and 3, respectively). Color could be useful information for researchers to investigate the pollution source of MP particles (Wagner et al., 2018) and shape has been shown to be relevant in understanding the behavior of MP particles in the environment (Khatmullina et al., 2019). While these pieces of information might not be directly related to the research study which presented the data, it could be useful for other researchers in the field and, therefore, it might be worthwhile to report characteristics like shape and color if available.

Most studies in the review discussed the size of the particles, but the sizes are typically provided in the form of a range and there is not always clarity on whether the size is diameter, length, or some other measurement (Figure 4). While the morphology of MP particles is complex, size has been shown to be relevant when considering the probability and consequences of a marine species interacting with MPs (Courtene-Jones et al., 2017; Li et al., 2016; Hartmann et al., 2019). Furthermore, the polymer types are not always reported, despite some MP experts expressing its importance in understanding the origin and fate of plastics (Eerkes-Medrano and Thompson, 2018; Li, 2018) and others highlighting the relevance of polymeric composition in terms of the interaction between MPs and sediment and marine organisms (Haegerbaeumer et al., 2019; Porter et al., 2018; Sharma and Chatterjee, 2017).

The literature review also demonstrated that there is not a univocal definition for “microplastics”. In some cases, different researchers utilized a definition from the same source, but displayed or interpreted the definition in different ways. This result can likely be attributed to the difficulties that MP experts face when searching to agree on a definition and characterization of this form of marine litter (Hartmann et al., 2019). While a univocal definition can be helpful in ensuring that members of the scientific and regulatory communities are on the same page during discussions of marine litter focused on MPs, it remains a challenge for experts to reach a consensus given the complexity of the particles.

The specifics of size, morphology, color, and polymer type are crucial information for understanding the many possible implications of ingestion of the microplastics by marine organisms or the ability of the particles to release toxins into the environment or adsorb other chemical compounds in the marine environment (Santana et al., 2016).

Following the performed review of existing studies on marine MPs, an outline for a General Reporting Protocol (GRP) is proposed that can be used by researchers to standardize the reporting of data on microplastics while supporting modelers to assess the impacts of plastic pollution on marine ecosystems.

