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Focus

A roadmap for a Plastisphere

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ABSTRACT

The constantly growing production of synthetic materials and their presence in the environment gradually transform our Blue Planet into the Plastic One. Microplastics (MPs) enlarge significantly their surface during fragmentation processes. Undoubtedly, nanoplastics (NPs), emerging contaminants, and the Plastisphere, the total available surface of debris, are currently on the edge of science. Although a few research are dedicated to the analysis of MPs and NPs from the physical and chemical point of view, there is a lack of the correlation between the material characterization and the microbiological data. The ecological approach, covering the description of numerical antibiotic or metal resistance bacteria, dealing with toxicological issues or biodegradation, is of great importance. This paper creates the bridge between the material science approach and the eighth continent (as sometimes Plastisphere is called). It points out that the Plastisphere significance will grow within the coming years and it should not be regarded as one ecological niche, but a set of different ones. As the properties mainly depend on the surface morphology, its numerical characterization will be the base for the classification purposes to better describe and model this phenomenon. Apart from concerning the currently important issues of NPs and the Plastisphere, this paper presents the emerging area of research namely the numerical approach to their characterization. This proposal of an interdisciplinary approach to the classification of the Plastisphere's types might be interesting for the members of different scientific communities: nanotechnology, material science and engineering, chemistry, physics, ecology, microbiology, marine microplastics or picture analysis.

1. Introduction and motivations

This paper draws attention to the emerging and important area of research – Plastisphere. It aims to present the original idea and propose the interdisciplinary approach needed to combine the information from various disciplines, namely the material science studies of the structure with the microbiological and ecological data. The main hypothesis is that the morphology of the surface directly influences the formation of biofilm and the presence of other species. Moreover, the structure of debris has an impact on its chemical and physical properties and due to that on the transport, behaviour in the environment and ecotoxicity. All those aspects are extensively studied on one hand by the ecologist and microbiologist, on the other, by the material scientist and chemists. However, there is a lack of bridge connecting the results that would combine the biological, chemical and physical approaches. Although the total surface of microplastics available in the environment is already featured by the term Plastisphere (Zettler, n.d.), one may claim to distinguish it further as a whole spectrum of diversified biological niches, not just a single one. Numerical modelling is proposed in order to classify and describe them. It would include the quantitative analyses and their correlation with data about the biofilm.

2. The sources, distribution and consequences of marine microplastics

Microplastics (MPs) (Pinto et al., 2016), particles of the synthetic materials <5 mm, are already ubiquitous in the environment (Jiang, 2018). Already macroplastics have a significant impact on biota (Arias-Andres et al., 2019), for instance threatening the seabirds (Phillips and Waluda, 2020) and mammals by entanglement and deaths due to false satiation (Ivar Do Sul and Costa, 2014). The consequences of MPs presence are more diversified. They are found in the blood, hurt digestive tracts, case stress and inflammations (Jakubowska et al., 2020), accumulate in a trophic chain (Guzzetti et al., 2018). Although the

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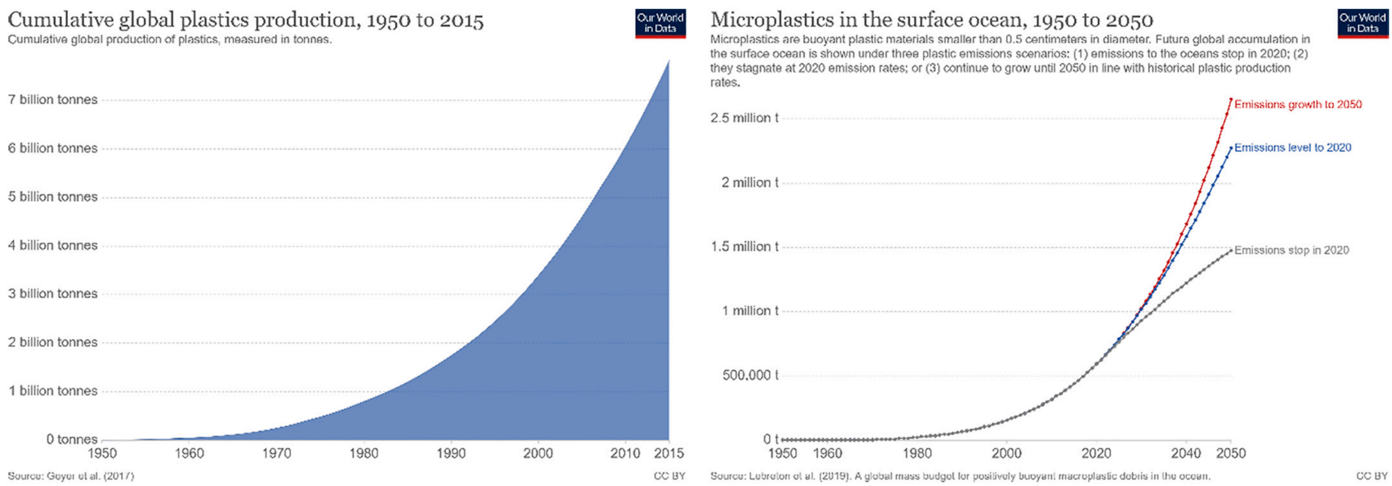

