Utilizing Cypress Needles To Spatially Profile Atmospheric Polyfluoroalkyl Substances (PFAS)

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INTRODUCTION

Per- and polyfluoroalkyl substances (PFAS) are a large group of synthetic chemicals characterized by highly stable carbon–fluorine bonds, conferring exceptional thermal stability, hydrophobicity, and oleophobicity. These unique physicochemical properties have led to their extensive use in industrial processes, consumer products, and specialized applications such as firefighting foams, textiles, coatings, and semiconductors. However, PFAS are environmentally persistent, resistant to degradation, and capable of long-range atmospheric transport, which leads to their widespread presence in the environment. Moreover, PFAS exposure can lead to adverse health outcomes in wildlife and humans. Therefore, monitoring PFAS occurrence and distribution is urgently needed.

Atmospheric deposition is one of the major pathways for PFAS to the environment. Conifer needles, with their waxy cuticle and year-round retention, act as an effective passive biomonitor by accumulating airborne contaminants over extended periods. In this study, we investigate the spatial distribution and composition of PFAS in bald cypress needles collected from urban and suburban sites in Taipei metropolitan area. we aim to:

(1) Quantify and characterize PFAS composition in bald cypress needles.
(2) Identify potential emission sources via correlation analysis.
(3) Evaluate the feasibility of using conifer needles as a large-scale passive biomonitoring tool for PFAS atmospheric deposition.

MATERIALS & METHODS

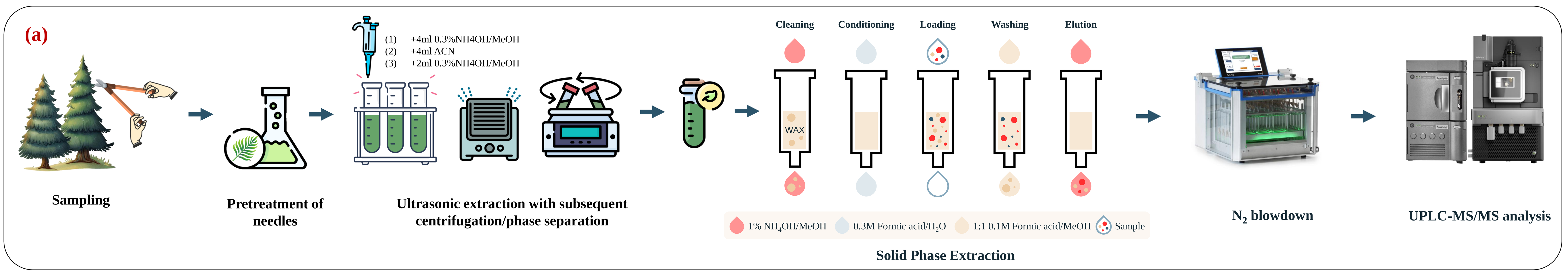


Fig. a. PFAS extraction and analysis workflow. Conifer needles underwent pretreatment, ultrasonic-assisted extraction, and centrifugation, followed by WAX SPE cleanup, nitrogen evaporation, and UPLC–MS/MS analysis.

