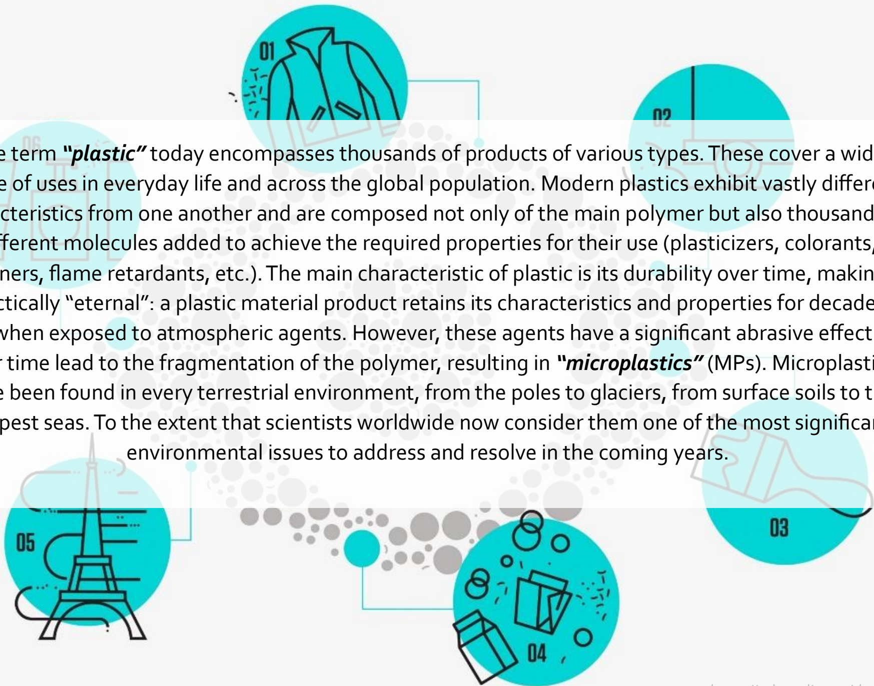
THE ENVIRONMENTAL CHALLENGE OF THE FUTURE:

MICROPLASTIC POLLUTION



The term ***"plastic"*** today encompasses thousands of products of various types. These cover a wide range of uses in everyday life and across the global population. Modern plastics exhibit vastly different characteristics from one another and are composed not only of the main polymer but also thousands of different molecules added to achieve the required properties for their use (plasticizers, colorants, softeners, flame retardants, etc.). The main characteristic of plastic is its durability over time, making it practically "eternal": a plastic material product retains its characteristics and properties for decades, even when exposed to atmospheric agents. However, these agents have a significant abrasive effect and over time lead to the fragmentation of the polymer, resulting in ***"microplastics"*** (MPs). Microplastics have been found in every terrestrial environment, from the poles to glaciers, from surface soils to the deepest seas. To the extent that scientists worldwide now consider them one of the most significant environmental issues to address and resolve in the coming years.

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For decades, Eco Research has been an environmental research institution dedicated to addressing environmental challenges. Now, we have taken on the challenge of measuring the extent of microplastic dispersion in the province of Bolzano.

Plastic

The term ***"plastic"*** commonly refers to a vast array of materials, each with distinct characteristics. Plastic materials are organic compounds primarily composed of carbon (C) atoms, forming covalent bonds with other elements, especially hydrogen (H) and oxygen (O), to create intricate chains. These chains, which can vary in length and branching patterns, constitute complex macromolecules known as ***"polymers"***. Polymers can be either in their pure form or combined with additives to modify their properties. Furthermore, plastics can be reinforced with diverse fibers like carbon, glass, or wood, resulting in composite materials where the polymer serves as the base matrix. The incorporation of additional components is intended to enhance qualities or lower production expenses.

Why is plastic so widespread? Because it's an extremely versatile and economical material.

Plastic is now ubiquitous, and it's hard to imagine daily life without it. Plastic plays a pivotal role in critical medical apparatus, clothing production, children's toys, transportation systems, packaging for food items, and cosmetic products. For a considerable duration, plastic held an aura of sophistication, cleanliness, and modernity. However, this perception is undergoing transformation: a significant portion of plastic utilization now embodies a "disposable" way of life, a trend regrettably widespread today. This trend, however, starkly contrasts with the principles of sustainable living, which emphasize longevity, conservation, and environmental harmony. As societies grapple with the ramifications of plastic waste and pollution, there is an increasing imperative to reshape attitudes towards plastic use and cultivate a more responsible and ecologically conscious approach.

