Marine Policy xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Marine Policy

journal homepage: www.elsevier.com/locate/marpol

Marine plastic pollution as a planetary boundary threat – The drifting piece in the sustainability puzzle

Patricia Villarrubia-Gómez[a,*], Sarah E. Cornell[a], Joan Fabres[b]

[a] Stockholm Resilience Centre, Stockholm University, SE-106 91 Stockholm, Sweden
[b] GRID-Arendal, Teaterplassen 3, 4836 Arendal, Norway

ARTICLE INFO

Keywords:
Marine plastic
Pollution
Marine litter
Planetary boundaries
Microplastics
Earth-system processes
Earth system governance
Earth resilience

ABSTRACT

The exponential increase in the use of plastic in modern society and the inadequate management of the resulting waste have led to its accumulation in the marine environment. There is increasing evidence of numerous mechanisms by which marine plastic pollution is causing effects across successive levels of biological organization. This will unavoidably impact ecological communities and ecosystem functions. A remaining question to be answered is if the concentration of plastic in the ocean, today or in the future, will reach levels above a critical threshold leading to global effects in vital Earth-system processes, thus granting the consideration of marine plastic pollution as a key component of the planetary boundary threat associated with chemical pollutants. Possible answers to this question are explored by reviewing and evaluating existing knowledge of the effects of plastic pollution in marine ecosystems and the 'core planetary boundaries', biosphere integrity and climate change. The irreversibility and global ubiquity of marine plastic pollution mean that two essential conditions for a planetary boundary threat are already met. The Earth system consequences of plastic pollution are still uncertain, but pathways and mechanisms for thresholds and global systemic change are identified. Irrespective of the recognition of plastic as a novel entity in the planetary boundaries framework, it is certain that marine plastic pollution is closely intertwined with global processes to a point that deserves careful management and prevention.

1. Introduction: marine plastic pollution as an emerging Anthropocene risk

Human activities are capable of changing the normal functioning of Earth-system processes in ways that amplify risks to societies worldwide [1]. One of the most conspicuous anthropogenic activities is the manufacture, use and disposal of plastic. This synthetic material is so widespread throughout the environment that plastic is now considered as a geological marker of the Anthropocene, the emerging epoch in which human activities have a decisive influence on the state, dynamics and future of the Earth system [2]

Mass production of plastic took off rapidly since the 1950s, shaping the development of modern society [3,4]. Global production of plastic resin increased from around 1.5 million tonnes in 1950 [5] to 322 million tonnes in 2015 [6]. Estimates are that during 2010, between 4.8 and 12.7 million tonnes of mismanaged land-based plastic waste entered the oceans [7]. The absolute amount is difficult to calculate, due to the many different sources and environmental transport pathways, but marine plastic pollution (MPP)[1] is now ubiquitous in the marine environment. It has been documented to negatively affect organisms, ecosystems, human wellbeing, and socioeconomic sectors such as tourism, aquaculture and navigation [8–10]. The recent rise in MPP studies reflects growing concern about its impacts [11]. A first global assessment has been made of the sources, fates and effects of microplastic in the oceans [12,13], highlighting the need for policy and societal action and identifying key research priorities to inform this action.

Recently, scientific attention has turned to plastics as a potential planetary boundary threat [14–16]. The planetary boundaries framework [17] defines precautionary boundaries for several anthropogenic perturbations, set at levels to avoid thresholds or shifts in Earth-system functioning that would generate rising risks for the world's societies. By identifying measurable control variables and setting boundaries, the framework demarcates a global 'safe operating space' for humanity. In

* Corresponding author.
E-mail address: patricia.villarrubia@su.se (P. Villarrubia-Gómez).

[1] The term 'marine pollution' refers to the introduction of harmful or potentially harmful substances into the sea, but it can be politically ambiguous, referring either to the substances themselves or to the moral responsibility for the harm caused by pollution [99]. The use of 'marine plastic pollution' (rather than plastic litter or plastic debris) highlights this socio-political nature of the material.

https://doi.org/10.1016/j.marpol.2017.11.035
Received 15 August 2017; Received in revised form 17 November 2017; Accepted 29 November 2017
0308-597X/

the scientific synthesis of Rockström et al. [17] and later Steffen et al. [1], chemical pollution/novel entities were flagged as issues of concern, but no quantified planetary boundary was proposed.

Along with efforts to operationalise the planetary boundaries as a global sustainability policy integration framework [18–21], the novel entities boundary is increasingly being discussed in the scientific community. Rockström et al. [17] suggested that control variables could be defined in terms of emissions, concentrations or effects of chemicals such as persistent organic pollutants (POPs), heavy metals, or plastics. Sala and Saouter [22] noted that in principle, chemicals could be prioritized according to their impacts on particular ecological functions, allowing for an aggregate quantified planetary boundary. In contrast, Persson et al. [23] argued that *"there is no single chemical pollution planetary boundary, but rather that many planetary boundary issues governed by chemical pollution exist"*. Persson et al. [23] and MacLeod et al. [24] proposed criteria for a chemical pollutant to pose a planetary boundary threat. These criteria are explored and adapted in the following sections. Steffen et al. [1] outlined the rationale for the chemical pollution boundary more fully, expanding the issue to include a wider range of novel synthetic or anthropogenic entities released into the environment. However, the lack of consensus on the kinds of thresholds that should not be crossed, the great diversity of substances released to the environment, and the high uncertainty about their individual and interacting behaviour, has meant that no boundary has been suggested [25], although the planetary threat from chemical pollution is indeed recognised as an unaddressed societal task [24]. These severe knowledge constraints also apply to MPP.