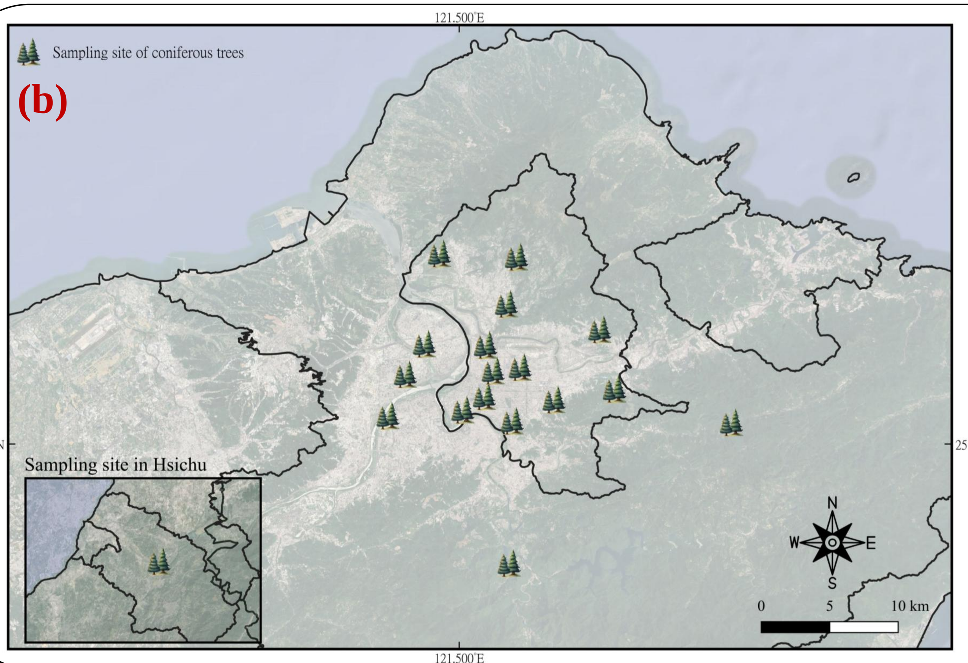


Fig. b. Geographical distribution of the 18 sampling sites of bald cypress in Taipei metropolitan area.

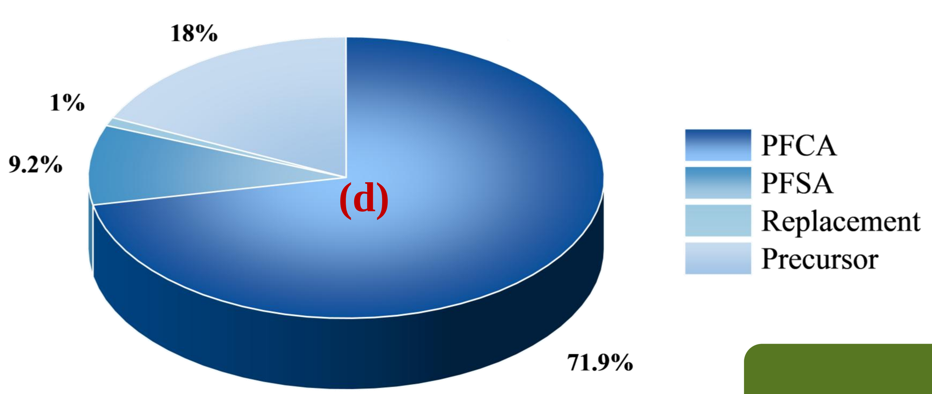
Sampling locations are distributed across both urban areas of Taipei City and its surrounding suburban regions, allowing comparison of environmental influences between distinct settings. Each tree icon indicates a site where leaf samples were collected for subsequent chemical and environmental analyses. The inset highlights an additional sampling site in Hsinchu.

