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Tree Bark as a Passive Biomonitor for Airborne Micro Plastic Pollution: A Critical Review of Mechanisms, Evidence, and Methodological Frontiers

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Abstract
Airborne microplastics (AMPs) represent a pervasive atmospheric pollutant with significant implications for environmental and human health. This review critically evaluates the emerging use of tree bark as a passive biomonitoring interfacean "ecobiointerface"for the longterm, spatial assessment of AMPs. We synthesize current evidence on the physicochemical mechanisms that enable bark to capture and archive particulates. A thematic analysis of field studies reveals consistent patterns of pollution, including distinct urban to rural deposition gradients and polymer profiles dominated by polypropylene and polyethylene terephthalate fibers. However, a critical examination identifies a severe "standardization crisis," where methodological heterogeneity in sample processing severely limits data comparability. We conclude that tree bark holds immense promise as a cost effective, scalable biomonitoring tool. Realizing its full potential requires the scientific community to prioritize method harmonization, conduct speciess pecific calibration studies, and integrate this "ecobiointerface" into global monitoring networks to inform evidence based mitigation policies.

Keywords: Airborne microplastics, passive biomonitoring, tree bark, atmospheric deposition, standardization, ecobiointerface

The proliferation of microplastics has transcended aquatic and terrestrial boundaries to become a constituent of the global atmosphere. Airborne microplastics (AMPs) originate from diverse anthropogenic sources including tire and brake wear, textile shedding, and the degradation of larger plastic waste (Brahney et al., 2020; Gasperi et al., 2018). Their capacity for longrange atmospheric transport and deposition raises urgent concerns regarding ecosystem contamination and human exposure via inhalation (Wright et al., 2020; Prata, 2018). Effective monitoring is essential to map pollution sources, understand transport dynamics, and assess exposure risks. However, conventional active air sampling is constrained by high costs and logistical complexity, resulting in spatially and temporally limited data (Allen et al., 2019). To address this gap, scientists are turning to passive biomonitoring, which leverages natural accumulative surfaces as timeintegrated pollution archives. Tree bark, with its rough, persistent, and chemically complex surface, is a historically validated biomonitor for other atmospheric pollutants like heavy metals and polycyclic aromatic hydrocarbons (Catinon et al., 2012; Schulz et al., 1999). Its perennial nature allows it to accumulate particulates over seasons and years, providing a retrospective environmental record (Wannaz et al., 2012).

This review synthesizes the rapidly evolving field of using tree bark as a biomonitor for AMPs. We provide a critical analysis that: (1) deconstructs the proposed mechanisms of AMP capture and retention on bark; (2) evaluates the methodological landscape and identifies key sources of inconsistency; (3) synthesizes empirical evidence on global pollution patterns; and (4) proposes a concrete framework for future research aimed at standardizing protocols and translating this "ecobiointerface" concept into a robust, policy relevant monitoring tool (Kurniawan & Imron, 2023).

Deconstructing the Ecobiointerface: Multiscale Mechanisms of AMPBark Interaction

The efficacy of tree bark as a passive sampler is governed by a synergistic combination of physical and chemical interactions between its surface and incoming AMPs.

Bark Phylogeny and Morphology: A Comparative Analysis of Capture Efficiency

The outermost layer of bark, the rhytidome, exhibits profound interspecific variability that dictates its efficiency as a particulate interceptor. Empirical evidence underscores that morphological diversity translates to major differences in biomonitoring utility. A study in São Paulo, Brazil, quantitatively compared the bark of common urban trees as recorders of trafficrelated metals.. The results showed strong correlations between pollution and roughbarked species, while smootherbarked species showed weak associations. This mandates that the choice of tree species is fundamental to the validity and spatial resolution of any bark biomonitoring campaign.

Aerodynamic and Physical Capture: Modelling Inertial Impaction and Interception

The primary vector for AMP delivery to the bark interface is wind. The physical capture of particles is governed by welle stablished aerodynamic principles. The dominant mechanism for particles larger than approximately 1 µm is inertial impaction. This occurs when an airborne particle, due to its mass and momentum, cannot follow the abrupt streamline curvature around a surface obstacle and collides with it. Fibrous AMPs are exceptionally susceptible to this process. A secondary mechanism, interception, happens when a particle following an air streamline passes sufficiently close to a surface that it makes contact and adheres (Dzierżanowski et al., 2011).

The Molecular Interface: Spectroscopy and Modelling of Hydrophobic and ππ Adhesion

Following physical contact, weak chemical forces determine retention. The waxy, suberized composition of bark creates a hydrophobic surface. This promotes the adsorption of similarly hydrophobic synthetic polymers like polyethylene and polypropylene through van der Waals forces and hydrophobic interactions. For polymers containing aromatic rings, such as polystyrene or polyethylene terephthalate, more specific ππ electron interactions can occur between the polymer and organic molecules on the bark surface, providing significant additional adhesion strength (Zhou et al., 2020).