A Historical Perspective

How did people manage before the advent of plastic? Historically, there was a period when a material similar to today's plastic was used, but we need to go back to the times of ancient Romans.

It was the Romans who discovered that lead could be used for a multitude of purposes. Lead melts at less than 330°C, making it easy to shape in any form. A lead ingot could be turned into a vase, utensil, piece of piping, or pot within minutes. Lead resisted corrosion relatively well and could be melted and transformed into various forms multiple times. The same holds true for plastic polymers, which, through processes like extrusion or molding, can be shaped into pieces of varying forms.

However, as often happens, where there is light, there is also shadow. The Romans quickly experienced the toxic effects of lead on humans, an intrinsic property of this metal. And as with many historical patterns, unfortunately, history repeats itself: plastic, especially its fragments, can be highly detrimental to the environment and humans.

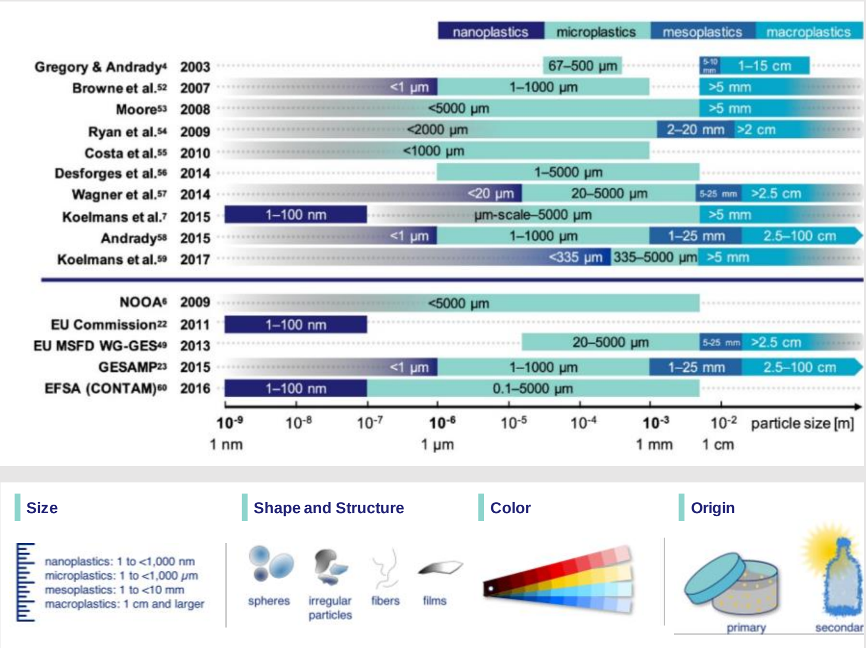
Although industrial plastic production only began in the 1950s, its usage has significantly increased over the decades, along with its subsequent dispersion into the environment. Today, plastic represents the largest anthropogenic pollutant debris in the environment, estimated at nearly 10,000 million metric tons (Geyer et al., 2017; Li et al., 2018). Both terrestrial and aquatic environments suffer the consequences. The issue is particularly severe in the oceans, where over ***100 million metric tons*** of plastic are presumed to be dispersed. Additionally, rivers contribute about ten million metric tons annually. Since the degradation of these macromolecules can take decades to hundreds of years, their persistence poses a significant environmental problem that should not be underestimated.

Environmental Pollution

Plastic comes in a multitude of shapes and sizes: bags, spheres, packaging materials, construction coatings, containers. Over time, however, they break down and can give rise to micron-sized plastic particles, known as ***"microplastics"*** (MP), or even nanoparticles,

What is meant by the terms "microplastics" and "nanoplastics"?

Although there is no universally accepted definition, conventionally plastic waste has been divided into four classes based on their size (macroplastics, mesoplastics, microplastics, and nanoplastics), with additional criteria such as shape and structure, color, and origin also taken into account (Figures adapted from Hartmann et al., 2019).



termed ***"nanoplastics"*** (NP). The disintegration and degradation of macroplastics can be triggered by various processes, including mechanical degradation, biodegradation, photodegradation, thermooxidative degradation, and hydrolysis. These processes, widespread and challenging to control, substantially contribute to the production of microplastics (MPs). An example? The wear and tear of tires on the road surface or the shedding of textile fibers during clothing laundering. A study found that after a 15-minute drying cycle of cotton and polyester fabrics, up to half a million plastic microfibers can be found in the air filter (Österlund et al., 2023).

