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Study of the environmental impact in show caves: a multidisciplinary research

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Caves are one of the most important and well-known geological features in the world, an environmental and cultural heritage, as well as an important economic resource for many countries. Their scientific and aesthetic value is often threatened by tourism, which unfortunately exposes them to a series of risks of degradation and, sometimes, irreparably changes. Therefore, the study of underground environment becomes essential in order to protect and preserve it over time. The national project "SHOWCAVE" aims to study, classify and mitigate the environmental impact in the tourist caves to finally propose useful solutions for their management. In particular, the DIATI team of the Politecnico di Torino deals with the acquisition of monitoring data of the main environmental parameters, the analysis of the speleothems corrosion and the analysis of the presence of microplastics in caves. The most advanced geomatics techniques are used to illustrate the topography of these cavities, their development relative to the surface and the studied areas. The researches have just begun, and in this work the study methodologies used and the first results obtained by our multidisciplinary research group are presented.

Keywords: Geoheritage, microplastics, speleothems corrosion, environmental parameters monitoring, geomatics.

Studio dell'impatto ambientale nelle grotte turistiche: una ricerca multidisciplinare. *Le cavità naturali rappresentano una tra le più importanti e conosciute manifestazioni geologiche del mondo, e sono un patrimonio ambientale e culturale, oltre che un'importante risorsa economica per molti paesi. Il loro valore scientifico ed estetico è spesso minacciato dalla fruizione turistica, che purtroppo le espone ad una serie di rischi di degrado e talvolta le modifica irrimediabilmente. Diventa dunque essenziale lo studio dell'ambiente ipogeo per poterlo tutelare e conservare nel tempo. Il progetto nazionale "SHOWCAVE" ha lo scopo di studiare, classificare e mitigare l'impatto ambientale nelle grotte turistiche per proporre infine soluzioni utili alla loro gestione. In particolare, il team del DIATI del Politecnico di Torino si occupa dell'acquisizione dei dati di monitoraggio dei principali parametri ambientali, dell'analisi dei fenomeni legati alla corrosione degli speleotemi e dell'analisi della presenza di microplastiche in grotta. Per illustrare la topografia di tali cavità, il loro sviluppo rispetto alla superficie e le zone oggetto di studio, vengono utilizzate le tecniche geomatiche più avanzate. Gli studi sono appena iniziati e in questo lavoro vengono presentate le metodologie di studio utilizzate e i primi risultati ottenuti dal nostro gruppo di ricerca multidisciplinare.*

Parole chiave: *Patrimonio geologico, microplastiche, corrosione degli speleotemi, monitoraggio dei parametri ambientali, geomatica.*

1. Introduction

Show caves are made accessible to the public for touristic purposes, managed by a governmental or commercial organization. Over the past decades, the interest for the underground karst environments and its natural wonders has grown remarkably, not only from a scientific viewpoint, but also from an economic perspective (Cigna, 2016; Cigna & Forti, 2013). The numbers of visitors (sometimes up to 50,000/year/cave) and the profits deriving from such activities have recently gained importance at global scale (Cigna & Forti, 2013). Caves are fragile environments which can be easily damaged by negative effects of tourism, such as air temperature and CO_2 increment (e.g. Cuevas-González *et al.*, 2010; Dominguez-Villar *et al.*, 2010; Faimon *et al.*, 2006; Fernandez-Cortes *et al.*, 2011; Lang *et al.*, 2015a; Lang *et al.*, 2015b; Lang *et al.*, 2017; Lobo *et al.*, 2014; Pulido-Bosch *et al.*, 1997; Šebela *et al.*, 2013; Singh, 2011), lampenflora growth (e.g. Baquedano Estevez *et al.*, 2019; Havlena, 2019; Kurniawan *et al.*, 2018; Mulec & Kosi, 2009; Piano *et al.*, 2015; Pulido-Bosch *et al.*, 1997) or pollution (e.g. Chang *et al.*, 2008; Christman, 2019; Šebela *et al.*, 2015), therefore, scientific investigations are necessary to better understand cave environment and to protect them (Cigna, 2016; Cigna & Forti, 2013; De Freitas, 2010).

