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Perspective

Far from a distraction: Plastic pollution and the planetary emergency

Jennifer L. Lavers [a,b], Alexander L. Bond [c,*], Charles Rolsky [d,e]

[a] Institute for Marine and Antarctic Studies, University of Tasmania, Sandy Bay, Tasmania 7004, Australia
[b] Centre for Marine Socioecology, University of Tasmania, Hobart, Tasmania 7001, Australia
[c] Bird Group, Department of Life Sciences, Natural History Museum, Akeman Street, Tring, Hertfordshire HP23 6AP, United Kingdom
[d] Plastic Oceans International, Malibu, California, 90265, USA
[e] Shaw Institute, 55 Main St. Blue Hill, Maine, 04614 USA

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ABSTRACT

Pollution of the environment with plastics has garnered significant public attention, but the topic has also been the focus of controversy, including assertions that resources are better spent on other topics, such as global warming. Here, we argue that plastic pollution and climate change are fundamentally linked, from the extraction of fossil fuels to the production of plastics, and eventual disposal. We demonstrate how plastics research and funding currently lag significantly behind that of climate change and conclude by advocating for a more integrated approach to addressing pressing conservation issues in the time of a planetary emergency.

1. Introduction

The pollution of the environment with plastics has garnered significant public attention in the last decade, including popular campaigns to reduce single use plastics (e.g., National Geographic “Planet or Plastic” campaign and Plastic Free July) and widely viewed documentaries (e.g., Blue Planet; Males and Van Aelst, 2021). Research into its presence and effects on biota, particularly marine vertebrates, has also increased markedly (Kühn and van Franeker, 2020), and more recently peer-reviewed journals (e.g., Microplastics and Nanoplastics; Koelmans, 2021) and conferences/sessions dedicated to plastics as contaminants have been established (e.g., 6th IMDC, 2019; MICRO2020).

The topic is not without controversy, which includes assertions that research time and resources are better spent on other topics like global warming, overfishing, or coral bleaching (Cunningham et al., 2020; Stafford and Jones, 2019). This is because plastics are not seen as great a threat to oceans as climate change or over-fishing (Stafford and Jones, 2019), there has been little tractable mitigation at local or regional levels (Borrelle et al., 2020), and there are few conclusive studies on population level effects of plastic pollution (Bucci et al., 2019; Rochman et al., 2016; Wilcox et al., 2016), except see Marn et al. (2020) which identified ‘ecological breakpoints’ (cessation of reproduction or negative population growth) associated with exposure to ingested plastics in sea turtles. Furthermore, toxicity effects, especially for humans, are sometimes overstated (Völker et al., 2019) leading to confusion, mistrust, and taking attention away from studies more accurately linking plastics to harmful consequences (CIEL, 2019). Many of these indirect impacts or costs are often overlooked (e.g., plastics manufacturing facilities are poisoning their workers and local communities; Simmonds et al., 2021) and much of the data on sublethal effects of plastics on biota are from experimental studies that are not always at environmentally relevant exposures (Bucci et al., 2019; Rochman, 2016; Wang et al., 2019). The consequences of exposure are also highly complex, with many of the negative impacts likely to be associated with the smallest particles (i.e., nanoplastics; Hamed et al., 2022) and associated chemicals, but precise relationships are still poorly described (Kumar et al., 2021; Rai et al., 2022).

Here, we argue the topics of plastic pollution and climate change are fundamentally linked, and that contrary to some assertions, research and funding into plastic pollution lags significantly behind that for climate change. We conclude by advocating for a more integrated approach to addressing pressing conservation issues in the time of a planetary emergency.

2. Plastic pollution is intrinsically linked to climate change

While plastic pollution and climate change have been presented in opposition (Stafford and Jones, 2019), as environmental crises, their common features are especially notable. Failing to recognize these intimate connections not only makes tackling these issues inefficient,

* Corresponding author.
E-mail address: a.bond@nhm.ac.uk (A.L. Bond).