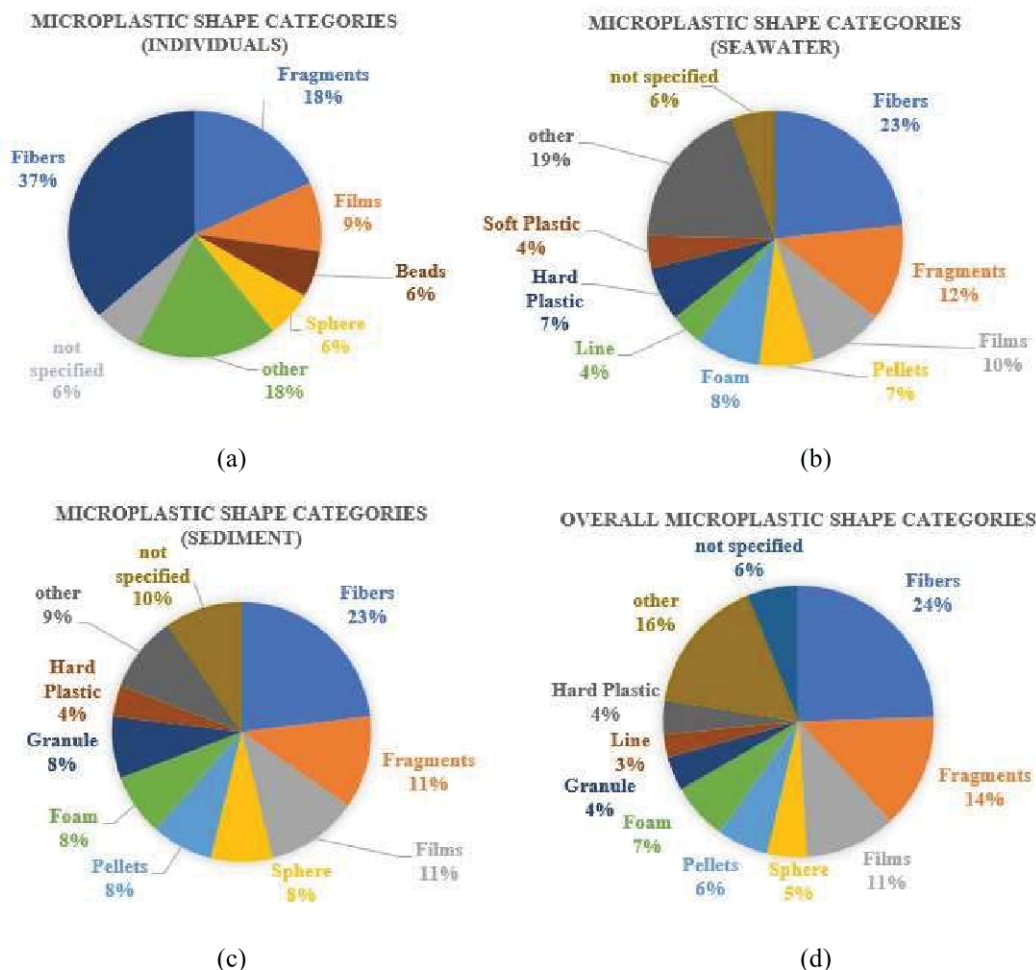


Fig. 2 Statistical graphs representing the various shape categories reported in recent articles focusing on methodologies for microplastic extraction and analysis. The percentage of articles that did not specify shape categories is also displayed. a) Shape categories used in studies focused on MPs found in marine organisms. b) Shape categories used in studies focused on MPs found in seawater. c) Shape categories used in studies focused on MPs found in sediment. d) Overall variation in shape categories considering all types of samples.

3 General reporting protocol recommendation

3.1 Microplastic classifications

The microplastic classifications that are considered in the proposed GRP outline are developed based on categorizations regarding polymers, morphology, sizes, and colors which have been used to report MP findings in the literature (for example, the polymer library created from the TARA expedition and presented in Kedzierski et al. (2019)). These polymer classifications have their own μ FTIR library available with the POSEIDON microplastic analysis software (Kedzierski et al., 2019). The reason for using this particular library is due to its connection with the Mediterranean Sea which is where the researchers are currently investigating marine MPs. Meanwhile, the suggested size range categories are based on Frias and Nash (2018) but altered to avoid double counting sizes. The reason for considering the Frias and Nash (2018) size category recommendations is to encourage comparability among studies. Shape classifications are determined based on Porter (2018) and Khatmullina et al. (2019). Finally, color classifications are determined based on the RAL color chart for plastics which is used for the coloration of plastic products in European industries (RAL PLASTICS, 2020).

