The invisible environmental impact of tourism in show caves: microplastic pollution in three Italian show caves

The invisible environmental impact of tourism in show caves: microplastic pollution in three Italian show caves

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Abstract. Show caves are the most important geological heritage in the world, a significant economic resource and unique ecosystems characterized by speleothems, particular species and important drinking water reserves, however, microplastic (MP) pollution in caves is poorly studied. The deposits of three NW Italian show caves were investigated: for each cave, six sediment samples were collected along the tourist paths and one in a non-touristic area. MPs were identified and characterized using MUPL automated software, observed with and without UV light under a microscope, and verified under μFTIR-ATR. MPs were present in sediments of all examined caves: an average of 4300 MPs/kg were found along the tourist paths and of 2570 MPs/kg in the speleological zones. MPs less than 1 mm, fibre-shaped, polyesters and polyolefins dominated the samples suggesting that synthetic clothes are the main source of pollution in show caves. Our results highlight a high pollution of MPs in the examined show caves, despite the different touristic and environmental characteristics. The subterranean environment monitoring gives useful information to assess risks posed by MPs in show caves and consequently define strategies for the conservation and management of caves and natural resources.

Keywords: microplastic, show cave, geological heritage, sediment, tourist impact

1. Introduction

Caves are the most important geological heritage worldwide (Cigna & Forti, 2013; Piano et al., 2022), famous especially for their peculiar speleothems, extremely interesting habitats hosting particular species (Culver & Pipan, 2019; Mammola, 2019), often containing important water reserves (Moldovan et al., 2020). Recently, the interest in underground karst environments has grown remarkably, highlighting the importance of conservation and sustainable management actions (Chiarini et al., 2022; Cigna, 2013; Cigna, 2016). Caves can be considered “conservative environments” (Chiarini et al., 2022), therefore, they can easily damaged by pollution and climate variations, irreparably loosing scientific information and natural habitats (Chiarini et al., 2022; Gillieson, 2011). When cavities became show caves, different anthropogenic impact are produced (Calaforra et al., 2003; Cigna & Forti, 2013): the installation of lighting systems, the construction of paths and the passage of tourists can modify the cave atmosphere and microclimate (Lang et al., 2015a; Lang et al., 2015b) and introduce lint, dust, pollutants and organic materials (Balestra & Bellopede, 2022; Chelius et al., 2009; Christman, 2019).

Microplastic (MP) pollution was found in different natural environments worldwide (Bertoldi et al., 2021; Boyle & Örmeci, 2020; Liu et al., 2022; Phuong et al., 2018), remote areas included (e.g. Ambrosini et al., 2019; Neelavannan et al., 2022; Zhang et al., 2021), however, this kind of pollution in underground environments is little investigated (e.g. Balestra & Bellopede, 2022; Balestra et al., 2023; Panno et al., 2019; Romano et al., 2023; Valentić et al., 2022). Previously analysis of cave lint and MPs gave a synthetic fibre content between 30 and 85% (Balestra & Bellopede, 2022; Christman, 2019; Jablonsky et al., 1993).

MPs can endanger the hypogeal ecosystems, pollute karst water, be consumed by subterranean organisms, and irreversibly damage speleothems and findings. The economic impact of the possible damage on speleothems and habitats could be high for show caves and their connected tourist activities (Chiarini et al., 2022).

For conservational purposes, the aims of this study are: i) to verify if MPs are present in all examined show caves, ii) to investigate the presence, abundance, and characteristics of MPs in sediments of the cavities, and iii) to check if the MP amount is always greater along the tourist route than the speleological areas.

2. Materials and method

Sediment samples were collected in Bossea, Borgio Verezzi and Toirano show caves (NW Italy), within the national project PRIN “SHOWCAVE”, a multidisciplinary research project to study, classify and mitigate the environmental impact in tourist caves (Balestra et al., 2021).

In all examined show caves five sampling areas of 1x1 m were defined near the tourist path in different areas of the caves and one in a speleological zone. For each sampling area, a minimum of 150 g of superficial sediments (upper 5 cm) were collected. Bossea cave samples were collected once in 2021, instead Borgio Verezzi and Toirano cave samples were collected once in 2022. Being caves conservative environments (Chiarini et al., 2022), variations in environmental parameters are often minimal, unaffecting data on MPs, with exceptions for active caves. Moreover, sampling areas along the tourist paths are away from watercourses, which could seasonally modify the amounts of MPs in sediments. Sediment samples of Bossea cave were previously analyzed using the method described in Balestra & Bellopede (2022); samples collected in Borgio Verezzi and Toirano caves were analyzed according to this method, improved.