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but may also undermine efforts on both fronts (Avery-Gomm et al., 2019; Zhu, 2021). Plastics and climate are intrinsically linked through multiple processes, endpoints, and a shared chemical blueprint. Greenhouse gases (GHGs) and plastic polymers share a common bond in the form of carbon, and the complex mixture of chemicals often referred to as a 'cocktail', most of which are not disclosed and/or poorly described (Bucci and Rochman, 2022; Rochman, 2015; Rochman et al., 2019). GHG emissions also occur at every stage of the plastic life cycle (Bauer et al., 2022), including extraction and transportation of raw materials, plastic manufacturing, waste treatment, and weathering (Royer et al., 2018; Shen et al., 2020; Walker and McKay, 2021). Petrochemicals are rapidly becoming the largest driver of global oil consumption (IEA, 2018). GHG outputs as a result of plastic production-related processes are predicted to reach 2.8 gigatons per year by 2050, with U.S. based plastics manufacturing (~21 % of global production; Law et al., 2020) accounting for ~114 million tons of CO_2 annually, roughly equivalent to 57 average sized (500-megawatt) coal-fired power plants (Beyond Plastics, 2021). While next-generation polymers offer the possibility of zero emissions, their manufacture is associated with potentially serious side effects, such as terrestrial acidification and water eutrophication due to biomass utilization (Meys et al., 2021). In the meantime, all this CO_2 seriously threatens the global community's ability to keep global temperatures within the 2015 Paris Agreement targets (Shen et al., 2020; Zheng and Suh, 2019), and the 2021 Glasgow Climate Pact (UNFCCC, 2021). Plastics and climate are also linked through their distribution and effects, with changes in climate potentially exacerbating the spread of plastic in the natural environment through increased extreme weather events and flooding (Ford et al., 2022). Finally, higher temperatures and UV exposure associated with a changing climate could accelerate rates of plastic fragmentation in the environment (Born and Brüll, 2022).

Like climate change, the focus on individual actions as a solution is often misplaced, though it remains a focus of media and industry. For decades, the petrochemical industry has offloaded responsibility onto individuals through promoting concepts such as the "carbon footprint", championed in a 2004 advertising campaign by British Petroleum (Cherry and Sneirson, 2011). Capitalising on the success of such schemes, the plastics industry has also stalled negotiations and prevented legislation through advocating for similar programs (e.g., "plastic footprint"; Anonymous, 2014) and through aggressively promoting recycling, incineration (e.g., waste to energy), and reusable shopping bags as meaningful solutions, despite evidence to the contrary (CFSWS, 1989; Edwards and Meyhoff Fry, 2011; Root, 2019). For example, reusable bags must be used up to 131 times to ensure that they have a lower global warming impact than conventional, polyethylene plastic bags (Edwards and Meyhoff Fry, 2011). Partially in response to China's 2018 National Sword Policy (Ministry of Environmental Protection, 2017), the U.S. is now burning six times the amount of plastic than it is recycling (USEPA, 2018). Here, too, the links between plastic and the worrying changes to our climate are undeniable with plastic incineration in the U.S. alone estimated to produce 2.41–4.81 million tonnes of CO_2 annually (CCC, 2020; Moon and Morris, 2019; USEPA, 2018).

3. Plastics denialism and climate scepticism

Just as climate change has been denied and presented in terms of false equivalences and debate (Kaula, 1990; Kerr, 1989; Lindzen, 1990), so too has the issue of plastic pollution (Cunningham et al., 2020; Senko et al., 2020; Stafford and Jones, 2019). Though the potential for fossil fuel combustion (in the form of coal) to cause global heating was first postulated in 1856 (Foote, 1856), and the "Keeling Curve" of CO_2 measured at Mauna Loa, Hawai'i showing rises in atmospheric CO_2 was first presented in 1960 (Keeling, 1960), it was not until 1988 that climate change became a mainstream issue (Government Printing Office, 1988). However, there was widespread recognition of the serious threat GHG emissions posed a decade before both within government (Suomi et al., 1979) and the fossil fuel industry (e.g., Holland, 1970), though it would be decades before the latter admitted complicity (Raymond, 1998). And while the petrochemical industry and plastic companies have been quick to pledge money towards beach clean-ups or sustainability partnerships in recent years, their emphasis on circular economy and questionable recycling strategies demonstrates their continued dedication to "future-proofing" capitalism against similar types of environmental perils (Mah, 2021).