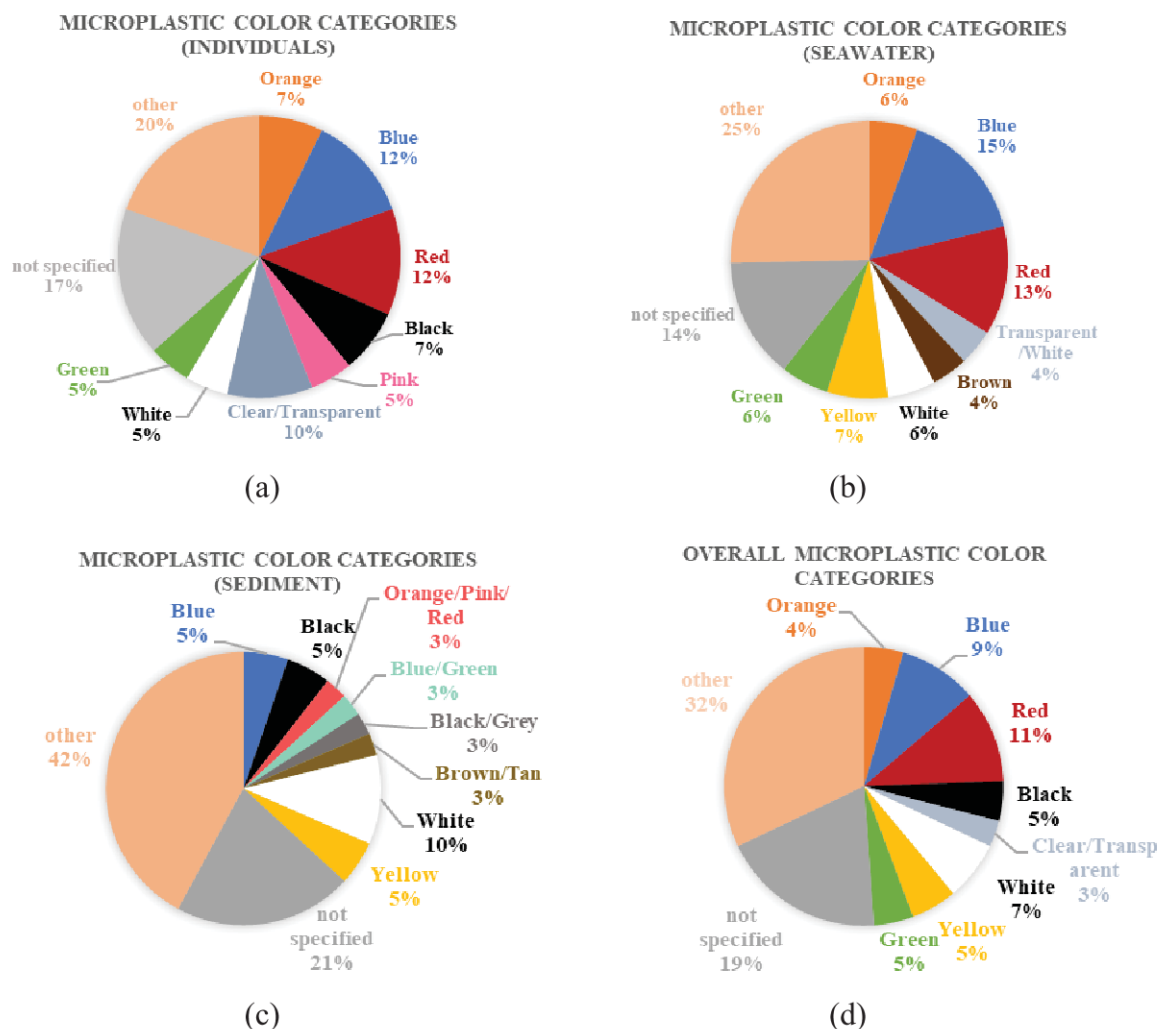


Fig. 3 Statistical graphs representing the various color categories used for reporting microplastics and the frequency of use of these categories for samples of a) marine organisms, b) seawater, and c) sediment. Chart d) represents the overall variation in shape categories considering all types of samples. The “other” category includes the color categories which had a low frequency of use with respect to the other categories; each color category used in the articles reviewed can be found in Appendix I.

3.1.1 Size range

When the MPs are categorized it could be useful from a reporting point of view to first discuss size. From an experimental point of view, size is the only characteristic that can be used to separate MPs without visual analysis which is time consuming and can introduce bias. Filtration or density separation can be used to initially divide the particles, while a visual check can be used to verify the results. The size ranges presented here are derived by the categories presented in Frias and Nash (2019) and have been altered in such a way to avoid overlapping of the sizes included in each category: $1\ \mu\text{m} \leq \text{Size} < 100\ \mu\text{m}$, $100\ \mu\text{m} \leq \text{Size} < 350\ \mu\text{m}$, and $350\ \mu\text{m} \leq \text{Size} < 5\ \text{mm}$. The Frias and Nash (2019) size categories are considered here because they were developed with the hope of encouraging comparability among research studies. The debate on size likely will continue (Hartmann et al., 2019), therefore, the size categories suggested here are not intended to represent a final decision on this area of characterization.