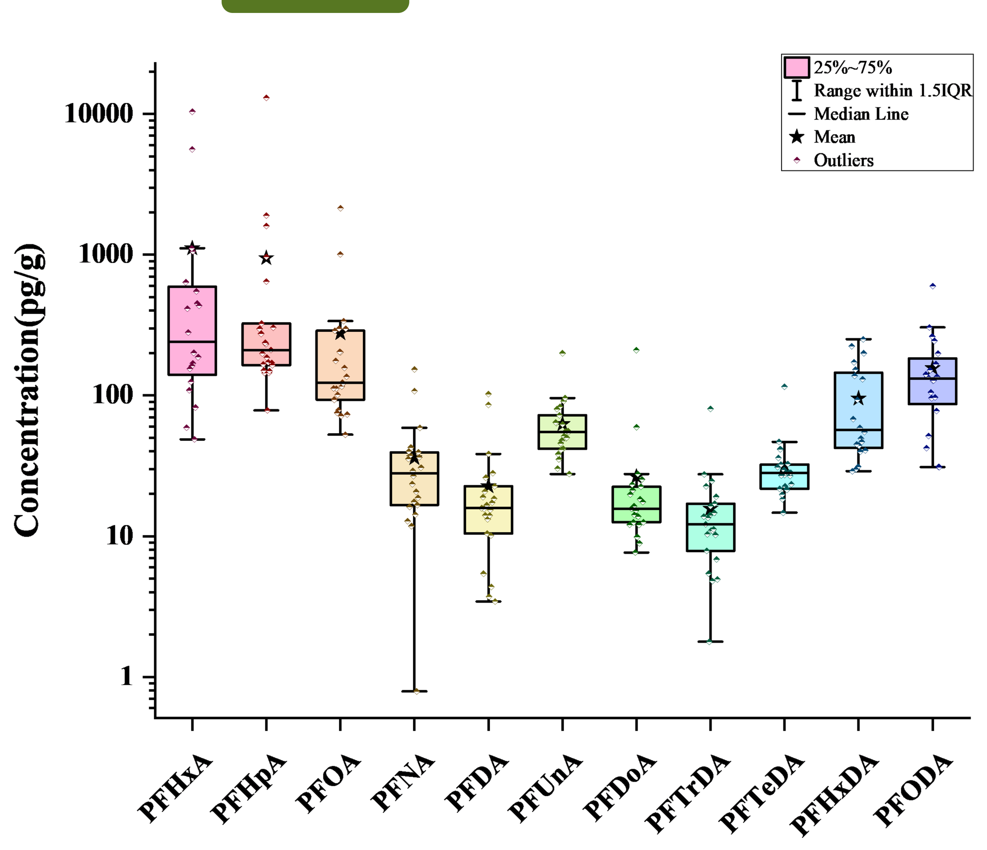
Fig. c. Collected bald cypress needles

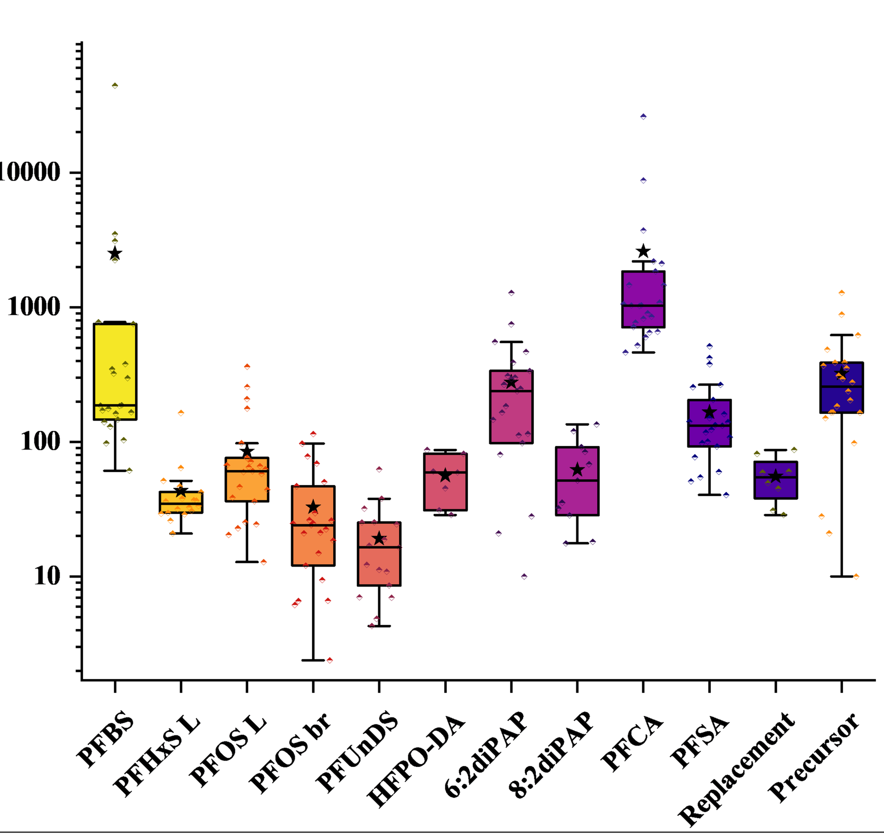
Needle-like leaves of *Taxodium distichum* (bald cypress), a deciduous conifer widely planted in lowland Taiwan. This species was selected due to its broad distribution in both urban and suburban areas, making it an effective bioindicator. Its needle morphology provides a large surface area for atmospheric pollutant deposition, while its adaptability to subtropical low-latitude environments ensures consistent seasonal sampling for air quality monitoring.

RESULTS

PFAS occurrence







Figures d-f. PFAS composition and compound-specific concentrations in bald cypress needles collected from 18 urban sites in Taipei and one site in Hsinchu. PFAS composition shows PFCA dominance (71.9%), followed by PFAS replacements (18%), PFSA (9.2%), and PFAS precursors (1%). Box plots (log scale) indicate higher and more variable PFCA concentrations compared to PFSA.