Another form of MP pollution arises from urban discharges. Despite being directed to wastewater treatment plants, these facilities can only capture macroplastics, while smaller fragments like microplastics can partially bypass filtration systems or become trapped in the sludge produced by the treatment process.

Thus, two distinct issues emerge in final discharges:

- The release of smaller particles, nanoplastics, into treated waters that flow into rivers (representing a minority fraction of the total);

- The presence of microplastics trapped in the sludge, constituting the larger fraction of particles not removed by purification systems, potentially posing severe consequences on the use of treatment sludge as fertilizer or soil amendment in agriculture.

Analytical Approach

At Eco Research, a direct analysis method for plastics and microplastics has been developed. By coupling a thermodesorber with a gas chromatograph and mass spectrometer (***Pyr-GC-MS***), it is possible to analyze even very small particles of polymeric material. The thermodesorber, through thermal decomposition, allows for a solvent-free and chemical reagent-free sample preparation method (***"green chemistry"*** approach). This approach aligns with green chemistry principles, involving an analysis method that minimizes the use of synthetic chemicals that could be potentially harmful to the environment.

On the other hand, the mass spectrometer is arguably the most advanced analytical technique developed thus far. It enables the identification and, within certain limits, quantification of chemical components within plastic materials. Just a few milligrams of material are sufficient to accurately identify the type of plastic, such as PVC, polypropylene, plexiglass, or nylon. Lastly, this technique is effective in assessing the presence of microplastics in complex matrices like living organisms (e.g., larvae, insects), influent water to treatment plants, or in the sludge from these plants.

The Importance of Environmental Studies

Microplastics (MPs) and nanoplastics (NPs) are internationally recognized as one of the major emerging pollutants of our times, with their environmental fate and impact on biota still relatively unknown.

They are ubiquitously distributed in aquatic ecosystems: their presence has been detected in ocean water, Arctic and Antarctic ice, and even in the most remote environments, including Mount Everest. Furthermore, research studies have highlighted their trace presence in samples of beef and pork, cow's milk, human blood, and feces. In 2021, a group of Italian researchers provided the world's first scientific evidence of microplastics present in the human placenta (Ragusa et al., 2021).

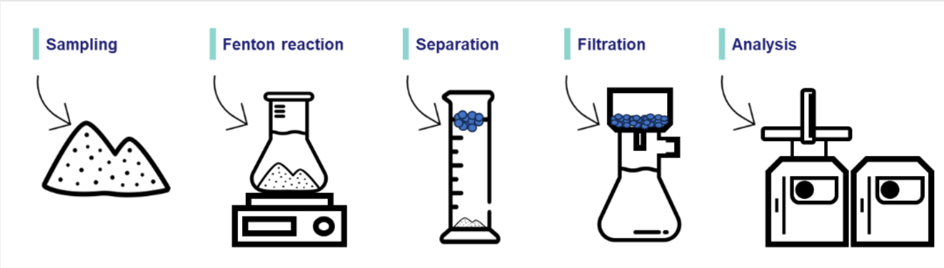
Their presence raises increasing concerns ***for the environment, living organisms, and public health***. The effects on coastal ecosystems, open seas, and seabeds are dire. Countless animal and plant species are threatened by plastic waste. Animals become entangled in plastic debris or mistake plastic fragments for food. The consequences are injuries, strangulation, stomachs full of plastic, and ultimately death.

Plastic also poses a threat to human health. Due to its properties, plastic acts like a sponge for environmental toxins, such as polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls, dioxins, pesticides, and industrial solvents (Bakir et al., 2014). These pollutants can be released into the gastrointestinal tract of various animal species and make their way to humans through the food chain. What is of even greater concern is the effect of ***hormone-like substances***. Xenobiotics like bisphenol A, nonylphenol, and phthalates fall into this category. They are used as plasticizers, additives that enhance plastic properties. Acting as hormone mimics, they interfere with the endocrine system in humans and can lead to the development of tumors, infertility, early puberty, obesity, allergies, and diabetes.