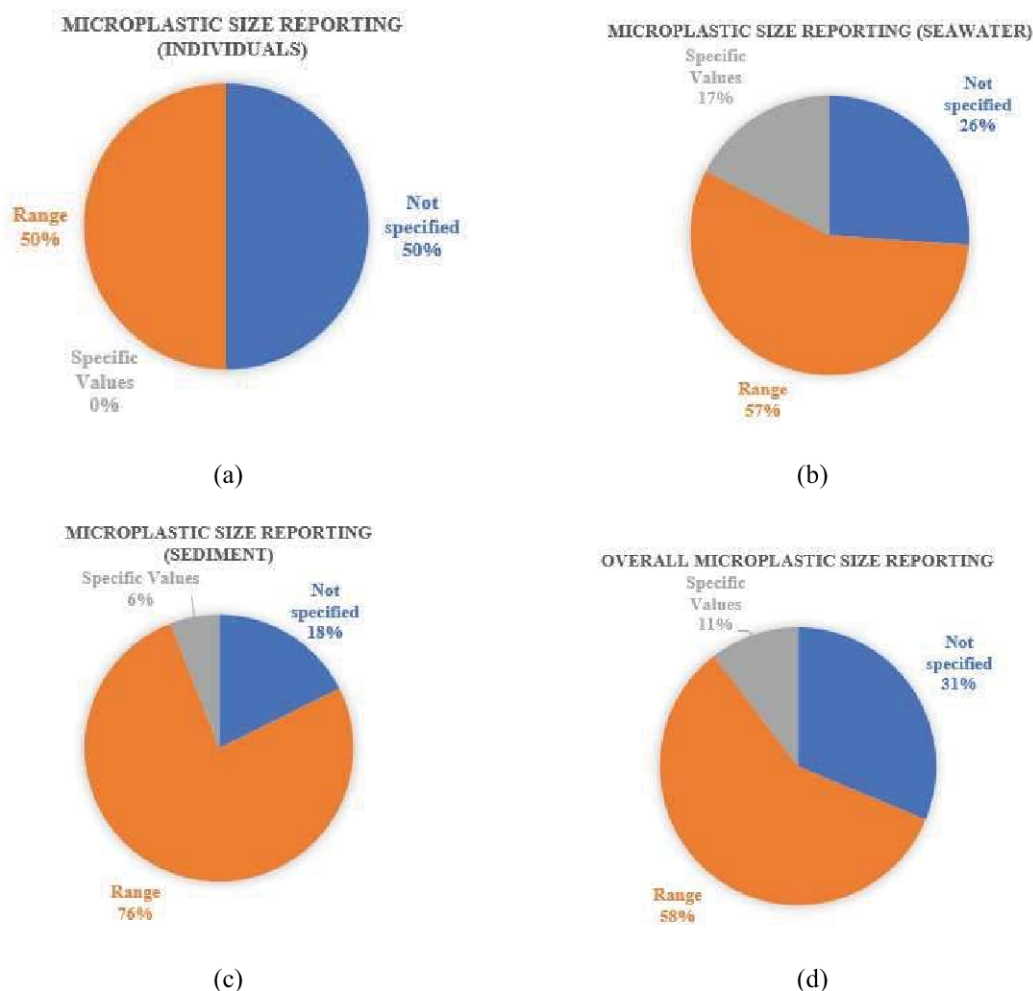


Fig. 4 Statistical graphs representing the various methods for reporting MP sizes, specifically, as a range, specific values, or not specified. The frequency of use of these methods are shown for samples of a) marine organisms, b) seawater, and c) sediment. Chart d) represents the overall variation in reporting MP sizes considering all types of samples.

3.1.2 Color

Within each size range, the particle colors should be recorded. Color is an important characteristic to be recorded because it is useful for the determination of the pollution source (Wagner et al., 2018). In addition, color can be important in terms of ingestion by animals or with regards to its influence on the thermal and UV stability of a plastic particle after weathering (Wagner et al., 2018). For this reason, colors should not be grouped together (i.e., blue/green) to avoid a pre-aggregation of the data. To start color recording, it could be useful to refer to the methods used in plastic recycling, for example, by using computer vision algorithms (Ramon et al., 2018). Determining colors visually creates an opportunity for bias, especially if only one analyst has classified the MP particles (GESAMP, 2019). Furthermore, the results from the literature review indicate that there is a lack of consistency in color categories, i.e. red and pink vs. red/pink, transparent vs. clear. The computer vision algorithm described in Ramon et al. (2018) refers to the RAL color library consisting of specific values which correlate to the colors used in industry. It could be effective to categorize the MP particles found in future studies with respect to the RAL color library for plastics (RAL PLASTICS, 2020).

3.1.3 Morphology

Fragment, line, film, and bead are relevant shape (morphology) categories to be reported because the shape of a MP particle can affect its behavior in the environment (Khatmullina et al., 2019) and their risk to marine organisms (Porter et al., 2018). However, shapes should still be clearly defined and photos of variations of the different shape categories would be effective in ensuring appropriate sorting. Moreover, it appears that more discussion is needed regarding shape categories to avoid over-counting MP concentrations. Given the importance of morphology on the movement of microplastics in the environment (Khatmullina et al., 2019; Porter et al., 2018), it appears that details regarding MP particle shape could be relevant for researchers to assess the risk of this type of marine litter.

3.1.4 Polymer type

Given the existing POSEIDON software (Kedzierski et al., 2019) that could increase the efficiency of MP polymer classification, the polymer types available in the software can be considered for future studies. These polymer types include: Cellulose acetate, cellulose like, ethylene propylene rubber, morphotype 1, morphotype 2, PEVA, PMMA, poly(amide), poly(ethylene), poly(ethylene) + fouling, poly(ethylene) like, poly(propylene), poly(propylene) like, poly(styrene), and poly(urethane). The POSEIDON software is referred to here because of its connection to MPs studies in the Mediterranean Sea.

3.2 What should be standardized?

Since plastics are so widespread throughout the environment, they can be now considered as markers of the Anthropocene (Villarrubia-Gómez et al., 2018). Although the implications of excessive plastic waste in the environment have not yet been completely assessed, MPs do appear to have an impact on organisms (Haegerbaeumer et al., 2019) and potentially on ecosystems (Anbumani and Kakkar, 2018) and human wellbeing via socioeconomic sectors such as tourism, aquaculture, and navigation (Villarrubia-Gómez et al., 2018). However, to effectively understand the impacts of MPs at the ecosystem scale, large datasets are required to develop models capable of predicting how ecosystems can be affected by increasing levels of plastic pollution. How can these data be retrieved?

Microplastics data are collected in many countries worldwide. An initial step that could aid in microplastic data availability is a clear and accepted definition for the term “microplastics” because this could help to create a more defined boundary in which data can be used collectively and for effective decision making (Frias and Nash, 2019). However, it is important to note that this may not be feasible or effective from the perspective of the MP researcher (Hartmann et al., 2019). Some experts suggest that the definition of “microplastics” should encompass the key characteristics which make them potentially harmful for the environment, namely size, shape, color, and type (polymer) (Cincinelli et al., 2019; Frias and Nash, 2019). In addition, comprehensive definitions of microplastics have been developed and continue to evolve as does the research of MPs (Hartmann et al., 2019).