The National Project "SHOWCAVE – A multidisciplinary research project to study, classify and mitigate the environmental impact in tourist caves" (PRIN2017.0000375.26-03-2018) started in 2020, aiming to provide an in-depth characterization and quantification of the environmental impacts related to tourist exploitation in show caves, focusing on the biological, geological, hydrogeological, archaeological and physical components of the cave environment. Within this research, the Department of Environment, Land and Infrastructure Engineering (DIATI) team of the Politecnico di Torino (PoliTO) is carrying out different studies with an innovative and multidisciplinary approach which will be described below.

The geological features of the show caves have been investigated with a special attention on the classification of speleothems and the study of the internal and external geomorphology of the karstic system. Physical indicators as temperature, relative humidity and CO_2, have been monitored to track the air and water quality. An internal and external 3D survey of the Borgio Verezzi Cave has been carried out with integrated GNSS Total Station, Lidar and photogrammetry techniques. The survey of the path allows to estimate the subjacency of the cave with respect to the urbanized territory. Microplastics (MPs) pollution in cave sediments has been monitored too, for the first time. MPs pollution in sediments has been observed in different natural environments (e.g. Ballent *et al.*, 2016; Blumenröder *et al.*, 2017; Mathalon & Hill, 2014; Naji *et al.*, 2017; Phuong *et al.*, 2018; Qiu *et al.*, 2015; Van Cauwenberghe *et al.*, 2013; Vianello *et al.*, 2013), moreover, only few researches on lint (natural and synthetic fibers from clothing) in cave have been done (e.g.Chelius *et al.*, 2009; Christman, 2019; Jablonsky *et al.*, 1993) and the potential impact of MPs in cave has not been studied. Secondly, it will be possible to make different correlations between the presence of MPs and biotic and abiotic factors in cave. Finally, a study on the indirect impact of tourism on the mineralogical and petrographic properties of the carbonate rocks have been started, with the aim of relating it to the corrosion degree.

In the present paper, we reported first evidences of our studies developed in the Bossea Cave, Toirano Caves, and Borgio Verezzi Cave (NW Italy), providing new insight on subterranean environments and on tourist impact in these caves.

2. *Study area*

This study provides a systematic monitoring of the Bossea Cave, Piedmont, Toirano Caves, Liguria, and Borgio Verezzi Cave, Liguria, in Italy (Fig. 1).