In the 1980s, at a time when global heating was at the fore of public environmental policy debates, the science was well established, having demonstrated known and predicted climate-related impacts on issues such as human health (Longstreth and Wiseman, 1989), forest loss (Cook and Johnson, 1989), precipitation patterns (Williams, 1989), bushfire risk (Beer et al., 1988), and potential harm to the economy (Sonka and Lamb, 1987). Scientists had also worked out the critical role cloud cover, aerosols, and other factors played in highly complex atmospheric and oceanic systems that drive climate patterns (Shaw, 1987; Slingo, 1989).

Plastic pollution, by comparison, is 40 or 50 years behind in terms of research, policy, and understanding of its effects (Borrelle et al., 2017), despite some early concerns (e.g., Pauly et al., 1998). In the late 1980s, when global plastic production already exceeded ~110 million tonnes annually (Geyer et al., 2017), plastics research in wildlife was nascent, with only a small number of studies documenting presence and intensity using fairly simple metrics (e.g., the number of ingested pieces). At the international level, the United Nations Group of Experts on the Scientific Aspects of Marine Environmental Protection held its first meeting on plastics in 2010 with the first report on the source and effects of debris on wildlife published in 2015 (GESAMP, 2015). To this day, presence/absence of plastics in wildlife remains a significant research focus (Provencher et al., 2019), and our understanding of key risks is extremely limited (e.g., how accumulating plastic raises the temperature of beach sediments; Lavers et al., 2021). Meanwhile, plastics production has more than tripled (PlasticsEurope, 2020). It is therefore perhaps unsurprising that we see the similar form of denialism that plagued climate science in the 1970s and 1980s.

Recent prioritization exercises of plastics research areas and gaps have regularly identified fundamental questions (identification of sources, spatial distributions of contamination, how plastics are measured and quantified; Provencher et al., 2020; Vegter et al., 2014), many of which are necessary for progressing the field to address the impacts and consequences, as well as the response of species and systems. Again, the fundamental nature of these research priorities contrasts with the progress made in climate science by the late 1980s, further hampering not only research and policy implementation, but fuelling scepticism. This can result in the dominance of a few voices, particularly in the public sphere, who may be well intentioned but who miss the mark and are too eager to be reductive and single-focused (e.g., Monbiot, 2021).

4. Plastic pollution is pervasive

The dissenting voices that have labelled plastics as a "distraction" are few. Instead, those working in this area have increasingly adopted terms such as "ocean emergency" (Wabnitz and Nichols, 2010), "persistent marine pollutant" (Worm et al., 2017), "environmental crisis" (Marks et al., 2020), "planetary boundary threat" (Persson et al., 2022; Villarrubia-Gómez et al., 2018), and "plasticene epoch" (Ross, 2018; Zalasiewicz et al., 2015) to highlight the pace of change we are witnessing, scale of the challenge we face, and broader scientific consensus about the threats posed by plastic pollution.

The sheer extent of plastic pollution is astounding. Like the impacts of climate change, there is no ecosystem on Earth untouched by plastics. Plastics are found in the Mariana Trench (Chiba et al., 2018), Mount Everest (Napper et al., 2020), remote oceanic islands (Lavers and Bond, 2017), polar ice sheets (Obbard et al., 2014), lungs and placenta of humans (Pauly et al., 1998; Ragusa et al., 2021), faeces of infants (Zhang et al., 2021), the food we eat (e.g., beer and salt; Kosuth et al., 2018), the air we all breathe (Brahney et al., 2020), and the water we all drink (Kirstein et al., 2021). By mass, there is twice as much plastic in the world (8 Gt) than animal life (4 Gt; Elhacham et al., 2020). It is ubiquitous in every sense of the word and its presence already has negative implications for soil temperature and habitat suitability (Lavers et al., 2021), disease likelihood in coral reefs (Lamb et al., 2018), melting rates of polar snow and ice (Zhang et al., 2022), and human health (Donkers et al., 2022). Many of these impacts have been identified as being "poorly reversible", due to the difficulty of reducing plastic emissions, resulting habitat changes within soils and aquatic ecosystems, and demonstrated risk to keystone species (MacLeod et al., 2021).