An additional step in developing a univocal definition of the term “microplastics” would be to consider the characteristics which are also significant from an inventory point of view. To be more specific, characteristics that can allow for a better understanding of which source contributed to the particles found in an *in-situ* sample. For example, color is not only important from the ecological harm perspective, but it can also be an indication of which industry the particle came from (Wagner et al., 2018).

There are six main types of plastics found in the form of MPs, referred to as the “big 6”. However, these polymer types often have different abbreviations from researcher to researcher. For example, polyurethane was abbreviated as PU in de Carvalho and Baptista Neto (2016), while in Dehaut et al. (2016) it was abbreviated as PUR.

Sampling is another aspect of MP research that should be urgently standardized. There are many opportunities to lose microplastics or experience contamination, therefore a simple and efficient sampling technique is imperative for accurate and consistent data. There have been several reviews on sampling methodologies

Table 1 Example of potential units for marine seawater, sediment, and organisms.

Sample Type	Reporting Unit
Seawater	n. of particles/L or mass/L
Sediment	n. of particles/kg wet weight or mass/kg wet weight
Individual	n. of particles/individual or mass/individual

discussing relevant parameters to measure in the field and quality control practices in the lab. However, these reviews lack recommendations for sampling regarding the pretreatment of organisms, seawater, and sediment. For example, organisms could be cleaned and divided at the sampling site to ensure that the organisms do not need to be cleaned and re-jarred in the laboratory (where there are other potential contaminants and risks) before digestion begins. Cleaning and re-jarring in the laboratory also creates another opportunity for loss of microplastic concentrations within the sample because living organisms tend to expel their interior fluids postmortem. In 2019, GESAMP published the “Guidelines for the monitoring and assessment of plastic litter in the ocean”, a thorough outline of best practices in sampling for biota, seawater, and sediment.

Finally, the units used for reporting the concentration of MPs found in samples should be standardized (Table 1). The units used to depict concentration should provide an adequate level of detail with respect to the surrounding environment to allow for a more accurate understanding of the temporal and spatial contributions to the concentration found (Cowger et al., 2020). It could be useful for the reporting units to be decided upon by experts of various disciplines, including data scientists who may provide some useful input regarding data needs for assessing MP impact at the ecosystem scale (Faghmous and Kumar, 2014; Blair et al., 2019).

3.3 An example for MP research to follow

The history of the development of GHG emissions inventories has many similarities with the current development of MP research and the challenges that policy makers are facing. The IPCC was created in 1988 and the first assessment report was published before the first general reporting protocol (GRP) of GHG was developed. At that time, the IPCC was certain of two impacts of GHG emissions (Watson et al., 1990):

- 1) “there is a natural greenhouse effect which already keeps the Earth warmer than it would otherwise be”;
- 2) “emissions resulting from human activities are substantially increasing the atmospheric concentrations of the greenhouse gases carbon dioxide, methane, chlorofluorocarbons (CFCs), and nitrous oxide. These increases will enhance the greenhouse effect, resulting on average in an additional warming of the Earth’s surface. The main greenhouse gas, water vapor, will increase in response to global warming and further enhance it”.

Their predictions contained some uncertainties mainly due to incomplete understanding of:

- 1) “sources and sinks of greenhouse gases, which affect predictions of future concentrations”
- 2) “clouds, which strongly influence the magnitude of climate change”
- 3) “oceans, which influence the timing and patterns of climate change”
- 4) “polar ice sheets which affect predictions of sea level rise. These processes are already partially understood, and we are confident that the uncertainties can be reduced by further research. However, the complexity of the system means that we cannot rule out surprises”.

These uncertainties, however, did not stop the IPCC from providing the world with useful predictions. The IPCC was aware that to improve their predictive capability, they needed:

- 1) to understand better the various climate-related processes, particularly those associated with clouds, oceans, and the carbon cycle;

- 2) to improve the systematic observation of climate related variables on a global basis, and further investigate changes which took place in the past;
- 3) to develop improved models of the Earth's climate system;
- 4) to increase support for national and international climate research activities, especially in developing countries;
- 5) to facilitate international exchange of climate data.

3.4 The utility of a microplastic GRP and inventory guidelines

The purpose of a GRP is to generate relevant data inventories that are transparent, complete, consistent, comparable, and accurate (Todorova et al., 2003). The GHG inventories are essential to ensure local, national, and global commitment to the monitoring of emissions' changes and to facilitate monitoring practices (Boitier, 2012). The development of a GRP by a diverse group of specialists, including data scientists, for microplastic research could improve the consistency of experiments regardless of the inevitable differences in the sampling and digestion methodologies adopted for organisms, sediment, and seawater. A GRP could also allow for more efficient local data acquisition which can result in datasets at a level of detail useful for assessing the impacts of microplastics at larger scales.