Correlation analysis of PFAS in samples

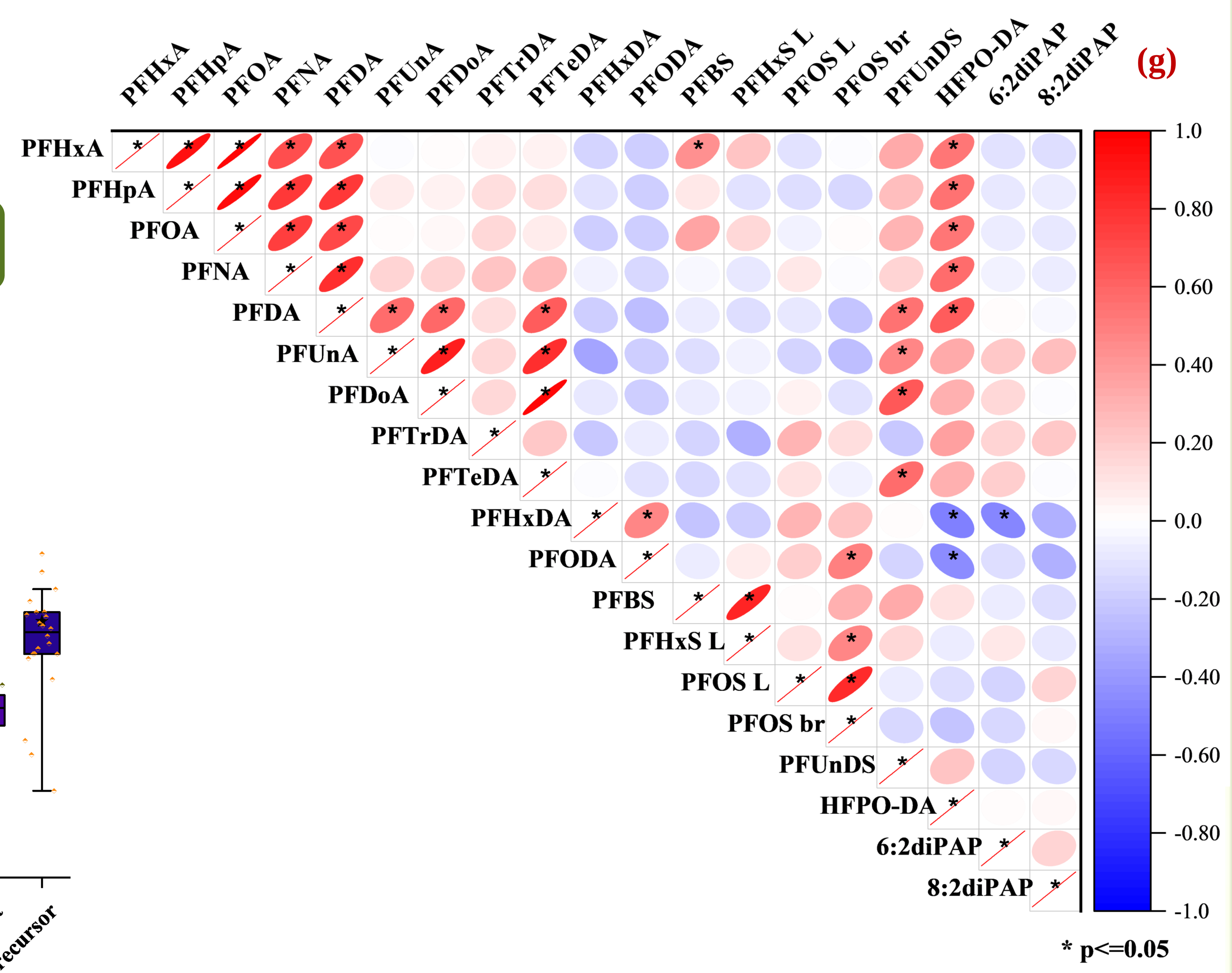