The impacts on, and relationships with, global planetary warming are not the only threats posed by plastic pollution. Myriad types and large quantities of plastic have now been recorded in the stomachs of wildlife ranging from tiny Antarctic krill (Dawson et al., 2018) to 40 ton sperm whales *Physeter macrocephalus* (Unger et al., 2016) and camels in the middle of the remote desert (Eriksen et al., 2021). These plastics act as an evolutionary trap, misleading wildlife into making maladaptive 'prey' choices that now affect numerous branches of the tree of life (Santos et al., 2021). Entanglement in rope and fishing line also poses a serious hazard to many wild species, particularly rare species such as Australian sea lions *Neophoca cinerea* (Page et al., 2004). The negative consequences of all this plastic demonstrated so far are equally astonishing, and yet over time, have also become unremarkable as more and more harm is documented. More than 1565 wild species are currently known to ingest plastic (Santos et al., 2021), and exposure has been linked with reduced body size (Lavers et al., 2014), nutrition levels (Puskic et al., 2019), altered blood chemistry (Lavers et al., 2019), and elevated contaminant loads (Lavers and Bond, 2016). New and previously undescribed consequences are being reported almost weekly (e.g., histological damage to soft tissues, impaired embryonic development; Hsieh et al., 2021; Rowlands et al., 2021) suggesting no matter the size of particles or species consuming it, plastic pollution poses serious issues we are yet to fully comprehend. What is clear is that we are now in a "zone of exceedance" of the Planetary Boundary for new materials, including plastics and associated chemicals, from a geological standpoint (Persson et al., 2022).

Both weathering microplastics, the associated chemicals, and broader marine plastic pollution exceed the criteria of a planetary boundary threat, a framework for bringing together multiple threats to the planet and humanity (Arp et al., 2021; Persson et al., 2022; Villarrubia-Gómez et al., 2018). It has impacts on cultural, regulatory, and provisioning of ecosystem services across the globe (Beaumont et al., 2019), which in turn can affect human health and wellbeing (Vethaak and Leslie, 2016). They originate from diverse human activities, not just direct pollution (Boucher and Friot, 2017; da Costa et al., 2016). With trillions of pieces of plastics in the oceans (Eriksen et al., 2014), and significant lag times between emissions and accumulation (Lebreton and Andrady, 2019), current mitigation measures are inadequate for stemming the tide of plastics entering the oceans (Borrelle et al., 2020).

The global agricultural industry uses plastics throughout its operations, from crop sowing and animal feeding to final packaging and delivery: most of these have exceptionally short commercial lifespans and total 12.5 million tonnes annually, making plastic pollution a threat to confidence in global agriculture systems and food security (FAO, 2021). This is also true of wild-caught foods which can disproportionately affect Indigenous communities who are often excluded from the management and study of plastic pollution (Chisholm Hatfield, 2019) and suffer land and water dispossession as a result of fossil fuel and plastics manufacturing (Spiegel, 2021). Because of the clear demonstrated and potential risk of future harm to people and the planet, global pervasiveness, and requirement for international cooperation, plastic pollution has recently been identified as a threat to global security (Dubois, 2021), including food security (Zhang et al., 2020). Dubois (2021) encourages a realignment of the definition of security from one solely focused on the state to one that considers the needs of the individual. Other realignments (e.g., to include non-military threats such as environmental instability that threaten human quality of life) have widespread support as they more accurately reflect our current global systems, connectivity, and reliance on natural resources (Dubois, 2021; Liu et al., 2022). Thus, the realignment and widened definition of security inherently encompasses the environmental degradation and human health risk created from plastic pollution to the individual, framing it as an infringement to human rights as the security of the individual would be compromised without coordinated global action.

Furthermore, if we view plastic pollution and climate change as threats to global security, more drastic steps can be taken to remediate the problem through global governance (Borrelle et al., 2017; Diana et al., 2022; Dubois, 2021). In short, plastics are here to stay (certainly within the next century, and likely much longer), which requires a fundamental shift in how they are addressed from both a research and regulatory perspective. Like chemical pollutants, such as polychlorinated biphenyls (PCBs), an approach of total elimination is, at present, not practical and efforts to reduce marine plastics should focus on the sources (MacLeod et al., 2021; Sherman and van Sebille, 2016). Devising a clean-up strategy for such a diverse array of contaminants spanning many orders of magnitude is not regulatorily or practically feasible (MacLeod et al., 2021).