In addition to the variation among sampling and experimentation methodologies, there is huge variation in the types of plastics found. The different types of plastic can help in identifying what industries represent the biggest "problem area" for marine ecosystems. A GRP could help ensure that these diverse MP types are recorded individually to allow for a more accurate understanding of the consequences resulting from each industry. In other words, knowing the biggest MP "culprit" in the study area of interest can help decision makers to address the problem of microplastics adopting precautionary principles. Nowadays, the most common polymers found in the Mediterranean Sea are PE, HDPE, LDPE, PP, PS, PET, and PVC (Figure 5), which are also known as "The Big 6" (Cincinelli et al., 2019).

4 Sampling protocols for microplastics

Characteristics such as polymer density, shape, position in water column, and possible interaction with other organisms should be reported in a standardized manner. This information could be relevant as these characteristics contribute to the fate of MPs (Cincinelli et al., 2019). Characteristics that are more difficult to detect directly, like the position in the water column and the possible interaction with other organisms, could be predicted in models based on size, shape, color, and type data, assuming adequate quantity and quality of data is provided. Therefore, sampling techniques should ensure that these data are available.

Current sampling protocols for sediment, seawater, and organisms tend to require many steps in the laboratory before pretreatment of the sample occurs. This increases the probability of contamination by nanoplastics, other microplastics, and other particulate matter that can enter experimental samples. However, a standardized sampling protocol that can be easily followed can help to reduce spending too much time preparing samples before they can be pretreated for MP extraction and analysis (Cincinelli et al., 2019; Lusher et al., 2017; Prata et al., 2019).

4.1 Recommended study areas

Porter (2018) highlighted the importance of choosing a study area with high biological productivity and reasonably high microplastic concentrations. High biological productivity can be identified considering areas with high Chlorophyll-a concentrations indicating in turn high concentrations of marine phytoplankton. In the case of the Mediterranean Sea, high Chlorophyll-a concentrations are detected at the coast lines which is convenient for



Fig. 5 Plastic types and industries that use them (World Economic Forum et al., 2016).

microplastics assessment since coastal areas are more exposed to pollution and, therefore, there is high potential for high microplastics concentrations (Desforges et al., 2014). As shown in Figure 6, there are several areas in the Mediterranean Sea which could have high biological productivity given the larger presence of Chlorophyll-a and high microplastic concentrations given that they are coastal areas.

4.2 Possible sampling methods

Table 2 lists some potentially adequate sampling methods for seawater, sediment, and organisms. Remotely operated vehicle (ROV) dive sampling is listed as a possibly useful sampling method for seawater because it can reflect the concentration of microplastics at different depths, showing the distribution of the MPs in the water column (Choy et al., 2019). However, if ROV sampling is not an available method, grab sampling could be useful given that it is not based on particle size like trawling is because filtering is not performed during the sampling process (Barrows et al., 2017). However, this method would not provide an adequate representation of the water column.

Sediment sampling should follow a protocol, which allows for reporting units to be given in mass or particles per volume since all toxicity tests are reported in these units. Ensuring that the results match those of toxicity reports allows the final results to be compared with impact studies for the development of an ecological harm assessment framework that can be effectively applied to decision-making regarding microplastics (Everaert et al., 2018).

It could be useful for marine organisms to be sampled with a standardized quantity of seawater decided upon

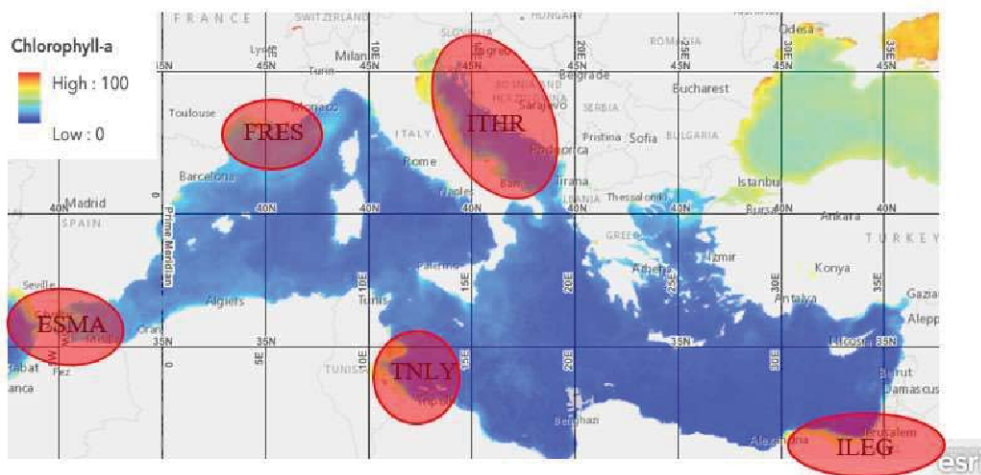


Fig. 6 Daily Chlorophyll-a concentrations (mg/m²) in the Mediterranean Sea (NASA et al., 2018). Recommended sampling areas are highlighted with red and show the created region code.

