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Editorial

Plastic pollution: the science we need for the planet we want

Winnie Courtene-Jones[1], Nathaniel J. Clark[1,2] and Richard C. Thompson[1]

[1]International Marine Litter Research Unit, School of Biological and Marine Sciences, University of Plymouth, Drake Circus, Plymouth, Devon PL4 8AA, U.K.; [2]School of Health Professions, University of Plymouth, Peninsula Allied Health Centre, Derriford Road, Plymouth, Devon PL6 8BH, U.K.

Correspondence: Winnie Courtene-Jones (winnie.courtene-jones@plymouth.ac.uk) or Nathaniel J. Clark (nathaniel.clark@plymouth.ac.uk)

Plastics are incredibly versatile materials that can bring diverse societal and environmental benefit, yet current practices of production, use and disposal have negative effects on wildlife, the environment and human health leading to growing concern across public, policy makers and industry. This Special Issue in *Emerging Topics in Life Sciences* describes recent advances in our understanding of the consequences of plastic pollution. In particular, it examines their potential to act as vectors for chemicals and pathogens in the environment; evaluates the effects of plastic pollution on biogeochemical cycling, ecosystem functioning and highlights the potential for enhanced effects in environments that are already subject to substantive changes in their climate. The impacts plastics pose to terrestrial ecosystems including soil communities are described and evaluated, along with evidence of potential issues for human health. With an increase in the production of plastics labelled as 'biodegradable' their context and ecological impacts are reviewed. Finally, we discuss the need to take an integrative, system approach when developing and evaluating solutions to plastic pollution, to achieve the ambitious yet necessary aims of the UN Plastics Treaty.

Undeniably, the use of plastic has provided great benefits to society, owing to its versatility, durability and low cost. This durability coupled with the increasing use of plastics, often in 'disposable, single-use' applications create a major waste management problem [1,2] and can lead to the mismanagement of plastic waste along with leakage into the environment. It is estimated that 60% of all plastic ever produced has been discarded and is accumulating in landfills or the natural environment [1], with the total quantity of waste released predicted to increase over coming decades [2,3]. When present in the environment, weathering can lead to the degradation of large pieces of plastics, forming microplastics (<5 mm [4]). At this scale, the physico-chemical properties of plastics are such that they can interact with other pollutants and wildlife in ways that cause adverse health effects. This Special Issue of themed articles explores the recent evidence relating to the ecological hazards posed by plastics and highlights pertinent future research to deliver the science we need for the planet we want (Table 1).

Early considerations on the potential impacts of plastic pollution identified the possibility for them to act as chemical vectors [5], whereby hydrophobic chemical pollutants could adsorb to the surface of the plastic and subsequent ingestion of this plastic would result in a co-exposure to pollutants. However, consensus for the environmental relevance of some high-dose laboratory assessments of sorption have been questioned, and in the review presented by Khan, Catarino [6] the authors emphasise the need for care when extrapolating the results derived from laboratory studies to the natural world.

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The potential for plastics to act as a vector also extends to biological transport, notably of pathogens, which are reviewed by Bowley, Austin [7]. In combination with oceanic and atmospheric transport, it is possible for plastic to enhance the dispersal of pathogens, exposing previously unaffected populations to these biological agents. There is also concern about exposure of varied plastic particles,

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Table 1 A summary of recommendations arising from the topics covered in this Special Issue aimed to guide future (micro)plastic pollution research to deliver the science we need for the planet we want

Topic from this Special Issue	Research recommendations	Reference
Plastic as a chemical vector	1. Bridging the gap in complexity from laboratory studies towards real world *in situ* processes, including utilising physiologically relevant matrices. 2. Assessment of 'new' particles as chemical vectors, including tyre wear particles, bio-based plastics and nanoplastics.	[6]
Plastic as a vector for pathogens	1. Establish the mechanisms by which microorganisms disperse from the plastic biofilm to organisms and the disease outcome. 2. Quantify the role of plastic in the transport of pathogens and anti-microbial resistant bacteria, as compared with natural particles.	[7]
Influence of plastics on human health	1. Assessment of the long-term consequences of micro and nanoplastic exposure *in vivo*. 2. Effect and accumulation studies using particle concentrations that reflect human exposure. 3. The role of microplastic exposure on the gut microbiome, with subsequent effects on other disease states.	[8]
Impact of plastic on marine carbon cycling	1. Improved understanding of plastic degradation *in situ*. 2. Elucidating the behaviour of marine plastics e.g. residence time in the upper ocean, sinking rates and depth profiles 3. Establish and quantify the long-term effects of plastics on biological carbon cycling (e.g.>100 years).	[12]
Impacts of plastic on understudied or vulnerable marine ecosystems	1. Field based correlation studies to demonstrate harm at population levels in difficult to study ecosystems. 2. Combined stressor effects (e.g. climate change). 3. Explore the ramifications of plastic pollution on ecosystem services, which could lead to negative effects on human health and wellbeing.	[13]
Combined effects of plastic pollution and climate change	1. Adopt a holistic approach to plastic pollution, climate change and biodiversity loss to address data gaps. 2. A focus of solutions to plastic pollution in the Global South. 3. Increase efforts on the global stage for environmental protection through policy/ treaties.	[17]
Effects of (micro)plastic on soil functioning and fauna	1. Incorporation of trophic linkages in study design (e.g. multiple species tests). 2. Develop understanding of plastic behaviour in field conditions. 3. Testing of biodegradable/compostable alternatives that are increasingly used.	[18]
Biodegradable plastics	1. Evaluate the ecological effects of biodegradable plastics, including their additives and degradation products. 2. Data quantifying environmental concentrations	[24]
Working towards effective solutions	1. Thinking to date has predominantly been siloed but must unite a diversity of stakeholders to inform opportunities and barriers for change. 2. The adoption of integrative systems approaches that consider the interrelations between problems and solutions are required to change the life cycle of plastic use from linear to a circular economy and achieve the goals of the UN Plastic Treaty.	[28]