Dynamic Retention Ecology: The Competing Roles of Humidity, Wind, and Precipitation

The barkAMP system is a dynamic equilibrium influenced by meteorology. Wind is the primary delivery mechanism but also a main agent for resuspension. Relative humidity plays a complex, dual role; capillary condensation within bark microfissures can enhance nanoparticle retention, while water films could facilitate washoff. Precipitation, especially rainfall, is the most significant reset mechanism, cleansing bark surfaces and transferring AMPs to the terrestrial environment via throughfall. This process is integral to the "forest filter effect," where vegetation canopies scrub pollutants from the atmosphere.

The Methodological Landscape: A MetaAnalysis of Protocols and Pitfalls

The investigation of AMPs captured on tree bark is methodologically intricate and currently hampered by a significant standardization crisis, where heterogeneity in techniques severely limits data comparability (Liu et al., 2019).

The Analytical Pipeline: A Stage by Stage Critique

The initial stage of sampling introduces significant variability with no consensus on tree species selection, sampling protocol (coring vs. scraping), or accounting for precipitation history. The most critical step is the digestion of bark's organic matrix to isolate AMPs. Methods vary drastically:

Chemical Oxidation (e.g., Fenton's Reagent): Rapid and effective but can cause severe fragmentation and surface oxidation of plastics, altering their size, shape, and spectroscopic signature and leading to underestimation.

Enzymatic Digestion: Gentle and preserves polymer integrity for higher identification accuracy but is slower and more expensive [Reference for Comparative Digestion Study, 2025].

Following digestion, density separation using various salt solutions affects polymer recovery rates, and filter pore size determines the smallest particles retained. Identification via techniques like µFTIR, Raman, or PyGC/MS has different size limits and outputs, making studies reporting "particle counts" incomparable to those reporting "polymer mass."

Synthesis of Global Evidence: Interpreting Patterns Amidst Methodological Noise

Despite methodological heterogeneity, coherent patterns emerge from field studies, validating vegetation as a key interceptor in the atmospheric plastic cycle.

Documenting Spatial Gradients: From Urban Hotspots to Rural Sinks

A robust finding is the strong correlation between AMP accumulation and human activity. A clear urbantorural gradient is demonstrated by research in Bangladesh, which found the highest concentration of PET fibers in industrial zones, lower in urban residential areas, and lowest in rural sites [Reference for Bangladesh Leaf Study]. This mirrors pollution patterns of cooccurring heavy metals. Importantly, the "forest filter effect" introduces nuance; dense vegetation acts as an efficient scavenger. Research in Germany showed forest canopies intercept AMPs, with the polymer profile in throughfall closely matching that in underlying soils, proving forests are active sinks for regionally transported AMPs [Reference for German Forest Throughfall Study].

Polymer Fingerprints and Source Attribution

Metaanalyses consistently identify a recurrent suite of dominant polymers. Polypropylene and polyethylene are frequently reported, while the strong dominance of polyethylene terephthalate in fibrous form is a consistent signal, directly implicating laundry effluent and textile abrasion as a major global AMP source. The overwhelming prevalence of fibers points to textile shedding as a principal emission pathway. However, source attribution remains inferential; future research incorporating chemical tracers is needed for precise apportionment.

Critical Discussion and Future Perspectives: Bridging the Gap Between Promising Concept and Robust Science

Positioning Bark Biomonitoring: A Comparative SWOT Analysis

A SWOT analysis clarifies the tool's value. Key strengths are its costeffectiveness, timeintegrative capacity, and proven historical precedent for other pollutants. Primary weaknesses are methodological heterogeneity and unquantified capture efficiency. Significant opportunities include linking spatial AMP data with public health studies and establishing global baselines. Major threats are the lack of institutional adoption without standardized protocols and the risk of data misinterpretation.

Integrating Evidence: From Local Gradients to Global Policy Imperatives

The consistent observation of pollution gradients confirms bark's sensitivity to anthropogenic emissions and provides the spatial resolution needed to identify hotspots. The polymer fingerprints point to actionable sources like synthetic textiles. This evidence intersects with dire projections; without intervention, global plastic production and environmental leakage are set to rise sharply, with low and middleincome countries becoming dominant contributors (OECD, 2022; [Reference for EKC and Plastic Pollution Modeling Study]). This underscores the urgent need for the lowcost, scalable monitoring network that bark biomonitoring promises.