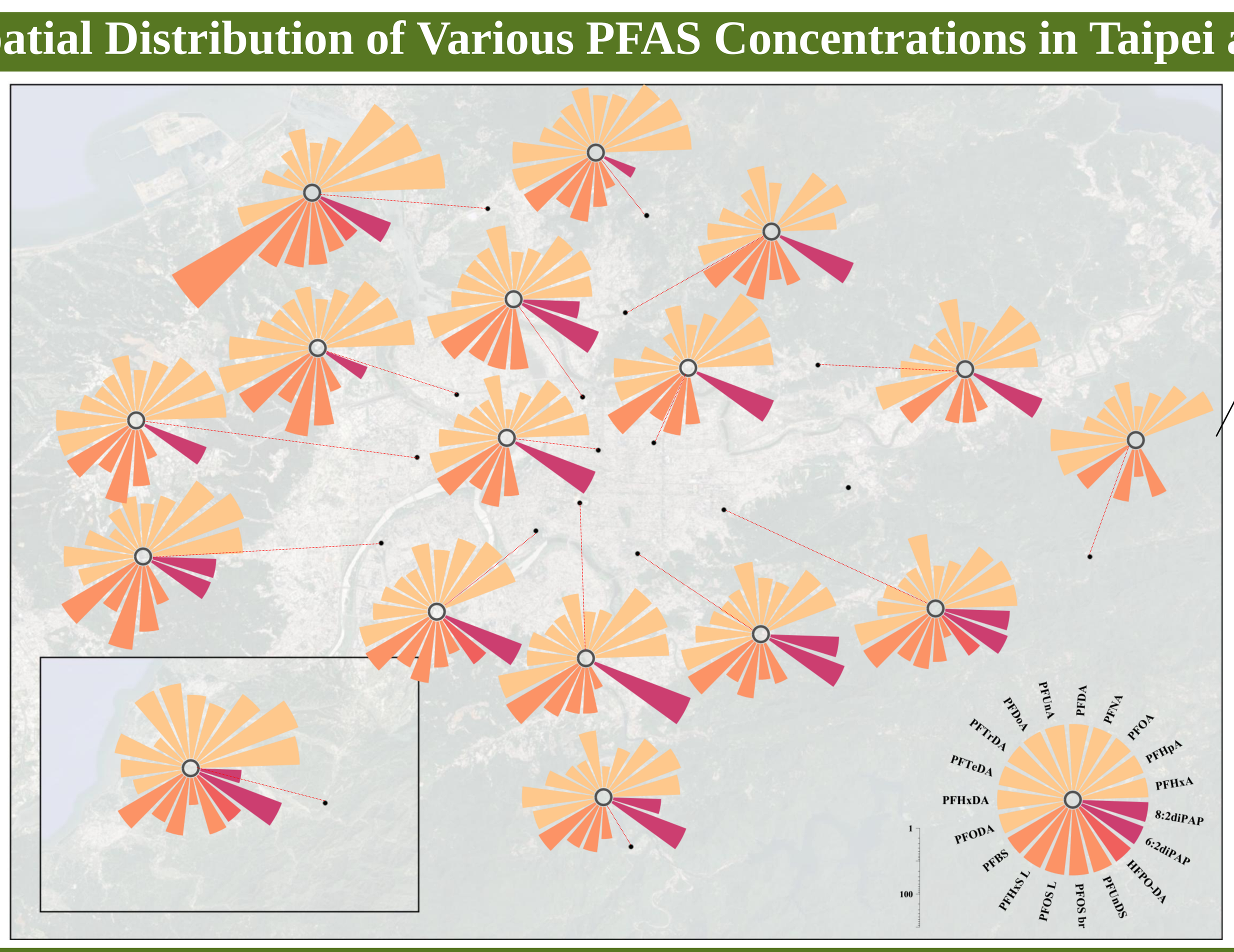