This study extends from ideas outlined in three recent studies [15,16,26] that have raised the issue of establishing a planetary boundary for marine plastic pollution, and reflect on its implications for operationalization in environmental management and policy. Ecological processes, from sub-cellular to ecosystem scales, can be impacted in many ways by marine plastics [16], and physical-biological interactions may play a determining role in the large-scale and long-term fate of marine plastics [15,26]. These studies outline a research agenda to characterize the sources, pathways, degradation and ultimate fates of plastic in the marine environment. Combining these different perspectives together and focusing on the ways that MPP affects Earth-system processes, informs the assessment of whether and how MPP fulfils the requirements to be designated as a sub-boundary of the novel entities boundary.

2. Rationale: the Earth-system perspective on novel entities

2.1. An Earth-system science and governance gap

At its most fundamental, the Earth system consists of the dynamic interactions of Earth's physical and living components [27–29]. The planetary boundaries framework views this as a coupled social-ecological system, where the world's societies increasingly influence Earth's biophysical trajectory.

Steffen et al. [1] defined novel entities as *"new substances […] that have the potential for unwanted geophysical and/or biological effects."* They argued that novel entities become a planetary concern when they exhibit persistence, cross-scale distribution, and the potential to impact vital Earth-system processes. In investigating MPP as a planetary boundary threat, the primary concern is not with its effects on people, or even on marine organisms as such, but rather on the biophysical behaviour of the Earth system as a whole, with the additional challenge for policy and operationalization that the behaviour of concern is, by definition, unprecedented.

Many open scientific questions arise about which aspects of planetary behaviour matter, over what timescales. For most planetary boundary processes, the Holocene provides a baseline of comparative climatic and ecological stability [30,31]. For novel entities, however, there is no such baseline. They exist because of modern humanity's ingenuity, capacity and technology for bypassing many ambient physical and material constraints. Earth-system science faces persistent difficulty in integrating human activity in its conceptual frames [32–34], and the emergence of novel entities (such as marine plastic) highlights the limitations of current scientific understanding. The Earth-system effects that might make MPP a planetary boundary threat could involve thresholds or regime shifts [35,36] within 'components' of the Earth system, such as ecosystem collapses, and in the dynamic links between system components, 'shifting gears' between physical and ecological processes.

There is only an emerging understanding of plastic pollution as a globally systemic problem. Recent assessments [13,37–40] still tend to document issues with an anthropocentric perspective on human health, or on currently economically significant ecosystems, rather than Earth's resilience. They also highlight fundamental gaps in knowledge about the fate of plastics, and its geophysical and biological effects.

In this context, policy on marine plastics is also still emerging [9,37]. The need for an international convention on marine plastic debris or pollution is presently being discussed [38,39]. Key international instruments dealing with sea-based pollution include the London Convention,[2] especially its 1996 London Protocol,[3] and MARPOL 73/78,[4] implemented through national law in signatory nations. Global instruments regulating land-based pollution, but not specifically plastic, include the Stockholm,[5] Rotterdam[6] and Basel Conventions.[7] Only the UN Convention on the Law of the Sea[8] provides a broad overarching duty to prevent land-based sources of all marine pollution. At European level, the Marine Strategic Framework Directive (Descriptor 10)[9] and Article 9 of the Joint Communication on international ocean governance [40] deal with plastic pollution, in support of Sustainable Development Goal 14 under UN Agenda 2030 [41]. Despite growing attention to marine plastic in these contexts, policy integration and coherence remain a very large governance gap [42].

2.2. A new approach for boundary assessment

This exploration of the feasibility of classifying marine plastic pollution as a sub-boundary contributes to an ongoing debate about chemical pollution and novel entities as a planetary boundary. An entity must simultaneously fulfil three proposed conditions and associated scenarios [23,24], outlined in Fig. 1 below, in order to be considered as a planetary boundary. These conditions were initially proposed for chemical pollution, primarily by synthetic substances, where there is broader agreement on how toxicity and hazard can be defined. In applying this conceptual approach to MPP, two major challenges arise, linked to significant knowledge, governance and policy gaps.

First, the vast majority of plastic has long been viewed as 'safe' (non-

[2] Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, www.imo.org/en/OurWork/Environment/LCLP/Pages/default.aspx.

[3] Protocol to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, www.imo.org/en/OurWork/Environment/LCLP/Documents/PROTOCOLAmended2006.pdf.

[4] International Convention for the Prevention of Pollution from Ships, www.imo.org/en/about/conventions/listofconventions/pages/international-convention-for-the-prevention-of-pollution-from-ships-(marpol).aspx.

[5] Stockholm Convention on Persistent Organic Pollutants, http://chm.pops.int/TheConvention/Overview.

[6] Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade, www.pic.int.

[7] Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal, www.basel.int, and action under its 2017 COP-13 Decision on marine litter, www.basel.int/Implementation/MarinePlasticLitterandMicroplastics/Overview/tabid/6068/Default.aspx.

[8] United Nations Convention on the Law of the Sea, www.un.org/depts/los.

[9] Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive) http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32008L0056.