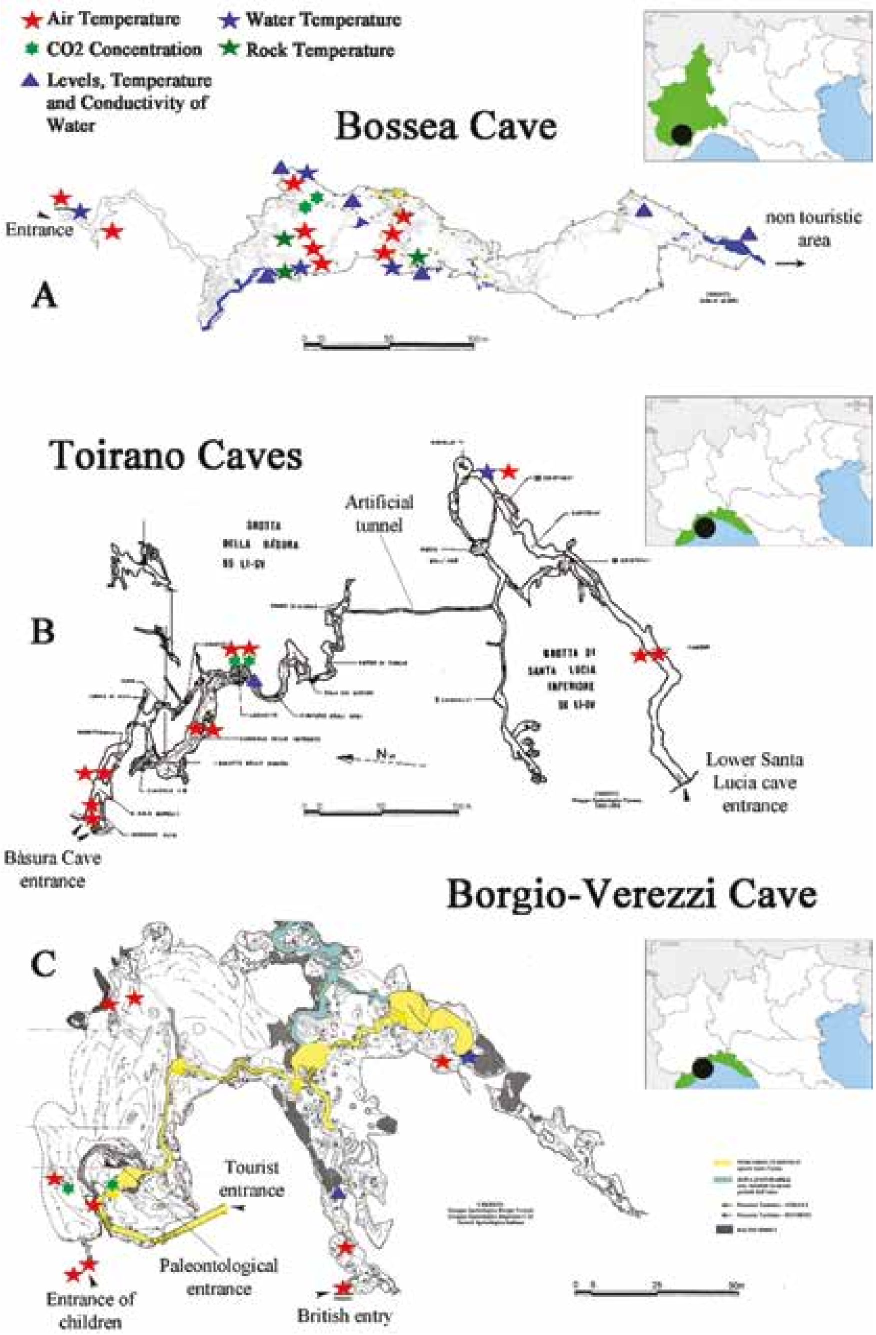

Fig. 1 – Location of the investigated tourist caves and their monitoring points. A-Bossea cave (survey: Sella *et al.* 2005, modified), B-Toirano Caves (survey: Gruppo Speleologico Cycnus, from http://www.openspeleo.org/openspeleo/, modified), C-Borgio Verezzi Cave (survey: Gruppo Speleologico Borgio Verezzi, Gruppo Speleologico Imperiese CAI, Società Speleologica Italiana, from http://www.openspeleo.org/openspeleo/, modified). The black dot indicates the location of the studied show caves (maps used for the plate retrieved from: https://d-maps.com/carte.php?num_car=5892&lang=en).

2.1. Bossea Cave

Bossea Cave (Fig. 1A) is located in Frabosa Soprana municipality, Piedmont, Italy at 836 m.a.s.l. The cave develops in a tectonic contact between permotriassic meta-volcanics and Dolomie di San Pietro dei Monti formation (Middle Triassic), composed by carbonate rocks and dolostone (Antonellini *et al.*, 2019). It is the first show cave of Italy and was opened to the public in 1874. In 1948 the tourist route was modified and the first electric lightning was installed. In 2020 a new LED lightning system was done. It is one of the nicest Italian tourist caves due to its variety of concretions, plenty of water and underground lakes. Different bear bones (*Ursus spelaeus*) were found in Bossea Cave and a skeletal reconstruction can be seen in the "Bear saloon". An underground karst laboratory is located inside the touristic trait of the cave, managed by Struttura Operativa (SO) Bossea CAI and by the DIATI of the PoliTO, working together with ARPA Piemonte. A secondary lab is located in a non-touristic area of the cave. Thanks to these laboratories, hydrogeology, hypogeal meteorology, Radon activity and subterranean biology are studied (Peano & Fisanotti, 1994).