Figure g. Correlation among PFAS detected in needles. Long-chain PFCAs and some PFSAs show strong positive correlations; diPAPs display weaker links, indicating different sources.

Spatial Distribution of Various PFAS Concentrations in Taipei and Hsinchu



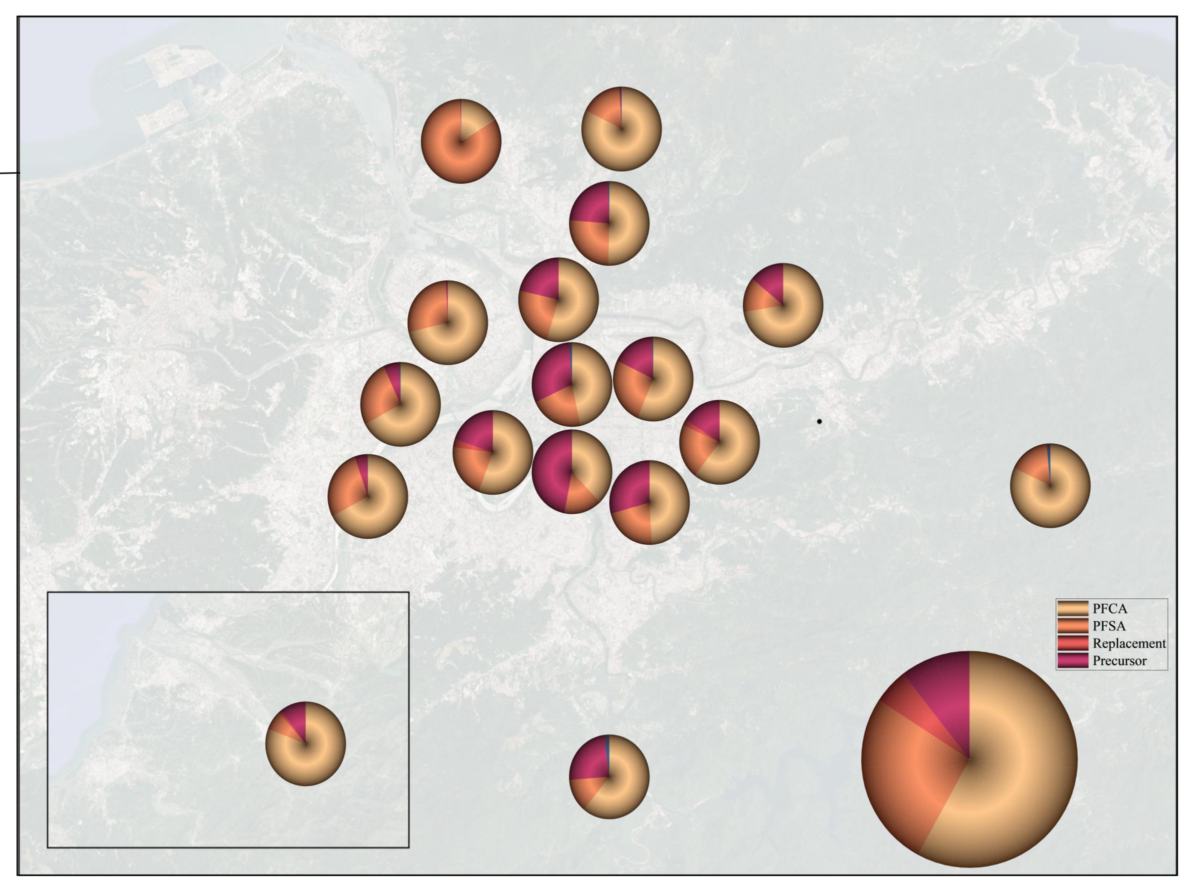


Fig. h. Compositional profiles of PFASs in conifer needles across northern Taiwan

Pie chart show the relative composition of PFAS in *Taxodium distichum* needles collected from 18 urban and suburban sites. Each sector represents a different compound, with length proportional to relative abundance and color intensity indicating concentration differences. Distinct compositional patterns across sites reflect the influence of urban activities and local environmental conditions on atmospheric deposition.

CONCLUSIONS

- Perfluorocarboxylic acids (PFCAs) dominated PFAS profiles in bald cypress needles (>70%), followed by replacement compounds, perfluorosulfonic acids (PFSAs), and precursors. This distribution indicates that PFCA-dominated sources may be present in the study area. Positive correlations among PFCAs and PFSAs indicate likely shared sources or similar atmospheric behaviors, while weak diPAP associations imply distinct origins, possibly from localized point source.
- Spatial variations across urban and suburban sites likely reflect differences in emissions, human activities, and meteorological conditions. Greater variability in PFCAs compared to PFSAs highlights the complex interplay between sources and atmospheric processes.
- These findings confirm bald cypress needles as cost-effective, reliable passive samplers for atmospheric PFAS, capable of capturing spatial gradients and compositional signatures. This approach has potentials to support source identification, long-term analysis, and early detection of emerging PFAS, providing a valuable tool for environmental monitoring and management.

*Reference: Glüge, J., et al. (2020). *Environ. Sci.: Processes & Impacts*, 22, 2345–2373. Pettersson, M., et al. (2024). *Environ. Pollut.*, 363, 125237. Kirkwood, K. I., et al. (2022). *Environ. Sci. Technol.*, 56, 3441–3451.