

PLASTIC POLLUTION
BIODIVERSITY UNDER THREAT



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éditions Quæ

Plastic pollution, biodiversity under threat

Xavier Cousin, Gaëlle Darmon, Marie-France Dignac, Franck Lartaud, Gaël Le Roux, Gaëlle Mathieu-Ernande, Claude Miaud (eds)

Preface by Angèle Préville and Philippe Bolo

Éditions Quæ

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Fabrice Pernet, Frédéric Gazeau, 2025, 116 p.

To cite this work:
Cousin X., Darmon G., Dignac M.-F., Lartaud F., Le Roux G., Mathieu-Ernande G., Miaud C. (eds), 2026. *Plastic Pollution, biodiversity under threat*, Versailles, éditions Quæ, 178 p., https://doi.org/10.35690/ 978-2-7592-4402-7

A scientific evaluation of the French version of this book, *Pollution plastique, la biodiversité menacée*, was carried out prior to publication (procedure described here: https://www.quae.com/store/page/199/processus-d-evaluation).

The editorial process also relies on software that detects similarities and texts potentially generated by artificial intelligence.

The publication of this book was financially supported by the *Défi Clé* BiodivOc, itself supported by the Occitanie Region and the University of Montpellier.

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Éditions Quæ
RD 10, 78026 Versailles Cedex, France
www.quae.com – www.quae-open.com

ISBN (paper): 978-2-7592-4401-0
ISBN (epub): 978-2-7592-4403-4
ISBN (PDF): 978-2-7592-4402-7

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Acknowledgements

The BiodivOc project was born from an initiative by the Occitanie Region to support research into the functioning and dynamics of biodiversity. This work was conducted at a regional scale, but its implications are much broader. Indeed, it would be futile to attempt to understand biodiversity within a restricted geographical space. It would be equally futile to neglect such research amidst the current erosion of biodiversity. The drivers of this decline are well-known and scientifically identified: major climate change, land-use change due to urbanization and agriculture, invasive species, and, of course, pollution in all its forms.

When discussing "pollution", one cannot ignore plastic—ubiquitous and massive, as Angèle Préville and Philippe Bolo remind us in the preface to this book. Yet our knowledge of plastic's impact on biodiversity, species and ecosystems remains limited and all too often overlooked. This led the *Défi Clé* BiodivOc to organize the symposium entitled "Biodiversity and Plastic Pollution: From Impacts to Solutions" in Banyuls-sur-Mer in January 2023. This event brought together a panel of scientists, policymakers, businesses, associations, and citizens to review current knowledge and explore potential ways forward. It is from this symposium that this book was created as a collective endeavour, a principle well worth upholding today.

Our primary thanks go therefore to the Occitanie Region for granting us complete freedom of choice and action; to the University of Montpellier for their unfailing support, without which this work would certainly not have seen the light of day; and to the Banyuls Oceanological Observatory (Sorbonne University) for hosting the symposium.

We also thank the thirty authors who contributed to this work. By drawing on concrete examples from recent scientific studies, they provide the reader with the keys to understanding the major challenges and risks posed by plastic pollution.

Sincere thanks are also due to the members of the coordinating committee—X. Cousin, G. Darmon, M.-F. Dignac, F. Lartaud, G. Mathieu-Ernande, G. Le Roux and C. Miaud—for their dedication. Under the tenacious and exacting leadership of G. Mathieu-Ernande, they ensured the coherence and quality of this work, and (nearly) succeeded in keeping us to the schedule.

I would like to extend a special thanks to Angèle Préville and Philippe Bolo for kindly writing the preface, and for their long-standing commitment alongside the scientific community to alert public authorities to the gravity of plastic pollution.

Finally, thanks to the entire team at Éditions Quæ for their confidence in us and for supporting us throughout the preparation of this book.

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Preface

What kind of world do we want for tomorrow? What kind of world do we wish to leave to future generations?

This work provides some answers to these essential questions. Supported by the extensive research of scientists and specialists in plastic pollution and its impacts, it represents a tremendous effort to raise awareness, which is essential for strong engagement of both citizens and policymakers.