5. Plastic pollution is a human rights issue

Plastic pollution is also, ultimately, an issue affecting livelihoods and human rights, rooted in colonialism. The extensive resources (e.g., oil, gas) required for the production and disposal of plastics (including land) are often taken from or imposed upon marginalized communities (Chisholm Hatfield, 2019; Liboiron, 2021), and it disproportionally affects the most vulnerable (workers, children, women, Indigenous peoples, coastal communities and those in poverty; Orellana, 2021; Yates et al., 2021). The effects span the entire lifecycle of plastics, from extraction and production (Orellana, 2021) through transport, use (Gonçalves, 2020), and disposal (He et al., 2015). More affluent nations often export plastic waste to the Global South, thereby offloading the environmental and humanitarian costs (Liang et al., 2021), often creating an artificial sense of lower environmental pollution in exporting countries ("out of sight, out of mind"; Barnes, 2019). In many of these countries, appropriate waste disposal infrastructure is lacking, meaning plastics are burned in open pits or crude incinerators, thereby creating significant health hazards for residents (Velis and Cook, 2021). The probability that someone in a coastal community of the Global South, which receives >8 million tons of imported plastic waste annually (Liang et al., 2021), would view plastic pollution as a "distraction" is likely very small.

Our current approach to understanding "waste" and "harm" is also problematic. While many have argued that the "gold standard" of the effects of plastic pollution is evidence of population declines or individual mortality, this is based on the threshold theory, whereby some level of pollution is deemed acceptable at a collective level (Novotny and Krenkel, 1975), and ignores the impacts on individuals, places, communities, and systems in other areas while assuming that environmental compartments (be they wildlife, beaches, oceans, food, or the air) are "Resources for waste disposal … premised on access to Land for settler and colonial goals" (Liboiron, 2021: 40). It also doesn't reflect the increasingly known sublethal effects and morbidity associated with plastics, such as reduced body size and altered blood chemistry (Lavers et al., 2019), which may have complex or long-lasting consequences that are as yet unknown.

The UN Development Programme's Sustainable Development Goals (SDGs) include several that refer to plastics and waste, including Goal 6 ("Ensure availability and sustainable management of water and sanitation for all"), 12 ("Ensure sustainable consumption and production patterns"), and 14 ("Conserve and sustainably use the oceans, seas and marine resources for sustainable development"), but given its disproportionate effects on marginalized communities, addressing plastic pollution will be beneficial to many others (Orellana, 2021; United Nations, 2015). The accelerating production of GHGs associated with our unsustainable use and disposal of plastic is also relevant to Goal 13 ("Take urgent action to combat climate change and its impacts"; Walker, 2021). While certain countries have addressed the impact of plastic pollution through the implementation of policies and long-term monitoring programs, many are broad and not species-specific enough to make a direct impact (Linnebjerg et al., 2021). There is also a lack of enforcement and continuous monitoring of such policies, leading to doubt about their overall impact (Linnebjerg et al., 2021).

The UN Special Rapporteur on the implications for human rights of the environmentally sound management and disposal of hazardous substances and wastes makes numerous recommendations for an informed, participatory approach to plastics management that recognizes the threats and harm posed throughout the plastics life cycle (Orellana, 2021).

6. Plastic pollution and climate change research should not be in competition

Though plastic pollution often garners significant media attention, this often ascribes a greater understanding of its effects and mitigation measures than is scientifically known (Henderson and Green, 2020; Völker et al., 2019). As a field coming of age in a time of increased digital media consumption and global connectivity, and with stark images of individual case studies (e.g., Keefe and Hoffman, 2017) plastic pollution lends itself to significant public engagement in a way that overfishing, or climate change did not have access to in their nascent discussion (Dilkes-Hoffman et al., 2019). Consequently, plastic pollution is often portrayed as a global conservation focus (Dilkes-Hoffman et al., 2019; Henderson and Green, 2020), when, in terms of resources and global research focus, it is often overlooked in comparison to climate change or overfishing, which have both been deemed to be more significant (Stafford and Jones, 2019). For example, between 2015 and 2021, four major research granting agencies (Australian Research Council, European Research Council, Natural Sciences and Engineering Research Council of Canada, and US National Science Foundation) funded >7000 projects totalling >$1.37 billion (2021 USD) that mention climate change (though some may do so only tangentially), compared to only 83 projects totalling $34.3 million (2021 USD) for those referencing "plastic pollution" or "marine debris" (Table 1). Far from being a "distraction" (Stafford and Jones, 2019), its research footprint is only 2.5 % that of climate change.

