State of the Art definition about nano- and microplastics (NMPs) environmental pollution

1. Community-based State of the Art on MNP Environmental Pollution (PRIORITY WGs)

The present State of the Art was developed within COST Action CA20101 – PRIORITY as a **community-driven synthesis**. For each Working Group (WG1–WG7), participants were invited to identify the scientific articles they considered most representative of the current knowledge, methodological advances, and open challenges in their thematic area. These references are publicly listed in the **"State of the art – WG participants"** sections of the WG webpages on the PRIORITY site.

This document therefore does **not** reflect an arbitrary literature selection, but synthesizes the themes and consensus emerging from:

- the curated reference lists provided by WG members,
- the description of WG objectives and activities on the PRIORITY website
- and the overarching perspective on micro- and nanoplastics (MNPs) developed in the PRIORITY opinion paper "COST Action PRIORITY: An EU Perspective on Micro- and Nanoplastics as Global Issues."

2. Cross-cutting view of micro- and nanoplastics as systemic pollutants

Across all Working Groups, the publications selected by participants converge on a picture of MNPs as **widespread, persistent, and systemic contaminants**. The references highlighted by WG1, WG2 and WG4 in particular document the detection of MNPs in marine and freshwater systems, drinking water, soils, sediments, air, biota and even human samples, emphasizing their ability to move between compartments via hydrological transport, atmospheric dispersion and food webs.

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The ensemble of WG selections shows that MNPs act simultaneously as **physical stressors** (e.g., particle effects, abrasion, occlusion), **chemical vectors** (carrying additives and sorbed pollutants), and **ecological modifiers** (altering microbial communities, soil structure and sediment properties). This multi-faceted nature is consistently reflected in the cited reviews and experimental studies, which treat MNPs not as isolated contaminants but as part of broader stressor cocktails in real environments.

At the same time, the State-of-the-art lists curated by WG3 and WG6 underline that our ability to **quantify** and **characterize** these pollutants, especially at the low-micrometre and nanometre scales, still lags behind their environmental complexity. Many of the selected references focus on analytical method development, interlaboratory comparisons, and discussions of uncertainty, confirming that metrology and harmonization are central bottlenecks for progress.

3. WG1 – Impacts and risks on human health and the environment

WG1's curated State-of-the-art list is dominated by **(eco)toxicological and risk-oriented studies**, spanning both human health and environmental compartments.

On the **environmental side**, the selected papers describe effects on aquatic organisms, soil invertebrates, and other biota, with endpoints including growth inhibition, behavioural changes, reproduction, oxidative stress, immunological responses and microbiome alterations. These works collectively point to MNPs as **chronic stressors**, often acting at low but continuous exposure levels, and frequently interacting with co-contaminants such as metals or organic pollutants.

On the **human health side**, the references chosen by WG1 participants reflect the rapid emergence of studies showing the presence of microplastics in food, drinking water, indoor and outdoor air, and even human tissues, as well as in vitro and in vivo models examining inflammatory, oxidative and metabolic responses to particle exposure. The overall picture that emerges is one of **plausible concern with substantial uncertainty**: exposure routes (inhalation, ingestion) are well documented, early mechanistic evidence is accumulating, but robust epidemiological proof of specific disease outcomes is still limited.

Several WG1-selected reviews and perspective articles emphasise a **One-Health framing**, connecting environmental pollution, ecosystem alterations and human health risks in a unified conceptual model. This aligns with WG1 activities such as the round table on "A one-health approach for risk assessment of micro and nanoplastics," which explicitly link risk assessment roadmaps, standardisation needs and policy development.

4. WG2 – Monitoring and sampling of microplastics

WG2 participants have compiled a State-of-the-art corpus that centres on **sampling strategies, contamination control, and monitoring in diverse environmental matrices**.

The selected publications cover:

- development and comparison of **sampling devices and protocols** for surface waters, groundwater, wastewater, sediments, soils and biota,
- evaluation of extraction and digestion methods and their impact on particle recovery,
- case studies of environmental occurrence (e.g., rivers, coastal areas, agricultural fields), often used as benchmarks for method performance.

A recurring theme across these references, reflected also in WG2 meetings and the dedicated round table on contamination problems, is that **contamination avoidance and data reporting** are as critical as the analytical technique itself. Fibers from air, procedural blanks, and inconsistent units (items/L, items/kg, mass-based measures) are identified as key sources of divergence across studies, and several WG2-selected articles provide detailed recommendations on how to standardize reporting and quality-assurance criteria.

Overall, WG2's curated literature portrays the current state of monitoring as **method-rich but not yet fully harmonized**, with water matrices comparatively better covered than soils, sediments, and air.

5. WG3 – Instrumentation, modelling, data evaluation, software and analytical procedures

WG3's State-of-the-art list reflects the **analytical backbone** of MNP research. It contains references on spectroscopic, microscopic, thermal and separation techniques, as well as on advanced data evaluation and modelling frameworks.

The spectroscopic component is represented by works on micro-FTIR and micro-Raman mapping, particle identification workflows, and automated classification routines, highlighting both the power and the pitfalls of chemometric and library-based approaches, especially for weathered or pigmented particles. Thermal and pyrolitic methods (e.g., Py-GC/MS, TGA-MS) are captured through articles focusing on **mass-based quantification** and polymer mass balances in complex matrices.