Fig. 1. The cumulative global plastics production and the estimations of the amount of the marine microplastics.
@ Hannah Ritchie (2018) - "Plastic Pollution". *Published online at* OurWorldInData.org. Retrieved from: 'https://ourworldindata.org/plastic_pollution' [Online Resource].

presence of MPs in soils (Chai et al., 2020), the atmosphere (Wang and Wang, 2018), rivers (Harrison et al., 2018), forests, beaches and polar regions (Halsband and Herzke, 2019) is outright and has a lot of consequences (Hallanger and Gabrielsen, 2018), the majority of fragmented polymers ends up in the global ocean (Wang et al., 2016). They are transported around the globe (Song et al., 2019) and exhibit different behaviour depending on the size (El Hadri et al., 2020), shape, type, hydrophobicity, density, adsorbed molecules, biofilm, etc. The roughness plays a key role in the particles adsorbing capacity thus influences the wettability and floatability (Zhu et al., 2020). MPs can float, form sediments, aggregate in one of the huge ocean gyres. In many sampling locations, the most commonly found are fibres and particles from the primary sources (those already produced <5 mm) such as textiles or cosmetics (Godoy et al., 2019), (Praveena et al., 2018) and the wave of secondary ones, formed due to the fragmentation of macro-litter, is yet to come. The MPs surface is constantly growing with the decrease of dimensions caused by the degradation processes (Delacuvellerie et al., 2019), (Zhang et al., 2020b), (Chai et al., 2020). It is called a Plastisphere (Dussud et al., 2018) and form an entirely new, expanding biological niche. Currently, nothing seems to indicate that this direction will change in the nearest future (Fig. 1). One should point out, that there are no troublefree substitutes of plastics in many advanced applications, for instance in electronics, the food industry, bioengineering. Thus, detailed quantitative studies are a prerequisite to better understand the environmental impact or to design the materials more sustainable from a longtime perspective. Moreover, as the production of synthetic materials is growing, fragmentation of those already in the environment proceeds, the primary sources (Godoy et al., 2019; Lei et al., 2017; Praveena et al., 2018) are easily available (for instance in form of the nurdles discarded directly on the beach), disposable items increase and wastes are not managed appropriately, one can observe the progressive invasion of the polymers of the high seas. The threshold of the sustainability and dynamic equilibria within the planetary boundary is yet unknown (Villarrubia-Gómez et al., 2018). Plastisphere differs from natural substrates in many aspects, such as its durability. All things considered, the Blue Planet is gradually transformed into the Plastic one with all its consequences to be studied and understood as soon as possible (Avio et al., 2017). One may claim that with this dynamic of change, the Plastisphere will certainly become an important niche colonized at the beginning by the biofilm and subsequently by other species. Thus the numerical modelling of surfaces may an important indicator to monitor and describe those populations.

3. Plastisphere as the variety of niches

Plastisphere regarded in detail comprises even the whole variety of niches depending on the different properties of a particular substrate. Among the phenomena related to this "*eighth continent*" one can list for instance:

- the evolution of bacteria (Delacuvellerie et al., 2019), insects and other groups of animals capable of plastics biodecomposition (Zhang et al., 2020b),
- the formation of biofilm with numerous metal- and antibiotic-resistant species (Yang et al., 2019),
- increased rate of the horizontal gene transfer (Arias-Andres et al., 2018),
- the availability of floating islands in the oceans and the "*sea snow*",
- the substrate for aggregation of the adsorbed molecules, in particular, persistent organic pollutants (POPs) (Corsolini et al., 2002; Mangano et al., 2017), or viruses,
- the creation of vectors for the transport of exotic invasive species (Węsławski and Kotwicki, 2018).