As part of our report, "Plastic Pollution: A Ticking Time Bomb?"[1], submitted to OPECST (Parliamentary Office for the Evaluation of Scientific and Technological Choices) in 2020, we interviewed many scientists working on this subject. They drew up an alarming assessment!

Since then, their research, experiments, and observations have continued, providing us with additional knowledge and an increasingly refined understanding of pollution and its effects. Sharing this knowledge is vital to ensuring that everyone understands this insidious and widespread pollution. It is a necessary prerequisite for initiating both individual and collective action. In this light, we commend the authors' generous and responsible initiative to share their scientific expertise.

The "revelations" contained in this book are likely to raise awareness, shake things up, and provoke reactions and actions that challenge our certainties and habits. Just as our report for OPECST was a landmark publication, this volume aims to be equally pivotal. It provides irrefutable evidence of the urgency with which we must address this subject. Our collective responsibility is to ensure that the state of the planet is no worse than it was before we came along.

Our various projects for OPECST—the aforementioned 2020 report, the 2023 public hearing summary on the scientific stakes of the international treaty to end plastic pollution[2], the 2023 note on plastic recycling[3], and the 2024 public hearing summary on the impacts of plastics on human health[4]—have allowed us to measure, sometimes with dread, the considerable long-term effects of this pollution. It is already so unacceptably extensive, disseminated and scattered across every part of the Earth, and within the organisms that inhabit it. It exists in all forms and at all scales, sometimes in fragments so small—micro- and nanoplastics—that they become invisible.

1. "Pollution plastique, une bombe à retardement ?", https://www2.assemblee-nationale.fr/content/download/320346/3119124/version/2/file/2020_0063_rapport_pollution_plastique-compress%C3%A9.pdf
2. https://www.senat.fr/rap/r22-641/r22-6411.pdf
3. https://www.philippe-bolo.fr/wp-content/uploads/2024/01/opecst_note_recyclage_plastiques_vf2.pdf
4. https://www.senat.fr/rap/r24-141/r24-141-syn.pdf

We have a responsibility to stem this massive and uninterrupted flow and to halt an accumulation that has, unfortunately, been going on for far too long.

Despite the warnings, plastic production continues to grow exponentially. Contrary to what one might imagine given the shocking pictures of seals entangled in discarded plastic fishing nets or turtles injured by straws lodged in their nostrils, plastic consumption has not decreased. "Ghost nets"—which are anything but ethereal—cause the death of marine animals. This is not a marginal phenomenon but a cruel and appalling reality, extremely detrimental and a primary driver of biodiversity decline.

As parliamentarians, we utilized the "Circular Economy and Anti-Waste" law (*loi AGEC*) to incorporate several measures aimed at curbing the negative impacts of the irrational use of plastics. Among the robust measures of this law, we should specifically mention the implementation of Extended Producer Responsibility (EPR) for fishing gear, the obligation to limit the leakage of virgin plastic pellets at production, transport and storage facilities, and the ban on plastic packaging for fruit and vegetables.

All these virtuous legislative intentions were met with circumvention by active lobbying, which is unscrupulous and indifferent to the urgency of preserving the planet, its biodiversity, and our collective health. These actions have delayed the law's implementation.

In many respects, certain plastics are no longer "fantastic", but horrific. Misplaced in nature, they do not decompose; they fragment. They become laden with the organic pollutants they encounter. They are colonised by numerous microorganisms that are potentially invasive and pathogenic. Finally, throughout their extensive life cycle, they leach the additives, plasticisers and other chemicals they contain. Some of these molecules are endocrine disruptors that continuously accumulate in every environmental compartment, in water, soil and in our bodies. Even low doses put our health and our ecosystems at risk.

This book documents, with scientific evidence, each of these phenomena and their consequences. It helps show that pollution from surface macrolitter on the oceans is merely the tip of the plastic pollution iceberg. It is beneath the visible surface, down to the seabed, that the problem is far more significant. Knowing that our beautiful Mediterranean Sea—the *Mare Nostrum* so dear to our hearts—is one of the most polluted marine areas on earth must serve as a stark wake-up call, demanding a forceful and immediate response.