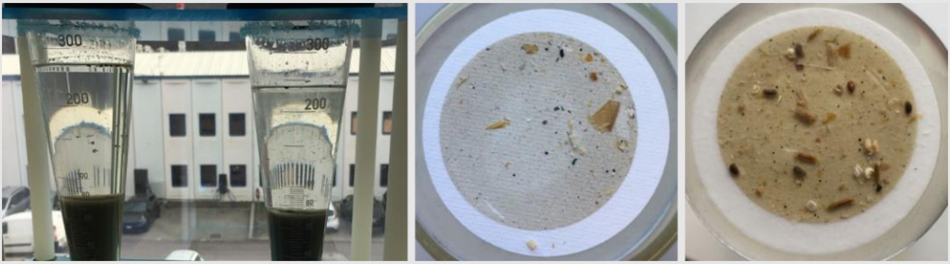
Speaking of environmental pollution, it's essential to remember the contribution of Rachel Carson, who, through her book **"Silent Spring"** (1962), documented the environmental disasters caused by the extensive use of pesticides produced by the chemical industry. The book had a profound impact on public opinion, leading to the consideration of the environmental aspects of technological and industrial progress. This shift encouraged a turn towards alternatives with lower environmental and health impacts.

Case Study: Microplastics in Wastewater Sludge

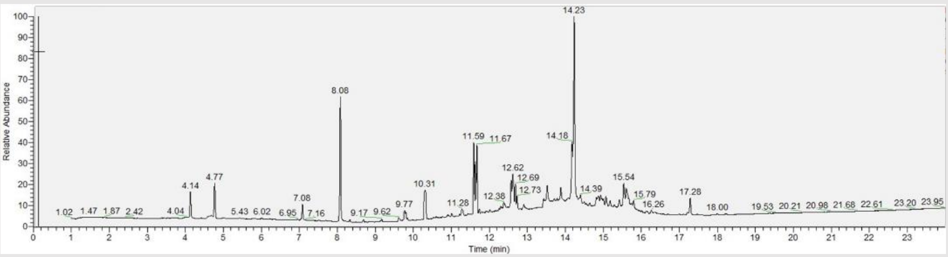
The sludge sample (2 g) is treated with a Fenton reagent, a mixture containing hydrogen peroxide and iron salts. This mixture generates reactive species (hydroxyl radicals) capable of selectively degrading organic compounds, except for natural polymers (cellulose) and artificial polymers (plastics). This process allows for the isolation of microplastic particles present in the sludge. These particles are then made to "float" in a high-density saline solution (over 1.5 g/mL) and filtered through a 0.45 µm pore size filter. The filter is subsequently analyzed using Pyr-GC-MS. From the obtained chromatograms, specific peaks can be identified, enabling qualitative recognition of plastic fragments. Through comparison with calibration curves prepared for specific thermal degradation products of polymers, quantitative information about the presence of different types of microplastics can also be derived.



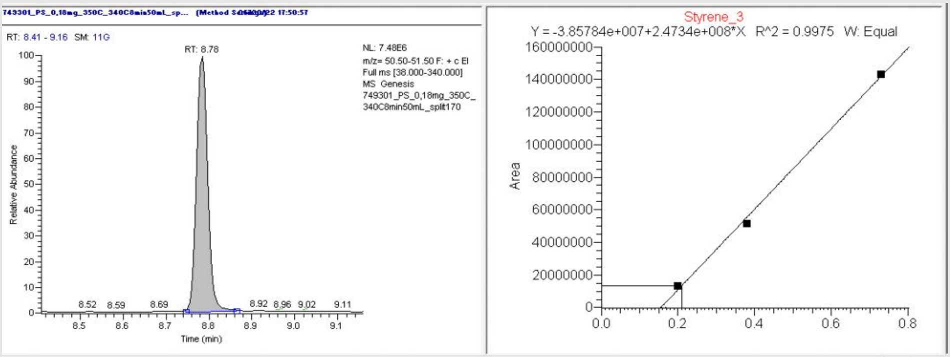
Preparation and analysis scheme for samples.