This is not a complete collection of processes related to the Plastisphere, as probably some new, not studied yet, phenomena will occur in the future. Moreover, the nanoplastics (Barbosa et al., 2020) with their huge surface to volume ratio, contribute significantly to this picture. Although not all relationships between the physical and chemical properties of the material and the biota formed on its surface are studied, the system of dependencies between the morphology and types of species exists. Overall, the quantitative characterization and classification of a Plastisphere seem crucial. Since the weathering roughens the surface, the number of cracks, pits, faults increases and the average diameter of a plain and homogenous piece of material decreases. Those effects are essential to be modelled in a quantitative way enabling the classification and comparison of particles. The total surface available and its morphology is important for the biofilm formation as well as for the physical and chemical interactions (Dussud et al., 2018). It has been already proven (Tallec et al., 2019; Zhang et al., 2020a) that the functional groups and adsorbed chemicals and organic matter significantly influences the properties and behaviour of nano- and microplastics in the aquatic environments. Finally, some of the biointeractions with the polymer surfaces starts already before the disposal, for instance in endoprosthesis or inside the food packaging. In those cases, the quantitative model of morphology will provide the crucial parameters for a

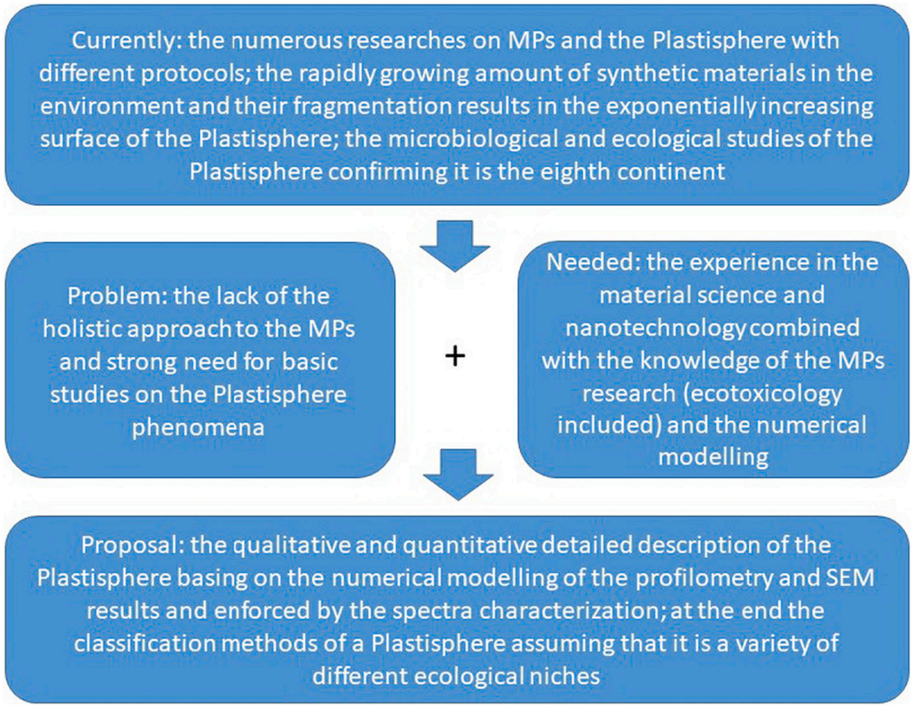

Fig. 2. The proposed roadmap for the research of the Plastisphere.

better design of those products.

4. Qualitative and quantitative methods of structure characterization

The advanced physical and chemical measurements (Stock et al., 2019), such as the gas-chromatography mass-spectrometry (Picó and Barceló, 2020), X-ray, the Raman (Araujo et al., 2018) and FTIR and micro-FTIR spectroscopy (Corami et al., 2020), are already a standard in MMs qualitative studies (Xu et al., 2019). The FTIR can be successfully coupled with the TGA approach (Yu et al., 2019). Raman spectroscopy (Sobhani et al., 2020) is also a valuable tool for biofilm monitoring (Ghosal et al., 2018). Both techniques are complementary and require proper data processing and interpretation (Renner et al., 2019). Also, different techniques of surface visualization, starting with optical microscopy, via SEM (Wang et al., 2017), environmental SEM (Wagner et al., 2017) with AFM (Burrows et al., 2020) at the end, are getting more popular with the increasing awareness of the Plastisphere complex impact on the environment. However, the purely qualitative study of a polymer type does not resolve the main issues related to the MMs behaviour and consequences of their presence in the oceans. Data processing is a crucial step in the analysis of the results of all physical and chemical measurements and consist of:

- image processing and objects classification (colours, shape, morphology, quantity, fluorescence, references, libraries, etc.),
- spectral processing and description (background, baseline, noise, smoothing, references libraries and matching, etc.).

