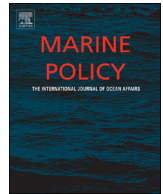




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## Marine Policy

journal homepage: [www.elsevier.com/locate/marpol](http://www.elsevier.com/locate/marpol)

## From problem to crisis to interdisciplinary solutions: Plastic marine debris

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## A B S T R A C T

Marine plastic debris has evolved from being a problem to a cross-cutting crisis impacting natural and human environments across the world. Holistic approaches are needed to address the multifaceted, wide-spread and complex nature of this issue. We argue that a new global governance approach is essential, however, it needs to be aligned with interdisciplinary solutions – sound science and data collection; changes to behavioural psychology; utilising education as a tool; and through changes to management and policy processes. We argue that truly effective prevention is a long-term process that must begin at the ground level with smarter consumer choices, industrial consciousness and responsibility, and an overarching local to global governance framework.

Marine plastic pollution, which is largely a land-based pollution source, can be subdivided into three basic categories: (1) *macroplastic*, including debris such as fishing nets, large pieces of Styrofoam, and parcels that have been lost or discarded from cargo ships; (2) *microplastic*, particles under 5 mm in diameter, including both plastic nurdles (used in various production processes) as well as fragments that remain when larger plastic objects enter marine ecosystems and phytodegrade, and (3) *nanoplastics*, either manufactured as such or the end state of microplastic degradation, invisible to the naked eye (1000 times smaller than an algal cell), and more likely than microplastics to pass through biological membranes [see 1]. (We note that the terms pollution, debris, and litter are often used interchangeably, and that a debate is raging over which term is most appropriate and/or galvanizing. We hope to address this question later but for now will use them all.)

All categories of plastic litter have been found in even the most remote parts of the world's oceans and along the majority of coastlines (as well as most terrestrial ecosystems). Recent studies have revealed the extent of the problem – that in 2010 between 4.8 and 12.7 million metric tonnes of plastic had entered the ocean [2]; and that of the 6300 million metric tonnes of plastics produced in 2015, 79% accumulated in landfills or the environment [3]. Consequently, plastics are regrettable intrusions on natural ecosystems and are particularly worrisome for those concerned with environmental change, food security, and biodiversity loss, and leading some scientists to call for the inclusion of plastics in the planetary boundaries calculus. In recent essays [4,5] we argued that the extent of plastic pollution has reached the point where

it must be effectively linked, and even considered inseparable from, other serious problems associated with climate change, biodiversity loss, and human health. It is now a cross-cutting crisis, and we need interdisciplinary analyses and responses to move forward with operable solutions.

In this special issue, we reveal some of the latest interdisciplinary responses to the plastic marine debris crisis. We utilize the word “crisis” very deliberately here and it is not intended to be taken lightly. We move from a mere problem to a crisis when we cannot fathom an immediate solution amidst the realization that real harm is being done on a daily basis; when there is widespread recognition that an emergency situation coexists with a wicked problem, often a collective action problem that no one actor or institution can solve on its own; when the costs of doing nothing far outweigh the costs of immediate action, but no overarching immediate solution has presented itself. Of course, crisis brings opportunity, but it can also result in fearful paralysis of the imagination and conflict as entrenched interests bear down for the long fight.

With marine plastic pollution, we have arrived at a critical period in human and environmental history. Thankfully, it is no longer necessary to make the point (at least not, we assume, with readers of this journal) that we have a tremendous challenge before us as plastic pollution threatens to outweigh biomass in some bodies of water, contaminates drinking water in urban centres in all hemispheres, and chokes seabirds and turtles. Not only is the crisis well-documented and accepted by its chief industrial sources (including the oil, cosmetics, food and

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<https://doi.org/10.1016/j.marpol.2018.05.006>

Received 3 May 2018; Accepted 3 May 2018

Available online 05 June 2018

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packaging sectors), but governments have acknowledged it at the United Nations Environment Assembly and elsewhere. In 2016, the second United Nations Environment Assembly (UNEA) adopted resolution 2/11 which requested all countries to “raise awareness of the sources and negative effects and possible measures for reducing marine plastic debris and microplastics; to promote change in individual and corporate behaviour; and to cooperate in the prevention and clean-up of marine plastic debris.” In 2017 the UN General Assembly adopted a Ministerial Declaration by consensus that reinforced this resolution [6]. Thankfully, consensus is fairly clear and there are no denial-based protestations, though as the paper by Mendenhall [7] in this special edition suggests, there are many research questions remaining as we continue to explore the impact of plastic debris/litter on the environment, biodiversity, and human health.

This is at least partly a function of the fact that the observational science is so well established and, despite a few glitches along the way, has been largely uncontroversial. Even we are often surprised to read, however, about the true extent of the problem. This is illustrated in the initial articles in this special interdisciplinary volume. In the first article, Chiba and her colleagues [8] present original research demonstrating once again that macroplastic has contaminated even the deep sea. The Global Oceanographic Data Center (GODAC) of the Japan Agency for Marine-Earth Science and Technology (JAMSTEC) launched the Deep-sea Debris Database for public use in March 2017. In fact, evidence amassed in this decades-long project indicates that the relative occurrence of single-use plastic actually increases with depth, testament to the longevity of the problem. The image of a plastic bag found at 10,898 m in the famous Mariana Trench is a haunting one, suggesting that we have long passed the point where full or even partial recovery of extant plastic debris is feasible [9] (despite some noble attempts in The Netherlands, the Adriatic Sea, and elsewhere [10,11]). The authors call for the development of international frameworks for the monitoring of deep-sea plastic pollution as an Essential Ocean Variable, and the further development of a data sharing protocol, two recommendations we heartily support.