Table 2 Possible sampling methods for seawater, sediment, and biota.

Sample Type	Sampling Method
Seawater	ROV sampling if available or grab sampling
Sediment	Core sampling
Biota	Grab sampling (with standardized quantity of water)

Table 3 Example of recommended sampling region codes and locations in the Mediterranean Sea.

Region Code	Latitudinal Range	Longitudinal Range
ITHR	41N to 45N	12E to 16.5E
ILEG	31N to 33N	29.8E to 35.1E
TNLY	32N to 35.8N	10E to 12.7E
ESMA	35.2N to 36N	5W to 3.5W
FRES	42.3N to 43.2N	3E to 5.4E

by experts in the field to avoid the possibility of losing microplastics if the animal begins to regurgitate upon leaving the water.

Environmental characteristics, which describe the sampling site, should be recorded to allow for more accurate organization and aggregation of data. This information is also required when developing prediction models simulating marine ecosystems. Recording sheets developed by the JPI-Oceans BASEMAN project should be used when sampling sediment and seawater (Frias et al., 2018; Gago et al., 2019). When sampling organisms, either the sediment or seawater recording sheets could be used depending on the target species. However, it would be useful for a biota specific recording sheet to be developed. The latitude, longitude, and the region code of the sampling site should be also recorded as displayed in Table 3.

4.3 Recommended pretreatment/digestion methods

MPs can be deformed or further fragmented in separation/extraction procedures if the sediment samples are dried at a too high temperature (Qiu et al., 2016). The heat deflection temperature (HDT) of each polymer should be known and respected to avoid over or under estimations of MP particles found in sediment samples (Qiu et al., 2016). The most common polymers found in the marine environment are PE, HDPE, LDPE, PP, PS, PET, and PVC (Cincinelli et al., 2019). Therefore, pretreatment techniques used in MP analysis should not be

Table 4 Possible sampling methods for seawater, sediment, and organisms.

Sample Type	Pretreatment Method
Seawater	Pre-filter
Sediment	Pre-filter
Organisms	5% or 10% sodium dodecyl sulphate followed by enzymatic digestion (GESAMP, 2019)

Table 5 Possible separation methods for seawater, sediment, and biota.

Sample Type	Separation Method
Seawater	Density separation (saturated NaCl) 3 washes
Sediment	Density separation (saturated NaCl) 3 washes
Biota	Filtration of digested solution followed by density separation (saturated NaCl) 3 washes

capable of damaging these polymers. Table 4 lists some possible pretreatment methods for seawater, sediment, and organisms based on the researchers' currently unpublished experimentation and the GESAMP (2019) plastic litter monitoring method guidelines.

4.4 Recommended separation methodology

The most common polymers found in the Mediterranean Sea are PE, HDPE, LDPE, PP, PS, PET, and PVC (Cincinelli et al., 2019). Therefore, separation techniques used in MP analysis should not damage these polymers. Table 5 lists the recommended separation methods for seawater, sediment, and biota. Creon is a cost-effective enzyme that digests the organism completely (Catarino et al., 2016).

4.5 Detection methodology

Burns and Boxall (2018) showed that 42% of current microplastic studies (up until 2018) only used visual identification. This type of detection practice only allows for visibility lower than 500 μm and has an error ranging from 33% to 70% which is not an acceptable level of uncertainty. Instead, 58% of current microplastic studies use RAMAN or μFTIR in addition to visual identification, allowing for size detection lower than 1 or 10 μm , while the confidence in the detection decreases at $< 131 \mu\text{m}$. Concentrations can differ by orders of magnitude depending on the method used for detection. Table 6 lists the recommended detection methods for seawater, sediment, and biota. For studies in the Mediterranean Sea, it could be useful to use visual sorting along with μFTIR identification for MPs extracted from marine sediment, seawater, and organisms given the corresponding POSEIDON libraries (Kedzierski et al., 2019).

5 Conclusions

As microplastic research evolves, it could be useful for future studies to report data from sediment, sea water, and organisms. It is worth noting that the data reported is the result of sampling, analysis, and identification activities. This means that valuable pieces of information in each dataset come from each aspect of a microplastic study. Although the classifications described above are intended as suggestions for development in this aspect of microplastic research, recent work has been done to provide the scientific community with thorough guidelines in sampling, analysis, and reporting (Cowger et al., 2020; GESAMP, 2019). Classification recommendations that have been provided by experts in the field should not be overlooked. Furthermore, microplastic quantities that are not clearly defined or well organized should not be included in reported results; it is preferable to characterize particles as "undefined" if they cannot be characterized by the suggested classifications to avoid any confusion.