One has to consider for instance the thresholds values, classification routines, spectral libraries, sharing data and developing machine learning (Cowger et al., 2020). Already existing algorithms focus on the searching of polymer debris among the inorganic and organic particles of the matrix, size and colour classification. The crucial step of a detailed morphology description is still to be done and this paper aims to show possible directions and open the discussion on the topic.

As the SEM pictures are commonly available being a standard in the characterization of materials and have the best spatial resolution, their numerical analysis seems to be an advantageous approach. Regarding the different methodologies adopted in a few research areas, one can conclude that the SEM + AFM data are the most frequently used for a quantitative study of surfaces. The AFM results serve as calibration of the z-axis. Finally, a conventional profilometer can be used to recover 3 D data and roughness parameters.

5. Possible directions of numerical research for the Plastisphere

Fig. 2 summarizes shorty the current state of the art and the proposed within this communication direction of research. One can consider it more in detail pointing out the main possible directions to be developed within the coming years.

Recovering the numerical data from 2 D SEM pictures is based on the picture analysis, the rapidly progressing science, and covers numerous algorithms not to be discussed here. The brightness canal is used as the source of information and for the tracking of edges. In principle, there are three paths:

1. the analyses of textures,
2. the 3 D profiles,
3. AI used for the correlation of morphology with the microbiological dataset.

The analyses of textures lead to conclusions about the homogeneity, self-similarity, defects, roughness and morphology of elemental structures with their size and distribution. Providing those data are available, one can conclude about the relationship between the surface morphology, interface structure and Plastisphere properties, probable interactions with biota and their long-term biological impact. On the other hand, it is also possible to start the AI searching (Giannatou et al., 2019), (Gesho et al., 2020) for a correlation between the surfaces' morphology and ecological impact directly, without a previous detailed description of the particular Plastisphere fragment. This approach requires the well-described and robust datasets so far not available.

6. Conclusions and future perspectives

Plastisphere is about to be one of the most important and dynamically evolving niches. It is not only the "eighth continent" with still growing available surface but the entirely new substrate for biofilm and many more species. Moreover, there is no just one type of Plastisphere, but the surface morphology and physical and chemical characteristics vary significantly from debris to debris forming substantially different classes of biological niches. Considering that, one may find crucial the development of proper characterization and classification. As the surface properties are dominant and determine the behaviour of the material, the numerical description of SEM pictures and proposal of quantitative parameters seems to be the promising approach. One may use also AFM (*Atomic Force Microscopy*) to recover the 3 D profile (Hameed et al., 2019) or provide the pair of tilted pictures that enables the reconstruction of roughness (Gontard et al., 2017).

All those basic numerical descriptions will be valuable e.g. for the monitoring of toxicity, adsorption, microbiological studies or event better design of new polymer materials (for electronics, food industry or biomedical applications). Among many standards and criteria to be met, polymers of the future should respect their longterm impact on biota, namely the type of the Plastisphere they will form.

In future research, one should think of the unbiased roughness measurements, as nowadays the majority of results is sensitive to the magnification or pixel size on the SEM pictures (Lorusso et al., 2018). The approach based on the applicability of deep Convolutional Neutral Networks (CNNs) to create the SEM image Denoising model (SEMD) for the Line Edge Roughness (LER) metrology seems promising (Giannatou et al., 2019).

Finally, one may hope to observe the development of this underlined here emerging area of research – the numerical studies of the MPs surface. To the author's best knowledge, a deep understanding of the Plastisphere phenomena will be crucial in the Anthropocene Era.

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CRediT authorship contribution statement

Agnieszka Dąbrowska: Conceptualization, Methodology, Writing - original draft, Investigation, Writing- review and editing.

Declaration of competing interest

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