Our hyper-consumerist society has made plastic omnipresent in our daily lives, creating habits and conveniences associated with "disposable" and pre-packaged culture. The problem of plastic pollution is far more complex than the simple abandonment of packaging in the environment. It touches upon our lifestyle habits, the very organization of our society, and our consumption model. The pace is still accelerating, as shown by the recent and emblematic phenomenon of ultra-fast fashion: the frenetic and massive consumption of synthetic fibre clothing purchased online at very low prices.

It should be shouted loud and clear: polyester and fleece fabrics are plastic! It is said that the quantity of clothing already manufactured and available in the world could clothe 12 billion human beings for four generations! With the rampant production

of synthetic textiles, the health risks and deleterious effects on ecosystems lie in the dissemination of plastic microfibres into the air and water during machine washing and daily wear.

We expect a great deal from the forthcoming United Nations treaty on plastic pollution currently under negotiation. We attended the second session of the Intergovernmental Negotiating Committee in Paris in May 2023. This legally binding instrument represents a formidable opportunity to push for solutions that must be taken on a global scale.

Within these negotiations, we have seen the influence of lobbies and the overly large number of countries hostile to a reduction in production, whether for economic and strategic interests or through a lack of understanding of the impacts of plastic pollution.

In the debates surrounding this international treaty, the issue of additives is emerging, which is a welcome development. However, while further scientific research is indeed necessary on these, for some—make no mistake—it serves as a pretext to further delay the binding decisions that would apply to them.

There is still a long way to go, and we need to see more initiatives of all kinds to reverse this trend. This is everyone's responsibility.

The strength provided to us by the scientific community lies in the power of knowledge and understanding, which allow us to act as informed citizens. Our sincere thanks go to all those who have dedicated their time and shared their expertise to make this vast subject accessible.

Expectations are high, and it is optimism that must sustain us.

We hope you enjoy the book!

Angèle Préville[5] *and Philippe Bolo*[6]

5. **Angèle Préville** is a former senator of the Lot department, member of the Committee on Regional Planning and Sustainable Development, and member of the Parliamentary Office for the Evaluation of Scientific and Technological Choices (*Office parlementaire d'évaluation des choix scientifiques et technologiques*) (2017-2023).

6. **Philippe Bolo** is the mayor of Avrillé, Vice-President of Angers Loire Métropole, former Member of Parliament (député) for Maine-et-Loire, former member of Economic Affairs Committee, Parliamentary Office for the Evaluation of Scientific and Technological Choices (2017-2026).

General introduction

Fabienne Lagarde and Pascale Fabre

Plastic: a revolutionary material

Plastics entered our lives on a massive scale starting in the 1960s, carrying the image of inert, resistant, and safe materials. What we call "plastic" is primarily composed of polymers, which are very long chains made of small molecules (or monomers) linked together. Additives are also included in their composition, though in smaller quantities, to grant them specific properties such as plasticity or resistance to ageing. These exceptional qualities constituted a true revolution in materials chemistry, as evidenced by the fact that several Nobel Prizes were awarded in the second half of the 20th century to researchers who discovered or studied them. Due to their very low cost, plastics have democratised access to consumer goods and technology and have improved medical care worldwide. They have quite simply revolutionised our lives. Yet, sixty years later, they are considered a global scourge and have become the central focus of international negotiations under the auspices of the United Nations to try to halt their proliferation.

The plastic bag perfectly illustrates this paradigm shift: the first polyethylene bag was patented in 1965 by the Swedish company Celloplast and, 25 years later, occupied more than 80% of the bag market in Europe (Figure I.1). These bags, presented as being



Figure I.1. From the first disposable polyethylene bag (patented in 1965) to plastic-filled landscapes (2011).

clearly superior to paper bags or reusable bags, entered the American market in the early 1980s and, following a meteoric success, brought us into the "fully-disposable" era. In barely 20 years, the world was invaded by plastic, including the famous disposable bags, and following the first alerts from explorers and scientists, some states began to act. Bangladesh was the first country in the world to ban plastic bags in 2002, after discovering during catastrophic floods that they were clogging drainage systems. Other countries followed suit, but without truly reversing the trend. In 2011, it was estimated that one million plastic bags were consumed every minute worldwide! To date, nearly 100 countries have partially or totally banned the use of disposable plastic bags, and numerous restrictions on the use of single-use plastics have emerged. Nevertheless, global production of plastic materials continues what seems to be an inexorable progression, with nearly 460 million tonnes produced in 2019.

