Time is running: top ways to avoid a plasticene

O tempo está passando: as principais maneiras de evitar um plasticeno

DOI: 10.55905/oelv21n8-083

Recebimento dos originais: 17/07/2023
Aceitação para publicação: 15/08/2023

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ABSTRACT
This article analyzes the importance of plastics that have shaped the lifestyle of contemporary society and highlights the impacts produced by its wide availability across the planet. Starting from a brief historical overview of the rise of plastics and their insertion in different social and economic activities over the last century, we address the growing awareness of the deleterious mass proliferation of plastic pollution. In particular, we emphasize the increasing knowledge about the harmful effects of microplastics on biota and human health. A change in the role of plastic in society is unavoidable, with an urgent need for behavior changes in all social strata. Rethinking the way of production, use and management of plastics must involve social changes at domestic, regional and national levels. Environmental education and governance efforts for plastic recycling and innovation for environmentally friendly materials are of utmost importance. The change of attitudes, reducing the entry of plastics into the natural environment is an urgent task and enhancing individual awareness might be deemed paramount in educational institutions, and among decision makers.

Keywords: plastic pollution, recycling, social changes, microplastic, environmental education.

RESUMO
Este artigo analisa a importância dos plásticos que moldaram o estilo de vida da sociedade contemporânea e destaca os impactos produzidos por sua ampla disponibilidade em todo o planeta. Partindo de uma breve panorâmica histórica do aumento dos plásticos e da sua inserção em diferentes atividades sociais e econômicas ao longo do último século, abordamos a crescente consciencialização para a proliferação maciça e deletéria da poluição por plásticos. Em particular, salientamos o crescente conhecimento sobre os efeitos nocivos dos microplásticos no biota e na saúde humana. Uma mudança no papel do plástico na sociedade é inevitável, com uma necessidade urgente de mudanças de comportamento em todos os estratos sociais. Repensar o modo de produção, utilização e gestão dos plásticos deve implicar mudanças sociais a nível nacional, regional e nacional. A educação ambiental e os esforços de governança para a reciclagem de plástico e a inovação para materiais que não agridan o meio ambiente são de extrema importância. A mudança de atitudes, reduzindo a entrada de plásticos no ambiente natural é uma tarefa urgente e aumentar a consciência individual pode ser considerada primordial nas instituições educacionais e entre os tomadores de decisão.

Palavras-chave: poluição plástica, reciclagem, mudanças sociais, microplástico, educação ambiental.

1 INTRODUCTION
Historically, humanity has been changing the environment in which it lives. Through the observation of nature, human beings began to build instruments capable of
helping them to perform certain tasks, from utensils made from stone to the search for new and better objects (PIATTI and RODRIGUES, 2005). The ivory, for example, has been molded since the 17th century, however, before the emergence of plastic the most used moldable materials were clay (ceramics) and glass - heavier and more fragile.

Plastics are synthetic organic polymers, formed by polymerization reactions, using petroleum derived monomers (BARNES et al., 2009). A milestone in the application of polymers occurred in 1839, when Charles Goodyear accidently combined sulfur with natural rubber that resulted in vulcanized rubber, thus changing elasticity, hardness and thermal resistance (RAUE et al., 2014). In 1860, the English metallurgist Alexander Parkes commenced research with a plastic prototype, being somewhat similar to what we know today. Parkesine was the first manufactured plastic, initially promoted as a synthetic version of ivory, formed through cellulose, nitric acid, sulfuric acid and castor oil. However, Parkesine was commercially unviable due to its high production cost (UTRACKI, 1995).

Between the decades of 1920 and 1930, the diversification of existing plastics further variegated due to the inception of new polymers such as polystyrene, polyvinyl chloride (PVC), polyurethane, polyamide (nylon), and the plastic industry in this branch was gradually growing. During the Second World War, there was a boom in plastic production to meet the demands of the war machine. For example, nylon was employed to replace silk in the manufacture of parachutes, whilst still a primary component in the production of tires and tents; molded plastic products were employed in protective helmets and components of vehicles, shipping and aircraft. As a result, the volume of plastic material tripled between 1940 and 1945 (MEIKLE, 1995).