2.2 Toirano Caves

Toirano Caves (Fig. 1B) are located in the municipality of Toirano, Liguria, Italy. They developed in Dolomie di San Pietro dei Monti formation and an hypogenic speleogenenis origin has been recently supposed in Columbu *et al.* (2021). Toirano Caves are characterised by two different caves: Bàsura Cave (Grotta della Bàsura, 186 m.a.s.l., 890 long) and Lower S. Lucia Cave (Grotta di Santa Lucia inferiore, 201 m.a.s.l., 778 long). Bàsura Cave was explored in 1950 and opened to the public in 1953. S. Lucia inf. Cave and new galleries of Bàsura Cave were explored in 1960. In 1967 a 110 m long artificial tunnel was made to connect the two caves. Bàsura Cave preserves hundreds human (14400 years old) and animal footprints (Avanzini *et al.*, 2018). Recent studies revealed that footprints in this cave belonged to 5 different individuals (*Homo sapiens* groups), 2 adults and 3 children, from the upper Paleolithic (Romano *et al.*, 2019). This cave contains also a lot of cave bear (*Ursus spelaeus*) bones and signs of presence (Giacobini & D'Errico, 1985; Rellini *et al.*, 2021), an extinct plantigrade from the upper Pleistocene (50000-24000 years old). Lower Santa Lucia Cave is characterised by beautiful speleothems such as coralloid and cave clouds (Martini, 2008).

2.3. Borgio Verezzi Cave

Borgio Verezzi Cave (Fig. 1C) was discovered in 1933 by three children but was opened to the public only in 1970. It is located in the municipality of Borgio Verezzi, Liguria, Italy at 32 m.a.s.l. and develops in Dolomie di San Pietro dei Monti formation. It is rich in coloured speleothems and has an 800 m touristic path. Different paleontological finds datable between 500,000 and 750,000 years ago were found in different parts of the cavity (Breda, 2015 and references therein), witnessing the alternation between glacial and hot periods.

3. Investigation method

3.1. Environmental parameters monitoring

Preliminary surveys were performed to better understand the environmental conditions of the caves, using portable instruments, in order to decide the representative sample points. The on-site instrumentation has been installed in different areas of caves, taking into account the tourist paths, in order to monitor the influence of tourism. Different instruments have been installed in non-touristic areas too, to measure natural cave conditions.

In Bossea Cave environmental parameters are monitored by two different laboratories. The Giovanni Badino Center for Climatological Research, funded by Paleolab – PoliTO and the Underground Karst Lab of Bossea – SO Bossea C.A.I., in collaboration with INRI Turin and ARPA Piedmont, monitor air, water and rock temperatures (T), air circulation, CO_2 air concentrations and atmospheric pressure. In the cavity have been installed four main stations to monitor air, rock and water temperature (Fig. 1A). The surface station detects air temperature, atmospheric pressure, air velocity and rock temperature near the entrance. Inside the cavity, different probes at different heights monitor the environmental conditions of the biggest halls characterizing the cave. Other probes are installed in the depth of the cave rocks from few centimeters up to 3 m. A detector with two probes at different heights detects the concentration of CO_2 in the air. Almemo multiple-channel sensors with temperature probe (accuracy: 0,01; resolution 0,001 °C) are used with a data acquisition interval of 10 minutes. The hydrogeological parameters are measured by the Karst Hydrogeology Lab (DIATI – PoliTO) which detects the flow values, electrical conductivity and water T of the main collector and of other 10 secondary water streams. A real-time OTT monitoring system and data recording every 10 minutes is used for hydrogeological parameters measurements. The electrical conductivity sensors are with double graphite cell and have an accuracy of 0.5 % mv, T probes have a resolution of 0.1 °C and an accuracy of 0. 5°C, water level measurement cells are ceramic-capacitive with 1 mm resolution and accuracy 0.05 % fs.