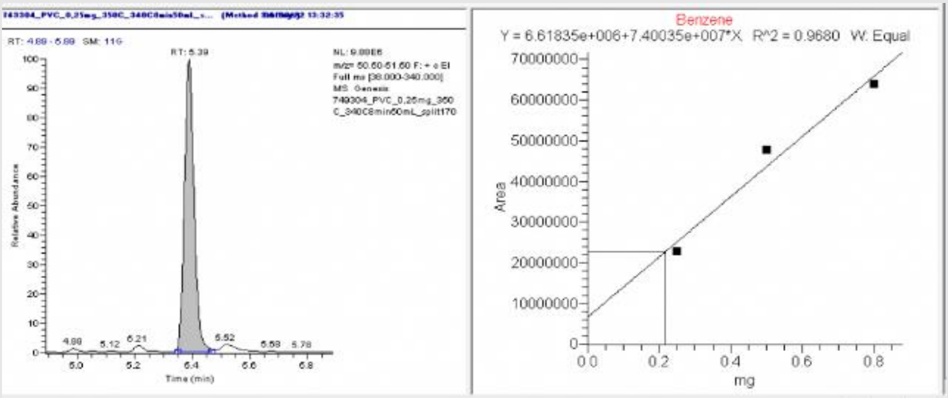
Treatment of Sludge Samples with Fenton Solution and Subsequent Filtration.



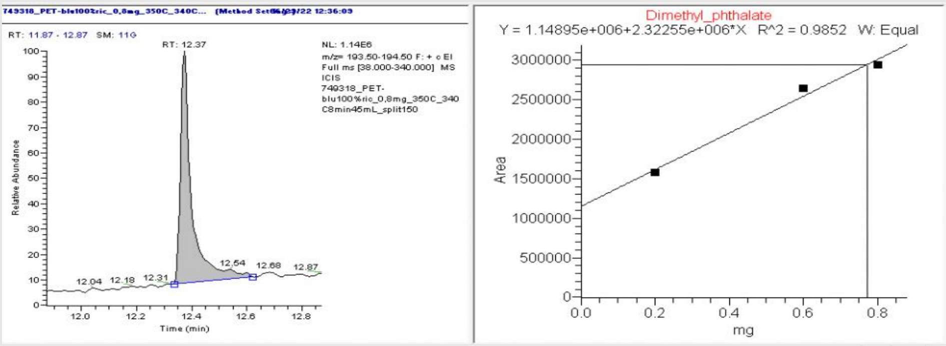
Example of Chromatogram Obtained for a Microplastic Sample Recovered from Wastewater Sludge.



Calibration Curve of Styrene, a Thermal Degradation Product of Polystyrene (PS).



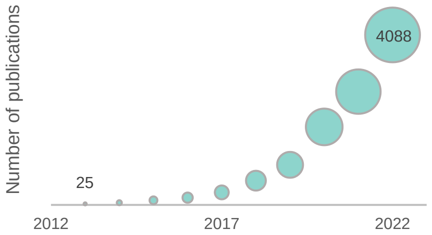
Calibration Curve of Benzene, a Thermal Degradation Product of Polyvinyl Chloride (PVC).



Calibration Curve of Dimethyl Phthalate, a Thermal Degradation Product of 100% Recycled Polyethylene Terephthalate (PET).

Research and Solutions

Once the problem is identified, it's possible to seek solutions. When examining the ***environmental issue*** stemming from microplastics, it's evident that only in recent years has this topic become a subject of study. This problem potentially poses a significant threat to the environment and health, and it was overlooked for decades. In fact, prior to 2010, the term microplastics" was hardly used. Looking at the production of scientific literature, it's clear that there has been an exponential increase in the number of publications related to microplastics since 2015. There were over 4000 publications in 2022 alone, compared to just 25 in 2013 (source: Scopus).



Given all the points discussed, a paradigm shift is imperative. Safer alternatives must be found, limiting and where possible eliminating plastic usage. Simultaneously, the danger posed by existing plastic and microplastics in the environment needs to be addressed. To do this, quantifying their presence is paramount.

Even from a legislative standpoint, only in recent years has pollution due to microplastics begun to be seriously considered. As an example, back in 2006, Regulation (EC) No. 1907/2006 of the European Parliament and of the Council, concerning the Registration, Evaluation, Authorization, and Restriction of Chemicals (REACH), which established the European Chemicals Agency (ECHA), included exemptions for drugs, waste, and polymers.

It wasn't until 2019 that ECHA proposed a comprehensive restriction on microplastics in products introduced to the market to prevent or minimize their release into the environment (source: https://echa.europa.eu/it/hot-topics/microplastics).

All of this underscores the complexity of the issue, which requires thorough examination to find appropriate solutions. The foundation lies in the need to quantify the extent of microplastic dispersion in the environment, an endeavor that Eco Research intends to undertake at a local level through collaborative research projects with key stakeholders in the area. Their technical and scientific expertise will be brought to bear on this endeavor.

"If you can't measure it, you can't manage it"

P. Drucker

Without data and research, addressing problems and seeking solutions remains impossible.

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