From 1945, the plastic industry experienced overwhelming and unrivaled growth thus pervading the daily lives of several generations regardless of socioeconomic status. Furthermore, plastic became the acceptable alternative to those utensils previously made from costly materials, such as ivory, wood, metals and cotton (MEIKLE, 1995; GARCÍA 2009). A timeline with the main events involving plastic production and uses is shown (Fig.1), including domestic utensils to cars and airplanes.
The plastic industry flourished in the 1960s, and since then plastic has become an indispensable product in daily human life (packaging, construction materials, personal care products, health care, agricultural products, etc.). The plastic serves as a raw material for the manufacture of numerous items, to include synthetic clothing, beauty products and personal hygiene, such as exfoliating and toothpaste, among a plethora of others (FENDALL and SEWELL 2009; PLASTICS EUROPE, 2022).

Decades of plastic production has resulted in colossal volumes of solid plastic waste, much of it concentrated in the environment as only a small fraction is collected for recycling (DE OLIVEIRA, 2012; PLASTICS EUROPE, 2022). Whilst the creation of plastic proved beneficial for society, via ways of multiple application, only recently has the advantage of durability been viewed as a distinct disadvantage for the biosphere. Plastics possess extremely high durability, which equates to a decomposition time of more than 400 years (GOMEZ, 2019). The beneficial features of extremely high durability have recently been seen as harmful to terrestrial and aquatic ecosystems. Beaches full of PET bottles, sea turtles biting plastic bags and seahorse resting on a cotton swab, among others, started to reveal a new dimension of the plastics’ spreading.
Figure 1 Timeline with the main events involving plastic.

Source: Adapted from British Plastics Federation, 2023.
Among the global themes, climate change and loss of biodiversity have been highlighted as environmental problems facing society everywhere (TEKWA et al., 2023; WANG et al., 2023). Here, we came to bring the subject of plastics recently considered as a “hot topic” (CERA et al., 2021) as an important theme to be urgently inserted as a global concern for humanity wellbeing. The greater challenge is to negotiate the improper disposal of plastic waste into the environment. Failure to address this intimidating challenge would result in persistent plastic pollution over the coming centuries. The formation of Plastic Islands in several oceans, accumulation in rivers and land being a recurring theme (LAW et al. 2010; UNEP, 2023), and with all the follow-on consequences for marine, freshwater and terrestrial organisms, including human beings. As suggested by Handley (2022), let us unwrap the plastic that coats our world and put it away.

2 HARD TO SEE BUT EVERYWHERE: THE MICROPLASTICS

Plastics are able to withstand weathering, thus becoming particulate. Several factors contribute to the disintegration process of plastics within the environment such as electromagnetic radiation (photolysis), high temperatures (thermo-oxidation and thermo-degradation), and physical abrasion by the action of wind, waves and microorganisms (WEINSTEIN et al. 2016). Those processes result in the proliferation of numerous plastic particles of different sizes. When attaining a size of 0.1 μm – 5 mm they are then recognized as microplastics, which pave routes across environments and into organisms. The presence of microplastics in all regions of the planet from the remote highlands of Himalaya to the deepest ocean part in the Mariana Trench (CHIBA et al., 2018; NEELAVANNAN et al., 2022), stunned ordinary people and scientists.

Microplastics can be adhered to terrestrial and aquatic vegetation and ingested by several groups of animals becoming bioavailable across food chains (COLE et al., 2013; WEINSTEIN et al., 2016). This ingestion can cause a multitude effect from several forms of mechanical damage to serious disorders in the digestive tract, including gut obstruction and intestinal wall adhesion. The feeling of a full stomach and the consequent false satiety can consequently decrease energy reserves of organisms, resulting in several
ecophysiological deficiencies and quite possibly eventuate in death (DUIS and COORS, 2016).

Numerous studies indicate that due to their physical and chemical properties, microplastics are capable of adsorbing substances from the surrounding environment that cause toxic effects like polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), antibiotics, organochlorine pesticides (OCPs) and heavy metals (VASSEUR and COSSU-LEGUILLE, 2006; XU et al., 2020). These compounds can generate a series of effects on organisms, including debilitating important physiological processes, such as cell division, hormonal action and immune system, and can also damage organs (VASSEUR and COSSU-LEGUILLE, 2006; COLE et al., 2011).