⏩ Plastics at the confluence of the triple planetary crisis of climate, pollution and biodiversity

Thus, in less than sixty years of existence, plastics have become the third most produced material in the world after cement and steel, representing absolutely considerable volumes. This massification of production and usage now places plastics at the confluence of the triple planetary crisis we are experiencing—that of climate, pollution, and biodiversity loss (Figure I.2).

The consequences of human activity on the environment are difficult to predict and even harder to quantify. The concept of "planetary boundaries" was recently proposed to quantify human-caused disturbances to the Earth system in ecological, biogeochemical, and climatic processes. It is throughout their entire life cycle—from raw material extraction to production, consumption, treatment, or release into the environment—that plastics have an environmental impact and contribute to exceeding planetary boundaries. At present, six of the nine planetary boundaries have been exceeded; plastic contributes directly to one of them—the introduction of novel entities into the biosphere—and indirectly to five other boundaries already exceeded, the main ones being climate change and biodiversity loss. Among the five chemical products most produced in Europe and responsible for approximately 50% of the impacts on planetary boundaries are two plastic materials: polypropylene and high-density polyethylene, in addition to styrene, a toxic monomer precursor to polystyrene.

To cite only a few of the main effects of plastic production on the environment, we note the greenhouse gas emissions during the extraction of fossil resources for the production and synthesis of polymers, the vast majority of which are derived from petrochemistry. These emissions currently represent 3% of total CO_2 emissions; projections predict this proportion will reach 15% in 2040 (Karali *et al.*, 2024). Thus, plastic production contributes to climate change and ocean acidification, which becomes less and less effective for carbon sequestration, creating a vicious circle. Furthermore, there is not one plastic, but many plastics, with more than 16,000 chemical molecules that can enter their formulation as components or additives to give them specific properties: fire-retardants, antioxidants, plasticisers… Some of these additives produced in very large quantities are toxic and invade our daily lives and our environment. Moreover, through their growing presence in the soil, the atmosphere, and aquatic environments, plastics and their additives also alter habitats and ecosystems, contributing to the modification of biodiversity.