Several WG3-selected references address **data processing and uncertainty**, including comparative studies of different software tools, thresholding approaches, and size-distribution reconstructions. Others focus on **numerical modelling**, for example of transport and fate of plastics in flowing waters, which are essential to interpret monitoring data at larger spatial and temporal scales.

Taken together, this WG3 corpus paints a State of the Art in which a wide toolbox of methods exists, but interoperability, data comparability and transparent reporting of detection limits, false positive rates and uncertainties remain crucial issues.

6. WG4 – Nanoplastics

WG4's State-of-the-art references concentrate on **nanoplastics as a distinct analytical and toxicological frontier**.

Many of the selected papers discuss:

- the **dimensional continuum** from micro- to nanoplastics and the challenges in defining operational boundaries;
- emergent **analytic approaches** tailored to nanoplastics, such as nanospectroscopic methods, field-flow fractionation coupled to light-scattering or mass spectrometry, and high-resolution microscopy;
- the interactions of nanoplastics with biological membranes, cells and microbial communities, including mechanisms of uptake, translocation and sub-cellular effects.

In addition, several references focus on **colloidal and interfacial behaviour** (aggregation, protein corona, eco-corona formation), which governs mobility and bioavailability at the nano-scale. Others emphasize the need for **environmentally realistic test materials**, including weathered nanoplastics and fragments originating from real products, rather than only idealised spheres.

The WG4 list, combined with the content of WG4 meetings, portrays nanoplastics research as an area where conceptual understanding of hazards is progressing, but **measurement capabilities and reference materials** are still the main constraints on quantitative risk assessment.

7. WG5 – Remediation, recovery and sustainable alternatives

WG5 participants have selected State-of-the-art publications that span **remediation technologies, advanced materials, and sustainable alternatives to conventional plastics**.

The cited works include:

- studies on **adsorption, filtration and advanced oxidation** processes for removing microplastics from water and wastewater, often coupled with co-removal of other contaminants;
- research on **catalytic and photochemical upcycling** of plastic waste into value-added chemicals;
- development of **biodegradable or bio-based polymers** and functional materials designed to reduce environmental persistence and toxicity.

The WG5 State-of-the-art list reflects a clear shift from purely diagnostic research towards **solution-oriented approaches**, linking mitigation of plastic pollution to circular-economy strategies and sustainable product design. It also resonates with WG5 activities such as the planned position paper on the application of Directive 2018/852 and related legal instruments, which aim to translate scientific knowledge into regulatory levers to reduce plastic leakage.

8. WG6 – Metrology and standardization

WG6's State-of-the-art selection is explicitly metrological and standardization-focused. It combines:

- key **scientific articles** on measurement uncertainty, traceability and interlaboratory studies in the context of microplastic analysis;
- **ISO and CEN documents** providing terminology, principles and guidance on environmental aspects of plastics and microplastics analysis (e.g., ISO/TR 21960, ISO 24187, ISO 4484-1).

The WG6 webpage also documents a Virtual Mobility mapping of more than **280 institutions worldwide** active in MNP research and a coordinated effort to link PRIORITY with metrology-driven projects such as PlasticTrace. These activities and references converge on the idea that **credible data on micro- and nanoplastics require the same metrological rigor as any other environmental contaminant**, including traceable calibration, reference materials, defined measurands, and well-characterised uncertainty budgets.

In this view, interlaboratory comparison exercises are not just quality checks, but a **core engine for method harmonization**, guiding the design of simpler, well-controlled test materials and the alignment between research laboratories and National Metrology Institutes.

9. WG7 – Synergies with society and education

WG7's State-of-the-art references move beyond pure environmental and analytical science, focusing instead on **science communication, environmental education, citizen science, and inclusive research practices**.

The selected articles address, for example:

- the integration of **"Gender+" and diversity perspectives** in STEM disciplines and research organizations;
- participatory and inquiry-based learning approaches;
- the role of serious games, board games and creative formats in environmental education;
- case studies of citizen-science initiatives applied to plastic pollution.

These themes are coherently reflected in WG7 activities, such as the Frontiers for Young Minds article on exploring microplastics in a "home lab" experiment, translated into twelve languages to maximize accessibility, and in workshops on Diversity, Equity and Inclusion (DEI) in research.

Within the overall State of the Art, WG7 reminds us that micro- and nanoplastic pollution is not only a technical or regulatory issue, but also a **societal and educational challenge**, requiring informed citizens, inclusive research cultures and effective science–society interfaces.

10. Integrated picture

When the seven WG-specific State-of-the-art corpora are viewed together, they delineate a coherent and multi-layered understanding of micro- and nanoplastic pollution:

- **WG1 and WG4** emphasize impacts and risks across scales, from ecosystems to human health, with a special focus on nano-scale phenomena.
- **WG2 and WG3** provide the observational and analytical backbone, from sampling to data evaluation.
- **WG5** connects diagnosis to **solutions**, through remediation and sustainable materials.
- **WG6** anchors the entire enterprise in **metrology and standardization**, ensuring that data can be trusted and compared.
- **WG7** embeds all of this within a framework of **education, communication and DEI**.

This integrated State of the Art thus reflects **what the PRIORITY community itself recognises as the most relevant knowledge base**: a layered, evolving and increasingly harmonized body of science, where the remaining gaps are as important as the established facts and where methodological rigor, interdisciplinarity and societal engagement are indispensable for moving from understanding to action.