All facets of plastic production, from production through usage and disposal contribute to climate change, more so than previously expected (Shen et al., 2020; Walker and McKay, 2021). Some suggest labelling the most harmful plastics as "hazardous materials", to expedite the transition to safer, more reusable materials (Rochman et al., 2013). Ultimately, it becomes imperative to see the effects of plastic pollution, climate, and other environmental pressures as intertwined and cumulative instead of isolating them and pitting them against one another (Foley et al., 2017; Gardner et al., 2020). Throughout our education, we are taught the importance of key ecological features, including cumulative and synergistic effects. Yet, as many of us move through our scientific careers, we become increasingly specialised in our fields, often resulting in discipline-specific ways of thinking about or approaching an issue (Young, 2010). A recent review showed climate change and plastic pollution studies in the ocean are often siloed in this way, with only 0.4% of articles examining both stressors simultaneously (Ford et al., 2022). Much as an ocean ecosystem is comprised of many delicate parts working in synergy, so are complexities of the threats. Tackling the many wicked challenges that plastic pollution presents will therefore require a genuine shift away from silo approaches to one where environmental scientists engage in cross-discipline dialogue (Young et al., 2014) and fully acknowledge the link between plastic production, usage, and disposal/reuse and other environmental crises, including global heating and biodiversity loss (Gall and Thompson, 2015; Shen et al., 2020).

Table 1
The amount and number of grants awarded between 2015 and 2021 by four major research councils in publicly searchable databases for "plastic pollution" or "marine debris", and "climate change". Values are presented in 2021 US dollars.

Granting agency	Number of awards		Award value (2021 USD)	
	"Plastic pollution" or "marine debris"	"Climate change"	"Plastic pollution" or "marine debris"	"Climate change"
Australian Research Council[a]	4	719	$1,627,287	$390,510,529
European Research Council[b]	2	160	$13,129,460	$376,906,050
Natural Sciences and Engineering Research Council of Canada[c]	34	5317	$1,483,253	$278,665,052
US National Science Foundation[d]	43	814	$18,024,867	$323,976,299
Total	83	7010	$34,264,868	$1,370,057,930

[a] https://dataportal.arc.gov.au/RGS/Web/Grants.
[b] https://erc.europa.eu/projects-figures/project-database.
[c] https://www.nserc-crsng.gc.ca/ase-oro/Results-Resultats_eng.asp.
[d] https://beta.nsf.gov/funding/opportunities.

Ultimately, rather than working in opposition, those involved in marine conservation are all pushing in the same direction against similar global pressures – ensuring sustainable livelihoods and marine ecosystems across the world in the face of a planetary emergency, of which plastics form a part (Arp et al., 2021; Persson et al., 2022; Villarrubia-Gómez et al., 2018). We need to disabuse ourselves of the notion that we are restricted to a financially limited way of operating that puts us in competition and results in devaluing the hard work of others – this applies in both research and public policy (Avery-Gomm et al., 2019). For example, in Australia, threatened species research funding from the Commonwealth government amounted to AU$10 million (Australian Government, 2021), meanwhile fossil fuel subsidies from Commonwealth and state governments exceeded AU$10 billion (Campbell et al., 2021). It has been clear for more than 20 years that the global financial resources to tackle conservation are present if we, as a society, valued it (Balmford and Whitten, 2003).

Why is this the case? It could be related to our poorer understanding of whole lifecycle costs of plastics and their alternatives (Davidson et al., 2021). From extraction to production and disposal, the environmental footprint of plastics is significant (Walker and McKay, 2021), and many of the approaches and solutions developed from more than 40 years of intensive study of climate change would also apply. It could also be related to the scarcity mindset that is common in conservation whereby a triage approach is applied, perhaps needlessly (Price et al., 2021). Either way, what's clear is that climate and plastics are intrinsically linked, thus, how can one be a distraction from the other? By addressing one, we invariably make progress on the other. What's required is a "levelling up" of research into plastic pollution given its scale, perniciousness, pervasiveness, and high uncertainty.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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