Further to adsorbed compounds, the microplastics can harbor materials such as dyes and additives, which greatly affect the health of flora and fauna. Lithner et al. (2011) found styrene monomers that are utilized in the production of polystyrene, to possess mutagenic or carcinogenic potential. In view of this, microplastics present major risks to biota via a combination of the toxic substances they adsorb and their inherent chemical components. Microplastics and their plasticizers can be conveyed along the food chain. Within this process, small components of aquatic food webs such as zooplankton serves as a key organism in the transfer of MPs from a lower trophic level to a higher base (SETÄLÄ et al., 2014). As the trophic level is increased, the concentration of microplastics, in tandem with concentrations of substances toxic, also increase, thus generating a bioaccumulation process (MA et al., 2023).

In this context, it is far from unreasonable to suggest that microplastics can form a pathway into the human diet. Some research unearthed microplastics in fish and bivalves earmarked for human consumption, and it is believed that - at least in Europe – 11 000 MPs were consumed by people who ate seafood (VAN CAUWENBERGHE and JANSSEN, 2014; ROCHMAN et al., 2015). Further studies demonstrate that in addition to food intake, microplastics admission can also derive from tap and bottled water (KOELMANS et al., 2019; WHO, 2019; GAMBINO et al., 2022), food packaging and via inhalation from both indoor and outdoor air (WHO, 2022).
The presence of microplastics in human stool, urine, blood, lung, cirrhotic liver and in patient undergoing cardiac surgery has already been confirmed (MOHAMED NOR et al., 2021; HORVATITS et al., 2022; JENNER et al., 2022; PIRONTI et al., 2022; YANG et al., 2023). A study published by Ragusa et al. (2021) detected 12 microscopic plastic particles in the placenta of four healthy women who had normal pregnancies and deliveries. One year after, Ragusa et al (2022) detected and characterizes microplastics in human breastmilk. But it is not yet known whether these plastic particles adversely impacted on the health of either the woman or the baby.

Notwithstanding the ever presence of microplastics in drinking water and in food, the study of the consequences on human health is still in its infancy (MA et al., 2023). Some studies have already shown that the human intestine absorbs microplastics (VAN CAUWENBERGHE AND JANSSSEN, 2014), and it is suggested that they can modify the composition of the intestinal microbiota and progress liver lipid disorders (LU et al., 2018). Microplastics can transmit bactericidal microorganisms to gut microbiota and can also act as disruptors of the endocrine system, by adhering to hormonal sites and creating blockages (HALDEN, 2010; LU et al., 2018). Epidemiological studies have also been conducted on the potential relation between occupational exposure to plastic dusts and cancer (WHO, 2022). An urgent need to elucidate the immunological hazards and risks of humans exposed to microplastic was enhanced recently (YANG et al., 2022).

Until now, the World Health Organization (WHO) enhances that human exposure to microplastics is ubiquitous and occurs by all routes, but information on exposure from air, drinking water, food, and beverages is limited (WHO, 2022). The lack of standardized methods, which limits comparison and quantification of microplastics from several sources led to WHO advocates the urgent need to develop a standard method for sampling and analysis. These approaches might be dependent of the media being sampled since methods for drinking-water will differ from those for foods and other beverages, as will those for indoor and outdoor air (WHO, 2022), and for type of biological material such as part of organisms and internal or secreted fluids. As such, the dilemma of microplastic is ultimately overlooked, highlighting that more research is mandatory to garner
knowledge on methods of sampling, analysis, and, at the same time, the effects on human health (SORCI and LOISEAU, 2022; YANG et al., 2022; MA et al., 2023; UNEP, 2023).