especially nanoplastics, since smaller particles have increased potential for biological availability. Indeed, the spread of pathogens via plastics, became increasingly topical during the Covid-19 pandemic. Greater understanding of the colonisation, dispersal and transfer of pathogens to organisms via plastic is needed [7]. This information is also pertinent to human populations as some environmental pathogens play roles in the progression of pathology, which the plastic can also potentially contribute too. Bastyans, Jackson [8] review the mechanism that plastic pollution can have in lung and gastrointestinal pathology. The authors highlight a current

Emerging Topics in Life Sciences (2022) 6 333–337
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concern surrounding data generation using murine models and cell culture systems as these may not respond in the same manner as humans, and these data are often derived from relatively short-term experiments. As such the authors call for future research to address the human health impacts arising from a diversity of microplastics over longer exposure periods and how predisposing factors may influence adverse health outcomes [8].

Recently, interest in the effects of plastic pollution has expanded beyond impacts on individuals to larger scales, notably those on biogeochemical processes, such as nutrient cycling and carbon sequestration [9–11]. Within this Special Issue, Kvale [12] highlights that the ramifications of plastics on global carbon cycling are not fully elucidated or quantified, and further studies to couple scientific models with empirical observations are required. From an ecosystem health perspective it has been suggested that plastic pollution could adversely affect vulnerable ecosystems, including mangroves, seagrass meadows, the polar regions and the deep sea as reviewed by Walther and Bergmann [13]. Within these four ecosystems plastics can accumulate; for example, the root system of mangroves traps plastic, and the deep seafloor is considered a sink for marine debris, which can result in detrimental impacts to organisms [13]. It is important to note that many ecosystems already face a myriad of stressors such as increased temperatures, noise, chemical pollution, eutrophication and over exploitation to name but a few. The addition of plastic pollution can interact with these other stressors, most widely considered are those associated with climate change [14–16]. Walther and Bergmann [13] discuss that for vulnerable ecosystems the added threat arising from plastic pollution may present an as yet unquantified strain on the functioning of these ecosystems and the services that they provide, which requires further study. Chowdhury, Koldewey [17] discuss linkages between the planetary-level threats of plastic pollution, climate change and biodiversity loss. They illustrate that the Global South is more susceptible to the combined effects of plastic pollution and climate change, and as these areas host biodiversity hotspots, key taxa and ecosystems are also impacted. While questions remain as to the combined effects of climate change and plastic pollution; within this Special Issue, several authors emphasise that threats arising from plastic pollution need to be considered inclusively among a suite of other stressors to more holistically assess environmental impacts [7,13,17] (Table 1).

The focus of plastic pollution research has typically been in the marine environment. However, the underlying causes of plastic pollution are firmly of terrestrial origin, and although less extensively documented, also affect organisms in freshwaters and on land. When present in the soil, plastic pollution can have biotic and abiotic effects, as summarised by Boots [18]; for example plastics may directly affect earthworms and plants and can alter soil properties, such as the porosity and pH. Boots [18] highlights that these can lead to cascading effects on overall ecosystem functioning and soil health; consequently, further research should be directed to quantify the impacts on ecosystem functioning.

Within the past few years there has been a gradually increasing focus on much needed evidence to inform solutions. The plastic production life cycle has become better understood, considering the potential to transition towards a more circular economy [19]. Movement away from a linear economy (i.e. production, use, disposal) has led to consideration of potential solutions along the life cycle stages, notably within product design, production, use, end-of-life and the policies to regulate these [19]. This has, in part, led to increased interest in the replacement of some conventional petrochemical based plastics with bio-based and/or biodegradable alternatives. Consumer awareness of the issue is fuelling demand for what are perceived to be more 'sustainable', or 'environmentally friendly' products [20,21] creating economic incentives to adapt products rapidly to meet demand, often without rigorous testing or life-cycle assessments being undertaken [22,23]. The perception that these products are less persistent and less ecologically harmful than conventional plastics remains largely untested. Research establishing the rate at which biodegradable plastics degrade in different environments and the effects the plastics, any associated chemical additives and degradation products may have on the environment is limited, yet urgently needed to inform risk assessments. The status of this research is summarised by Courtene-Jones, Martinez Rodriguez [24] who show that some of the evidence suggests that the impact of biodegradable polymers on species and ecosystem functioning may be similar to those reported for conventional polymers [24].

Understanding the multifaceted nature of plastic pollution and the connections between social, economic and environmental dimensions are complex. While there are scientific uncertainties regarding the absolute scale of the impacts and some specific risks posed by plastic, there is broad consensus among the public, industry, policymakers and scientists that current practices of production, use and disposal off plastics are unsustainable and that interventions are required [25]. Scientific evidence, global coordination and cooperation will be required to eliminate plastic pollution as outlined in the United Nations Resolution 'End plastic pollution:

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towards an international legally binding instrument' by 2024 [26]. To achieve the ambitious, yet necessary goals of the UN Plastics Treaty [26], an integrative system approach is needed that is solutions focused and takes into account the entire life-cycle of plastics. An integrative system approach will be essential to identify and help prioritise leverage points where transformative changes can be implemented in order to engender a culture focused on responsible use of plastics [27,28].

Competing Interests

The authors declare that there are no competing interests associated with the manuscript.

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