In Toirano Caves (Fig. 1B) and Borgio Verezzi Cave (Fig. 1C) from January 2021, a Tinytag acquirers (accuracy: 0.2 °C; resolution: 0,001 °C) to detect the air temperatures at different height (near the floor and the ceiling) have been installed, with data acquisition interval of one hour. For the monitoring of water levels, electrical conductivity and water temperature, OTT instrumentation has been installed with hourly data acquisition. Sensors' characteristics are the same described in the Bossea Cave monitoring system. A VAISALA system with INDINGO 520 acquirer and GMP 252 probes with an accuracy of 40 ppm is used for the CO_2 value. The data are captured every hour.

3.2. Geomatic surveys

The survey operations are performed both inside and outside the cave, to identify the path with respect to the external area and determine the thickness of the rock layer. However, the survey also serves to georeference points of interest or to detect speleothems in greater detail.

In complex surveys involving indoor and outdoor environments it is necessary to integrate different measurement techniques but first of all materialize a common and stable reference system consisting of some points of known coordinates to support photogrammetric and Lidar measurements. For compatibility with technical maps, the ETRF2000 national geodetic system was used. The external Grount Control Points (GCPs) are materialized with stable nails and 60 cm x 60 cm markers, clearly visible on the frames taken by a drone. They allow to determine with a photogrammetric operation of aerial triangulation (AT) the position and attitude of each frame for absolute orientation. The photogrammetric survey was done with DJI Phantom 4 RTK UAV. The position of the external points was surveyed with Trimble-Spectra Precision SP80 GNSS geodetic receivers in RTK mode, with the RTCM products transmitted by the Network RTK HxGN SmartNet (https://hxgnsmartnet.com/it-it/). Achieving the fixation of phase ambiguity allows to obtain a precision (standard deviation) of the planimetric and altimetric coordinates of 1 or 2 cm.

The interior of the cave was surveyed with LiDAR Optec Polaris. It allows you to directly georeference scans from station points and known orientation. The recognition of the orientation point occurs automatically by the instrument if a specific target is used. The operation is strongly conditioned by the lighting conditions, often critical in underground environments. The position of the station and orientation points was previously determined with a polygon, which extends from the entrance to the entire extension of the cave, with the Leica MS50 precision total station, oriented on the external GNSS points.

3.3. Laboratory analysis

An initial classification of speleothems has been made, simultaneously detecting the main types of alteration in caves (CO_2 corrosion, undersaturated water and lampenflora). In the first in situ campaigns the research of a proper method to sample a micro portion of speleothems has been carried out. After, a microdrilling technique to sample a representative portion has been chosen. The alteration and the characterization of speleothems have been analyzed in the DIATI Laboratory (PoliTO) with XRay Diffractometer Rigaku, SEM EDX Fei.

Different cave surveys with UV flashlight have been showed the presence of different kind of materials left by visitors, as shoes and clothes, with high probability of plastics. Hence the need to describe the anthropogenic impact measuring probable MPs pollution. MPs pollution in cave sediments has been evaluated testing different separation methods in the DIATI Laboratory of PoliTO.

4. First evidences and results

4.1. Environmental parameters in Bossea Cave

All data of Bossea Cave are collected from December 2019. In 2020, different periods of closure of the cavity, due to Covid 19 pandemic and the installation of the new LED lightning system (started in March 2020), allowed to monitor the natural parameters of the cave without the modifications caused by tourists and lights. Therefore, the data collected in the closing periods of the cave (with no visitors and no lights) (Fig. 2) and in periods of considerable tourist flow as during the Christmas holidays of 2019 (Fig. 3) are extremely interesting to better understand cave environment and tourist impact. Equally interesting are air temperatures influenced by lights, before (hot lights-incandescent lamps) and after LED lightning system installation (cold lights). Moreover, there is a considerable difference in temperature at the same site linked to the stratification of air: in the sectors close to the floor of the cavity, where the underground stream flows, temperature is over 1°C colder than the ceiling.