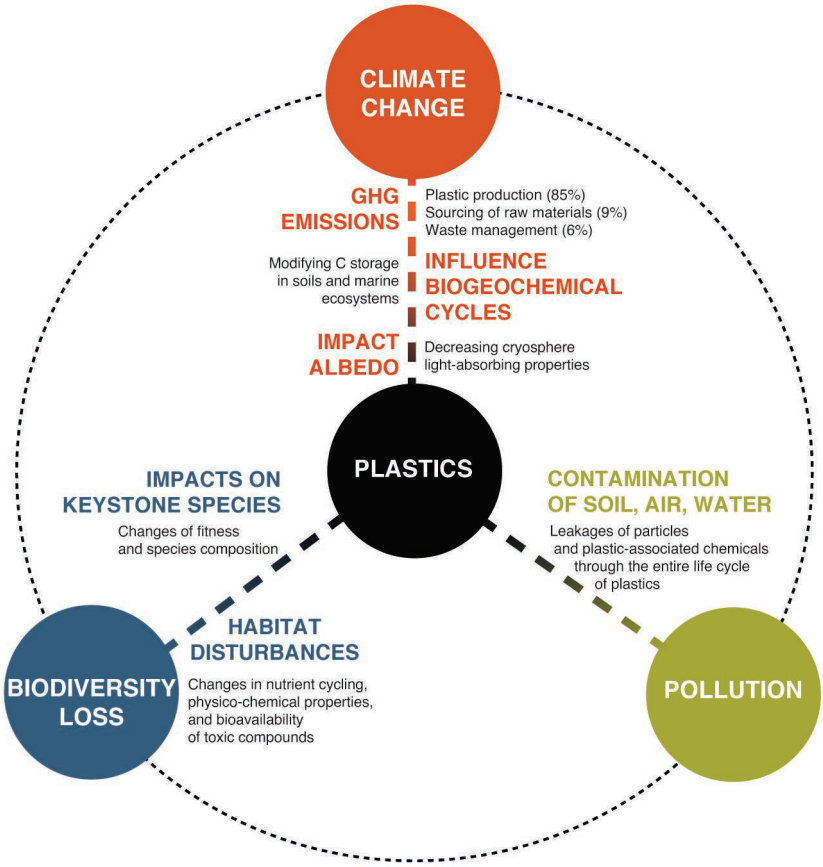


Figure I.2. Plastics are at the centre of the three planetary crises: climate change, biodiversity loss, and pollution.

GHG: greenhouse gas; C: carbon.

But of all the stages of its "life", it is in its "end of use" that plastic effectively turns into a problematic pollution, today clearly identified by the general public. Indeed, given the quantities produced and the fact that 40% of plastics are intended for short-term use, the volume of plastic waste generated is considerable and increases at the same rate as production. In its reference scenario, the Organization for Economic Co-operation and Development (OECD) predicts that the volume of plastic waste will further increase considerably in the coming decades, rising from 353 million tonnes (Mt) in 2019 to 1,014 Mt in 2060. These flows and the diversity of plastics that compose them make the management of these mountains of waste complex.

Recycling, presented as the essential link in this management, despite the efforts and costs incurred, is not living up to expectations. At present, worldwide, barely 10% of end-of-use plastics are actually recycled. More than 30% are still destined for landfills that are often poorly controlled, and it is estimated that every year, several tens of millions of tonnes of plastics enter the environment, quantities that could triple by 2040.

Like their production and usage phases, all plastic end-of-life stages have repercussions on the environment, but poorly managed waste that enters it directly and uncontrollably raises particular concerns, notably regarding its possible impacts on biodiversity.

It is estimated that every year, 8 to 12 million tonnes of plastics reach the world's oceans and seas via rivers and coastal areas. While the "plastic continent"[7] is the most infamous and constitutes the first giant plastic dump brought to public knowledge, we know today that plastic is present in all compartments of the environment: seabed, rivers, soil, atmosphere, and even in clouds. The presence of plastic in large quantities in the soil is less visible and publicised but is starting to be very well documented.

The durability of plastics is, in fact, both too great and not great enough: primarily under the effect of solar ultraviolet (UV) rays—much like the plastic chair on our terrace after several years—it crumbles and turns into smaller particles of a few millimetres: microplastics. These very light particles are easily transported by wind over great distances: they have been found even in remote regions of the Arctic. Until recently, it was even thought that microplastics could be used as a marker for the Anthropocene, had this era been validated: the depth of the sedimentary layers in which they are found was supposed to give us the starting point of the "all-plastic" era. But irony of fate: researchers have recently shown that the smallest particles slip deeper and deeper into the sediments, reaching zones corresponding to periods when plastic had not even been invented! Thus, it invades our present… and remodels the past.

However, the story does not end with microplastics: these particles can indeed continue to degrade into objects 1,000 to 10,000 times smaller: nanoplastics. Like all other nanoparticles, these are probably small enough to cross cell barriers and penetrate to the interior of organs, potentially causing much greater and more lasting damage than larger particles.

⏩ From plastic presence to plastic impacts

Not a day goes by without hearing about the loss of biodiversity, but what exactly does this term cover? Scientists speak of "biodiversity" at three levels: genetic diversity within a population or species, species diversity in a given location, and ecosystem diversity. For example, marine biodiversity includes coral reefs, kelp forests, seagrass beds, etc. Insofar as biodiversity covers a wide variety of species and ecosystems, assessing the consequences of plastic pollution on biodiversity is a very complex task. Furthermore, many factors influence biodiversity, and it is not easy to identify those specifically linked to polymers and their additives. To overcome this difficulty, scientists often reproduce environmental conditions as best as possible—but in a simplified way—in their laboratory. Another difficulty is linked to the complexity of plastic formulations, generally kept secret, and which range from ten to a hundred components: consequently, how can "the" culprit of an effect be isolated, especially as each plastic is different and different types of plastics are generally found in the places where they accumulate. Thus, it is difficult to prove that a given pollutant has an impact in such a multifactorial environment, and to convince the public, businesses, or the political world of this causality.