3 PRODUCTIONS VERSUS RECYCLING IMBALANCE: A PATH TOWARDS A PLASTICENE

Over the span of the last decades, plastic production has increased 200 times more than that of 1950, and has grown at a rate of 4% per year since 2000. From 1950 to 2017, 8.3 thousand million metric tons of plastic were produced globally and half of that was produced within the last decades (GEYER et al. 2017). From 2000 to 2016, all countries in total have produced the same amount of plastic as in all previous years combined (WWF 2019). Currently, the world produces 430 million metrics tons of plastic each year (UNEP, 2023).

Ten countries head the ranking of the largest global plastic producers, the first three being the United States, China and India. Other countries such as Brazil, Indonesia, Russia, Germany, the United Kingdom, Japan and Canada, also appear in this ranking. United States ranks first as the country that mostly recycles, followed by China. India and Brazil share similarities as they produce a much higher degree of plastic waste than that recycled or incinerated (WWF 2019). There are those countries that foster incineration as an alternative to combat plastic pollution. This process however, is not widely accepted, because in addition to being costly, it raises some hazardous aspects, such as the release of harmful gases with the combustion of solid residues, such as dioxins and furans (UNEP, 2023).

Recycling fails to keep pace with production (PLASTICS EUROPE, 2022), and this is primarily due to two overarching factors: technology and economy. The production of new plastics is substantially cheaper than recycled plastic, as recycling processors demand greater quantities of the material to ensure viable outcomes. The advancement in plastics recycling is perhaps the immediate initiative of practical societal action for the foreseeable future in the face of serious forecasts. Some of these forecasts indicate that should current pollution rates maintain, the volume of plastic in the oceans will exceed that of fish by 2050 (by weight) (SIMON and SCHULTE, 2017).
The unabated production of plastic in parallel with dire future forecasts should ultimately direct us to question: are we not experiencing a new geological era marked by the presence of plastic? The scientific community asserts the Anthropocene as the most recent period in the geological history of Planet Earth, commencing mid-18th century, at the same period of time the First Industrial Revolution. Human activity has overwhelmingly transformed the environment to the point that the employment of this term – Anthropocene - is now up for discussion to be adopted as a new era in geological classification (LEWIS and MASLIN, 2015). Anthropocene undoubtedly unveil the great “newness” of our era: anthropon (ἄνθρωπος), that is, “man”. This “newness” is currently preoccupying the lives of scientists and indeed broad swaths of the global population, as it persists as a threat to planet Earth.

Given the breathtaking pace of plastic production and its durability in the environment (GOMEZ, 2019), we can affirm plastic as one of the principal time markers of the Anthropocene and of human output. The ubiquity of plastics within marine sedimentary deposits, in shallow water environments and in terrestrial deposits are now factored in as a distinct stratum component of the Anthropocene's key geological indicator (ZALASIEWICZ et al., 2016). This being the case, that the ubiquitous presence of plastics within ecological, chemical and geological systems has even manifested new descriptive terms to chronicle proliferation of plastic-based materials in nature. Plasticene, the name attributed by Matt Dowling, assigns an era that began in the 1950s, marked stratigraphically in the depositional records by a new and expanding layer of plastic (HARAM et al., 2020).

In his seminal publication, The Imperative of Responsibility, Hans Jonas observed that only a policy guided by ethical principle could reverse the current state of affairs and, in this way, would guarantee meaningful life for future generations and of all living beings (JONAS, 2006). According to Stephen Emmott, we remain with two options: salvation through technological gain —highly improbable—or salvation via the radical transformation of our behavior: “We need to consume less. Much less. Less food, less energy, less stuff. Fewer cars, fewer electric cars, fewer cotton T-shirts, fewer notebooks, fewer new cell phones” (EMMOTT, 2013). In other words, not only are urgent and
extreme measures required by governments, but also an unprecedented transformation in the manner we conduct our daily lives.

4 RETHINKING THE USE OF PLASTICS

4.1 FOSTER GOVERNANCE FOR RECYCLING AND INNOVATION

Environmental plastic pollution is a challenging issue as it is associated with demanding environmental problems that require complex solutions. The policy of the 3R's – reducing, reusing and recycling interlocks a set of actions promoted back in 1993 by the 5th European Program for Environment and Development. The 3R's is the philosophy to essentially convey the general population, industry and government to reduce and reuse waste (BONELLI, 2010).