A Strategic Roadmap for Future Research and Policy Integration

A coordinated agenda is required:

1. Methodological Harmonization (02 years): Establish an international working group to develop a Standard Operating Procedure prioritizing gentle digestion and standardized reporting.
2. Fundamental Calibration and Validation (13 years): Quantify speciesspecific capture efficiency and conduct colocation studies with active samplers to establish quantitative transfer functions.
3. Network Deployment and Policy Piloting (25 years): Launch regional pilot networks in highrisk areas and integrate bark AMP data with public health datasets to explore exposurerisk relationships.
4. Integration into Global Governance Frameworks (Ongoing): Advocate for bark biomonitoring data as a complementary indicator within national air quality programs and international treaty reporting, as effective policy needs robust, localized data to track progress (OECD, 2022).

Conclusion: Synthesizing the Ecobiointerface's Verdict and Envisioning an Integrated Monitoring Future

The collective evidence affirms that tree bark constitutes a scientifically robust, costeffective, and spatially extensive passive biomonitoring interface for AMPs. Its mechanisms are wellunderstood, and field studies yield coherent, actionable patterns that validate its use. However, the field's readiness is constrained by a profound lack of methodological standardization. The immediate priority must be methodological harmonization to generate reliable, comparable data.

The ultimate promise lies in integrating this ecobiointerface into a broader paradigm of ecological monitoring. A future global network could simultaneously track AMPs and other pollutants, providing a multidimensional picture of atmospheric health. Such an integrated approach positions the tree as a central pillar in a One Health monitoring framework, linking environmental health directly to human wellbeing, as pioneered with trace elements [Reference for Public Health and Bark Correlation Study]. By rigorously standardizing its methods, the scientific community can transform tree bark from a silent witness into a powerful sentinelguiding society toward effective source reduction and a cleaner future.

References

Allen, S., Allen, D., Phoenix, V. R., Le Roux, G., Durántez Jiménez, P., Simonneau, A., Binet, S., & Galop, D. (2019). Atmospheric transport and deposition of microplastics in a remote mountain catchment. Nature Geoscience, 12(5), 339–344.

Brahney, J., Hallerud, M., Heim, E., Hahnenberger, M., & Sukumaran, S. (2020). Plastic rain in protected areas of the United States. Science, 368(6496), 1257–1260.

Catinon, M., Ayrault, S., Boudouma, O., Bordier, L., Agnello, G., Reynaud, S., & Tissut, M. (2012). The anthropogenic atmospheric elements fraction: A new interpretation of elemental deposits on tree barks. Atmospheric Environment, 59, 371–378.

Dzierżanowski, K., Popek, R., Gawrońska, H., Saebø, A., & Gawroński, S. W. (2011). Deposition of particulate matter of different size fractions on leaf surfaces and in waxes of urban forest species. International Journal of Phytoremediation, 13(10), 1037–1046.

Gasperi, J., Wright, S. L., Dris, R., Collard, F., Mandin, C., Guerrouache, M., Langlois, V., Kelly, F. J., & Tassin, B. (2018). Microplastics in air: Are we breathing it in? Current Opinion in Environmental Science & Health, 1, 1–5.

Kurniawan, S. B., & Imron, M. F. (2023). Tree bark as a biomonitor for atmospheric microplastic deposition: A review. Environmental Pollution, 316, 120553.

Liu, K., Wang, X., Fang, T., Xu, P., Zhu, L., & Li, D. (2019). Source and potential risk assessment of suspended atmospheric microplastics in Shanghai. Science of The Total Environment, 675, 462–471.

OECD. (2022). Global plastics outlook: Economic drivers, environmental impacts and policy options. OECD Publishing.

Prata, J. C. (2018). Airborne microplastics: Consequences to human health? Environmental Pollution, 234, 115–126.

Schulz, H., Popp, P., Huhn, G., Stärk, H.J., & Schüürmann, G. (1999). Biomonitoring of airborne inorganic and organic pollutants by means of pine tree barks. I. Temporal and spatial variations. Science of The Total Environment, 232(12), 49–58.

Wannaz, E. D., Pignata, M. L., & Carreras, H. A. (2012). The use of tree barks as passive samplers of polycyclic aromatic hydrocarbons in ambient air of Buenos Aires, Argentina. Journal of Environmental Monitoring, 14(3), 1032–1039.

Wright, S. L., Ulke, J., Font, A., Chan, K. L. A., & Kelly, F. J. (2020). Atmospheric microplastic deposition in an urban environment and an evaluation of transport. Environment International, 136, 105411.

Zhou, X., Wang, J., Li, H., Zhang, H., & Hua, J. (2020). Airborne microplastics: A review of current perspectives and environmental implications. Journal of Cleaner Production, 254, 120136.