7. Discovered in 1997 by the American oceanographer Charles Moore, the "7th continent", also known as the "Great Pacific Garbage Patch", is situated between Hawaii and California; it currently spans over 1.6 million square kilometres, an area three times the size of mainland France (Lebreton *et al.*, 2018).

Despite all this complexity, three major classes of phenomena are now considered to have an impact on biodiversity: entanglement, ingestion, and the "rafting" effect.

Today, the observation is simple: wherever we look for plastic, we find it. Plastics have thus been identified by the scientific community in very varied environments and in a vast number of organisms at different levels of the trophic chain[8]. As oceans are a final receptacle for many pollutants including plastics, one of the first victims of plastic pollution is marine biodiversity. More than 1.5 million marine animals die every year because of plastic pollution, including 100,000 marine mammals caught or entangled in plastic waste. The accumulation of macroplastics (such as fishing gear or single-use plastics) in the environment can also cover and deteriorate important ecosystems, durably altering heritage or landscapes but also leading to the destruction of certain natural habitats such as coral reefs and mangroves.

Depending on their size, these wastes can also be ingested. A recent study (Darmon *et al.*, 2022), for example, showed the presence of plastic in the digestive tracts of nearly 70% of turtles found dead around the Mediterranean, although it cannot be stated that their death was solely linked to the presence of this waste. In the bird species *Ardenna carneipes* from Lord Howe Island, Australia, the link between plastic ingestion and a new disease, ironically named plasticosis and consisting of a fibrosis of the digestive tract, was recently highlighted (Charlton-Howard *et al.*, 2023).

At micro- and nanometric sizes, plastic particles also affect smaller organisms that ingest them, right down to the fundamental bases of food chains such as plankton. By passing through their digestive system, these particles have deleterious effects on organisms by altering certain biological functions, such as filtration activities and digestive processes, with repercussions on the animal's energy metabolism and major physiological functions, such as growth or reproduction. Furthermore, certain chemical additives in plastics have also been identified as having negative effects on reproduction and development in mammals, birds, fish, invertebrates, insects, and, at the end of the chain, humans.

At a larger scale, the great variety of microorganisms, named the "plastisphere" (see Part 3, Chapter 4), which colonises plastic debris in the environment could lead to significant modifications of ecosystems. For example, five years after the tsunami that took place in Japan in 2011 on the Pacific coast of Tōhoku, hundreds of new species of bacteria and microorganisms that had travelled on plastic debris (rafting effect) from the Japanese coasts were found on the American coasts. These exotic species can become invasive and thus disrupt the balance of local ecosystems by competing with native species.

Even soils and their biodiversity are not spared. We know today that soils are also the receptacle for very large quantities of plastic waste via direct contamination (illegal dumping, agricultural tarps, etc.), but also in a more indirect way through the spreading of sludge from wastewater treatment which itself contains microplastics. The presence of these particles can lead to changes in soil properties and thus modify not only the bacterial communities found there, but also the entire soil biodiversity, which now constitutes a major concern for the agricultural sector.

8. We also talk about the "food web", which describes the totality of trophic interactions between organisms within an ecosystem. Within a food web, various trophic levels are identified, defining, for instance, predator-prey relationships.

This work aims to explore the different facets of a problem that has become global and complex. Through some examples of in-depth analyses and recent case studies, we will examine the multiple effects of plastic pollution on different terrestrial and aquatic ecosystems, as well as on the species that depend on them for their survival.

Throughout the book, you will better understand the challenges posed by the massification of plastic in our lives, as well as the urgency of putting in place innovative solutions and better practices to limit their use and their impacts on biodiversity and the environment. Finally, we will reflect on the individual and collective actions necessary to face this environmental crisis and preserve the richness and diversity of life on Earth, indispensable for long-term human survival.