The following articles continue on this trajectory of recognizing the extent of the problem and allowing it to form our perception of the crisis before us. Villarrubia-Gómez and colleagues [12] are convinced that the extent of the plastic crisis demands we integrate it into the calculus of planetary boundaries (along with biodiversity loss, excess phosphate from agricultural runoff, climate change and other issues) popularized by Rockström and others in their seminal piece published in *Nature* almost a decade ago [13]. In particular, plastic pollution is making ecosystem-altering contributions to the chemicals component of planetary boundaries. Perhaps the harshest aspect of their analysis is that one of the main characteristics that could earn plastic pollution its status as a planetary boundary indicator is its irreversibility.

Gattringer [14] goes deeper, arguing that the plastics crisis should not only change our scientific analysis of the global biosphere, but also our epistemological and ontological perspectives. He draws upon four fields of knowledge – (i) laws of thermodynamics and their relevance for economics, (ii) behavioural psychology and resulting limitations of individuals’ decision-making under conscious consumer theory, (iii) power theories of political science, and (iv) ethical considerations – to shape a perspective informed by acute consciousness of the plastic crisis. This engaging article will be of particular interest to scholars with a philosophical orientation, but policy analysts may also welcome the challenge to rethink their perceptual boundaries of how they perceive marine plastic pollution.

And it is never too early to start thinking about it: continuing with our interdisciplinary theme, in our next article psychologist Hartley and colleagues [15] examine educational activities designed to influence European children’s proclivity to discard waste in public spaces. This approach and study may seem somewhat removed from concerns about marine debris on the high seas but the importance of systematically investigating the ‘human dimension’ is increasingly being emphasised

[16,17], and early childhood education can influence litter awareness and behaviour. They present the promising results of two studies focused specifically on marine litter education, looking at the impact on educators and students alike. In an era when youth are mobilizing to force large fast food chains to discontinue the free distribution of plastic straws, it is evident that there is a bright future for litter reduction campaigns, and we need to integrate this into educational programs as early as possible.

Next, we turn to local/regional analyses that offer both descriptions of the empirical problem the crisis has raised as well as possible policy-based solutions. We may be accustomed to thinking of Costa Rica as an ecotourist destination, but heavy plastic pollution lurks close to its “golden coast.” Johnson and colleagues [18] describe recent, quite disturbing findings pertaining to the water column of the Costa Rica Thermal Dome; and suggest the Dome should be one of the first World Heritage sites located in Areas Beyond National Jurisdiction (ABNJ). Central American governments would have to work on this innovative policy step together, which evinces the literature on neofunctionalism crafted by Ernst Haas [19] and others as far back as the 1960s. Indeed, regional cooperation will be central to responding to the problem, regardless of the geographical context, and this could have positive “spillover” effects amongst participants.

Willis and colleagues [20] shift to a national scale with their study on another country famous for its beaches: Australia. They interviewed waste managers from 40 local councils, discussing and tabulating waste abatement strategies and investments, and used generalised linear models (GLMs) to compare outreach programs and state-led interventions. They found that investments in outreach campaigns led to larger reductions of waste in the environment than did investment in policies; and that councils that invested in a coastal waste management budget had fewer waste items on the coastline within their jurisdictions. Another Australian study, presented here by Schuyler and colleagues [21], compares container deposit legislation (CDL) across Australia and the U.S., finding that reduction in beverage containers in the presence of CDL was greater in areas with low socio-economic status, where plastic pollution loads are highest.

Australia is relatively well-studied in terms of marine debris, and indeed most things marine, but other geographic areas are lacking in assessments and policy analysis despite the severity of the plastics problem. Africa springs immediately to mind; anyone who has been on beaches on either the coast or, for that matter, has travelled inland, will most likely have seen the extent of plastic pollution and especially the ubiquity of plastic bags across that continent. Our next article by Jambeck and colleagues [22] seeks to correct this imbalance by looking at plastic-related waste management and mismanagement in several African countries. Following this, the next article localizes the issue further with an examination of public perceptions of the marine debris problem in Canada’s east coast Bay of Fundy, using participant observation, stakeholder roundtables, and interviews with stakeholders. The paper first reports on the differences in risk perceptions that were barriers to collaboration and the tactics used by stakeholders to influence priorities and actions. Rehn and colleagues [23] argue that Public Participation Geographic Information Systems should incorporate diverse data sets generated by different stakeholders, thereby motivating collaboration.

Another country less studied is Indonesia, despite its considerable impact on marine issues today in the Asia Pacific region. Spranz and colleagues [30] focus on Indonesia to examine and measure the effectiveness of non-monetary interventions – focusing on three different persuasion strategies – that can help to reduce plastic bag consumption. Results support the popular conjecture that local leaders play an important role in the Indonesian study area context. It will be interesting to see if this holds constant across other Indonesian regions and political cultures. The next article brings Indonesia and Australia together in an analysis by Richardson and colleagues [24] on lost fishing gear, a major source of marine debris and cause of sustained grief for marine

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