The geographical location of the sampling sites is a crucial aspect of microplastic research studies and should be clearly defined in published documentation associated with the data. Results should be provided in agreed

upon units of measure to ensure for comparability among various research studies.

The lack of consistency in reporting units appears to be a significant contributor to the current lack of comprehensive knowledge on MP interactions with the environment. Consistency in reporting units facilitates the comparison of data on marine microplastics and their potential integration in models capable of predicting the impacts of microplastics at local and global scales.

Appendix I

Source	Sediment, Seawater, Biota	Color
Catarino et al., 2017	biota	not specified
Claessens et al., 2013	biota	not specified
Courtene-Jones et al., 2017	biota	not specified
Dehaut et al., 2016	biota	not specified
Devriese et al., 2015	biota	purple-blue (43%), yellow-greenish (50%), translucent (15%) and orange (12%) fibers, but also transparent (8%) and pink (2%) fibers
Jamieson et al., 2019	biota	blue, twisted blue, red, dark/black, dark/blue, black, pink, purple
Li et al., 2016	biota	not specified
Mathalon and Hill, 2014	biota	brightly colored or clear
Remy et al., 2015	biota	blue, red
Santana et al., 2016	biota	white
Taylor et al., 2016	biota	not specified, only to describe what was shown in the images
Van Cauwenberghe and Janssen, 2014	biota	red, blue
von Moos et al., 2012	biota	not specified
Thompson et al., 2004	biota	not specified
Courtene-Jones et al., 2017	biota and seawater	deep sea water: blue, red, transparent; benthic macroinvertebrates: blue, red, black, orange, green, transparent, multicolored
Cole et al., 2014	biota and seawater	white or clear, black, red, orange or yellow, green, blue, brown
Courtene-Jones et al., 2017	biota and seawater	deep sea water: blue, red, transparent
Cole et al., 2014	biota and seawater	white or clear, black, red, orange or yellow, green, blue, brown
Brandon et al., 2016	seawater	not specified
Cincinelli et al., 2017	seawater	blue and red
Desforges et al., 2014	seawater	blue, red, black and purple most common
Dubaish and Liebezeit, 2013	seawater	not specified
Dyachenko et al., 2017	seawater	pink, blue
Enders et al., 2015	seawater	not specified

Source	Sediment, Seawater, Biota	Color
Frias et al., 2014	seawater	not specified
Gallagher et al., 2016	seawater	black, white, clear, blue, white/blue, grey, blue/black, brown, orange, red, yellow, green
Hall et al., 2015	seawater	not specified
Ivar do Sul et al., 2014	seawater	Transparent/white, blue/green, black/grey, yellow, red
Lima et al., 2014	seawater	soft and hard plastics: white, green and blue, threads: red and blue, paint chips: blue, green and yellow
Lusher et al., 2014	seawater	black, blue, grey, brown, red/pink, orange, green, yellow, white
Maes et al., 2017	seawater	white, transparent/translucent, black/grey, blue/green, brown/tan, orange/pink/red, yellow
Majewsky et al., 2016	seawater	not specified
Masura et al., 2015	seawater	not specified
McCormick et al., 2014	seawater	not specified
Mintenig et al., 2017	seawater	not specified
Reisser et al., 2013	seawater	white/transparent, blue, other colors
Sutton et al., 2016	seawater	multi-colored
Thompson et al., 2004	seawater and sediment	not specified
Guven et al., 2017	seawater and sediment	many
van Cauwenberghe et al., 2015	Seawater	blue
Thompson et al., 2004	seawater and sediment	not specified
Guven et al., 2017	seawater and sediment	many
Browne et al., 2010	sediment	not specified
Claessens et al., 2011	sediment	not specified
Claessens et al., 2013	sediment	not specified
Crichton et al., 2017	sediment	dark, red, yellow, blue, white, green
de Carvalho and Baptista Neto, 2016	sediment	translucent, black, white, yellow-brown, various pigments
Frias et al., 2010	sediment	black, white, and color
Fuller and Gautam, 2016	sediment	not specified
Horton et al., 2017	sediment	dyes: copper phthalocyanine, mortoperm blue, hostasol green, and chrome yellow
Maes et al., 2017a	sediment	not specified
Maes et al., 2017b	sediment	white, transparent/translucent, black/grey, blue/green, brown/tan, orange/pink/red, yellow
Martins and Sobral, 2011	sediment	white and colored
Masura et al., 2015	sediment	n/a
Mathalon & Hill, 2014	sediment	brightly colored or clear
Nor and Obbard, 2014	sediment	only mentioned in photos of particles
Quinn et al., 2017 (laboratory experiment)	sediment	
Thompson et al., 2004	sediment	not specified
van Cauwenberghe et al., 2015	sediment	blue
Wessel et al., 2016	sediment	not specified

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