Separated particles on filters were observed with and without a UV flashlight (Alonefire SV10 365 nm UV flashlight 5W) under a Leitz ORTHOLUX II POL-MK microscope equipped with a DeltaPix Invenio 12EIII 12 Mpx Camera, with 2.5x, 4x, 10x or higher magnifications (Balestra & Bellopede, 2022). Detected MPs were characterized according to the Standardized size and colour sorting system (SCS) (Crawford & Quinn, 2016).

Fluorescent MPs on filters of Borgio Verezzi and Toirano caves were also counted and characterized by shape and size using the automated software MUPL (Giardino et al., 2023) through the creation of high-definition photographs under UV light. The parameters were set to have a total mean error <10% and an error on each filter <15%.

Finally, a portion of MPs found in the Toirano and Borgio Verezzi caves was verified using a micro-Fourier Transform Infrared Spectroscope (micro-FTIR) Shimadzu AIM-9000 microscope equipped with a Shimadzu IRTracer-100 spectrophotometer and a Shimadzu ATR with a germanium prism. Spectra were compared with the ATR-Polymer library, followed by a visual analysis comparison of characteristic bands in the reference spectrum, and accepted only with a match degree ≥ 80% (Fossi et al., 2017).

3. Results and discussions

MPs were found in all cave sediment samples, non-touristic areas included, with higher amount along the tourist paths (Table 1). MP pollution in the touristic areas of the caves could be related to the visitors presence, however, it is not possible to exclude a MP contamination from the external environments, due to the open nature of the karst systems (Balestra et al., 2023), especially in the cave of Borgio Verezzi, located in the town of Borgio, in which it is possible that some of the pollution comes from the roads above. In the Toirano caves, MP amount in the speleological area was similar to the touristic ones; this fact could be related to presence of beautiful speleothems in this easy-to-access area, often visited by speleologists and researchers which can carry particles in this zone. Moreover, washing of the tourist path with pumped water is carried out, which can move the deposited material, accumulate it in certain areas and/or remove it from others.

Table 1. MP abundances in sediments of the examined show caves

Show cave	Touristic area [items/kg]	Not-touristic area [items/kg]
Toirano caves	1060.0	1033.3
Borgio Verezzi cave	1103.3	666.7
Bossea cave	1906.7	733.3

Fibre was the most common shape among the MPs present in the sediments of all caves, followed by fragments and other shapes (Table 2). Up to 60% of world textiles production are synthetic (Boucher & Friot, 2017) suggesting that synthetic clothes of tourists could be the main source of pollution in show cave sediments.

Table 2. MP shape in the examined show caves

Show cave	Fibres	Fragments	Other
Toirano caves	93.7%	6.3%	0.0%
Borgio Verezzi cave	87.9%	12.1%	0.0%
Bossea cave	94.2%	5.5%	0.3%

MPs less than 1 mm accounted for more than 70% in sediments of all caves (Table 3).

Table 3. MP size in the examined show caves

Show cave	5-1 mm	0.99-0.4 mm
Toirano caves	25.3%	74.7%
Borgio Verezzi cave	27.5%	72.5%
Bossea cave	27.3%	72.7%

The fluorescent MP percentages varied for each cave with a mean value of about 74%, highlighting the importance of visual identification under microscope, in order to not lose the non-fluorescent particles (about 25%) during MP detection.

Spectroscopic analysis highlights the presence of polyamide, polyester, polyethylene, polyethylene terephthalate, polyvinyl acetate, polyacrylamide, ethylene vinyl alcohol, copolymer and polyvinyl formal in Borgio Verezzi cave sediments and polyester, polyethylene terephthalate, polyacrylamide, ethylene vinyl acetate, and polypropylene in Toirano caves ones. The MP identification by spectroscopy is useful to understand the possible source of pollution: many of the plastics found in Borgio Verezzi and Toirano caves are used in textile manufacturing, supporting the assumptions on the primary origin of MPs in cave sediments due to the tourist clothes.

4. Conclusion

This study highlights the presence of microplastics in deposits of all examined Italian show caves. To obtain as much information as possible, visual identification under microscope and MUPL automated software were used, showing the importance of combine different methodologies. Microplastics were present in each sampling area of all caves, with higher amount along the tourist paths. Most of the particles were fluorescent under UV light. Small size, fibre-shape, polyester and polyolefin microplastics dominate the samples, suggesting that synthetic clothes could be the main source of microplastic pollution in show caves. Microplastic monitoring in subterranean environments is a fundamental step to establish the current degree of pollution and consequently define strategies for the protection and management of this geological heritages.

5. Acknowledgments

The authors are grateful to the Toirano, Borgio Verezzi and Bossea caves managers. Funding: This work was realised within the research project “SHOWCAVE: a multidisciplinary research project to study, classify and mitigate the environmental impact in tourist caves”, funded by the Italian Ministry of Education, University and Research [PRIN: Progetti di ricerca di rilevante interesse nazionale 2017 - Prot. 2017HTXT2R; PI: Prof. Marco Isaia, University of Torino].

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