Rethinking the use and management of plastics must include the reuse of plastic utensils or replacing them with glass and the use of cloth bags. Minor advancements such as the application of plastic bottle waste as a building material are underway as an effort to solve the housing deficit in developing countries, thus assisting to save the depletion of natural resources (DADZIE et al., 2020).

Governance over the use of plastics plays a key role in reducing the use of plastics and encouraging recycling. Laws often arrive to modify paths of economic production and/or social behaviour. The ban on the use of plastic drinking straws, cups and plastic bags is becoming commonplace in many parts of the world. Broader legislations are emerging in developed countries to reward efforts to decrease unrecycled contaminants in ecosystems aiming to tax virgin plastic used to make single-use products, including plastic packaging, beverage containers, bags and food service products. The funds collected go towards recycling, monitoring and removal pollution impacts of plastic production (EPA, 2020). Conversely, plastic waste management is frequently cost prohibitive for developing countries (DAUVERGNE, 2018; DALU et al., 2020) such as India, Brazil, and Indonesia with high plastic production. However, some of them such as Indonesia, while being a major producer of plastic waste, are currently restricting imports of non-recyclable waste (ZAMORA et al., 2020). This reflects the long journey to be encountered and the challenges to be confronted throughout the world.
One of these challenges was the COVID-19 pandemic that increased the amount of plastic waste generated from hospitals, post-used personal protective equipment, confirmatory COVID-19 testing, vaccination residues, from packaging due to higher delivery activities during lockdowns, and from online shopping (LEAL-FILHO et al., 2021; SOUSA, 2021). The impact of the uncontrolled disposal of plastic items on the biota and on the environment was found throughout the world. The lack of awareness of large part of the population as well as few strategies to penalize incorrect personal protective equipment disposal intensified the direct release of plastic items from pandemic to the environment.

The implementation of laws and public policies aimed at mitigating the global environmental problem regarding plastics might rely on robust and large-scale data to demonstrate the nature and complexity of the problem (BANK et al., 2021). The current monitoring of plastics and in special microplastics in most ecosystems and ecoregions remains poorly standardized and even implemented. This gap has been related to methodological differences among researches and inconsistencies in sampling, analysis and reporting (GAMBINO et al., 2022; WHO, 2022). The lack of standard values for the allowed amount of microplastics in aquatic and terrestrial ecosystems have contributed to delay more pertinent legislation. Being difficult to see for the human eye, the microplastics and risk perception depend upon the information given to citizens by educators, municipal leaders and often by television and digital media (WWF, 2020).

The possible salvation through technology must involve innovation on cheaper biodegradable biobased plastic and compostable are some of the ongoing developing alternatives. Fungal mycelium to create a biodegradable packing and seaweed-based food material packing are coming as sustainable alternatives to plastic packing (EPA, 2020). Unfortunately, bioremediation on microplastics is at an embryonic stage and laboratory scale and the identification of depolymerase from plastic-degrading strains is a promise for future (MIRI et al., 2022).

Here, we stress humanity as in a turning point for change habits and to stop the continuous spreading of plastics in the environments throughout the world. Innovations in sustainable packaging materials, development of less expensive production of
polymers not based on fossil fuels, and open new ways for biodegradation of plastics have the potential to be a part of the solution (EPA, 2020; MIRI et al., 2022). Those efforts can lead to a possible future salvation through technological gain.

4.2 FOSTER THE THEME PLASTIC IN ENVIRONMENTAL EDUCATION

Rethinking the management of plastics must involve economic, social change at domestic, regional and national levels. In a broader perspective, salvation via the radical transformation of our behavior (EMMOTT, 2013). Integrated solution for the reuse, manufacture and recycling of plastics depends directly on individual awareness. With that, the environmental education comes in as a non-negotiable form of action on the individual level that, over time, will expand to governmental spheres.

Among the fundamental, unquestionable tools for change of habits is the early age awareness. Childhood is a key period for developing awareness and the early age perception is of high relevance (FAN, 2021). Teachers, teaching technicians, cleaning staff and school leaders need to be together engaged in this task. Schools have introduced sessions and activities to 'teach' children about 'reduce, reuse, recycle' (3R’s). Recycling of waste throughout school communities, including paper, aluminium can, glass and plastics have been implemented for a long time. Integration of plastic management issues in the school activities is of utmost importance, especially in developing countries that lack more structured systems for waste disposal and recycling and still often receive plastic waste from other countries (DALU et al., 2020; PAREJO et al., 2021).

In another aspect, has been hard to ban plastic to enter at the pre-school and school since most of food items are sold packaged in plastic and water in plastic bottles, and few cheap alternatives around (DALU et al., 2020; PAREJO et al., 2021). Less plastic toys, bags and films in children's backpacks and more reusable utensils can help the environment. Reducing the numbers of plastic toys and encouraging creativity for new toys made by the children themselves and from recycled material is one way forward already ongoing in some countries.

Notwithstanding most curriculum of secondary schools covered several aspects of pollution, mainly water pollution, the issue of plastics has been included and diluted from
biology to chemistry. Students, as representatives of current generations need to know the products that contain or are made by plastics, and the impacts caused by these materials. Based on these notions, a sense of individual responsibility for the environment can be built, adding hope to mitigate plastic pollution since the information from school goes home where it can change daily habits of families. Effective action on students can so be extended to family members and the surrounding community, in a successful practice for the circular economy in the use and management of plastics.

Despite the urgent need of the inclusion of plastic pollution as a common theme in primary and secondary schools, Situmorang et al. (2020) also showed a gap in knowledge about the issue at the academic level. The authors reported, when comparing environmental science and social science undergraduate students, that the first ones had a greater perception of the negative impact of plastic wastes on human life and/or biota. Students more engaged in environmental education, learning in courses, fieldtrips, and experiments had higher awareness on environmental issues, particularly in the handling of plastic waste problems. This shows the need to carry out a continuous and multidisciplinary environmental education, from the early years to adulthood to diverse academic areas, and encompassing different audiences’ targets.

Several authors (STEG and VLEK, 2009; DALU et al., 2020; RAAB and BOGNER, 2020) have highlighted that the sensitivity of both children and adults to the adverse effects of plastics on fauna has been an important tool for the rising of awareness on the subject. The presence of a microplastic fibre in a deep-sea amphipod described recently for the first time to science led the authors named it as *Eurythenes plasticus* (WESTON et al., 2020). This discovery shocked scientists, non-governmental organizations, public, and foster an integrated campaign asking to put an end to marine plastic pollution (WWF, 2020). The example of this crustacean species as a witness of plastic pollution has been shown in several museums’ exhibition and in educational videos (GNM, 2022), and was an information from the academic world that was successfully popularized.

A socially critical curriculum engaging students in social problems, in contrast with the individualistic approach of Earth Education was highlighted by Gough and
Gough (2015), and might open minds to critical reflection, increasing awareness and collective activities towards recycling and plastic use decrease. According to these authors, despite teaching about or in the environment seems a lot less controversial, only when there is education for the environment that environmental education is actually happening.

5 CONCLUSIONS

Through this manuscript, we came to bring the subject of plastics as an important theme to be urgently inserted among the priority global concerns. Whilst the creation of plastic polymers was considered extraordinary and innovative, being part of our daily life, it came at a cost with a series of consequences that are proving hazardous for biota and humans. In accordance, we must consider that we have now certainly arrived at a turning point to a change regarding plastic production and use.

Above all, fundamental ways suggested for this change are foster environmental education and governance for recycling and encourage innovation for the production of ecologically friendly materials. Notwithstanding, reducing the spread of plastics across natural environments is an imperative task. Not only are urgent and extreme measures required by governments, but also an unprecedented transformation in the manner we conduct our daily lives. The clock is ticking to offset the dire 2050 forecast of more plastic debris than fish in the oceans. Educational efforts for reduce the consumption of plastic, enhancing individual awareness to increase recycling and correct disposal should be deemed paramount in schools where the seeds that will bear future generations are currently been planted.

ACKNOWLEDGEMENTS

The authors would like to thank the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) for the Doctorate scholarship to ALP and Master scholarship to MGRT.
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