Initial assumptions on cave T variations have been done comparing hydrogeological monitoring data (flow and T variations of collector water and secondary inputs) and surface air T data: air T in the cavity is influenced by the flow rate and T of the water collector, reaching the minimum annual values in May, linked to the great flood due to the snow fusion and to the spring precipitation. The air surface T minimum values occurred in January-February 2020 and 2021 both. The maximum thermal value found on the surface has monitored in August 2020 and it corresponds to that inside the cavity. In this period the flow rates of the hypogeum collector reached the minimum annual values and water temperature has its annual maximum.

Only after the concert of 26 December 2019 there was an abnormal increase in air T in the cavity, due to an influx of more than a hundred tourists within a few hours. Air T returned to normal value over the next three hours (Fig. 3).

The CO_2 concentrations in the cavity resulted quite high with values from 1200 ppm in November 2019 to 900 ppm in spring 2020.

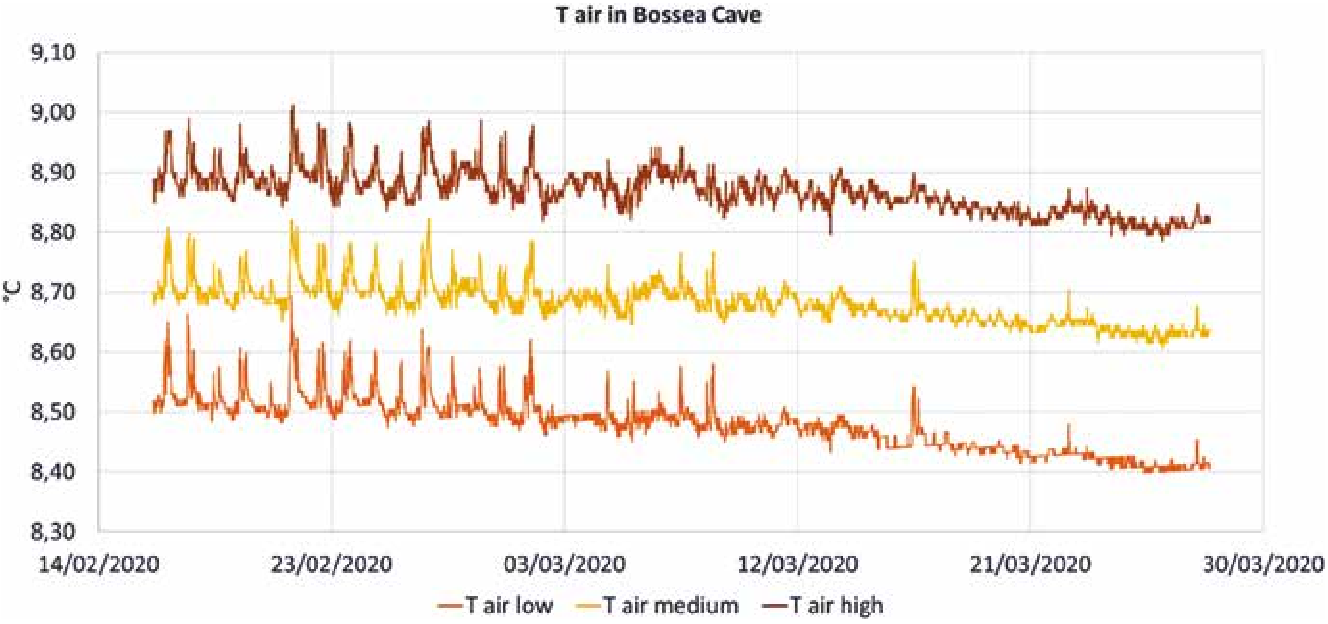

Fig. 2 – Air temperature trend at different heights in Bossea Cave, before and after Covid-19 pandemic. Air temperature is clearly conditioned by lighting system in the period before pandemic.

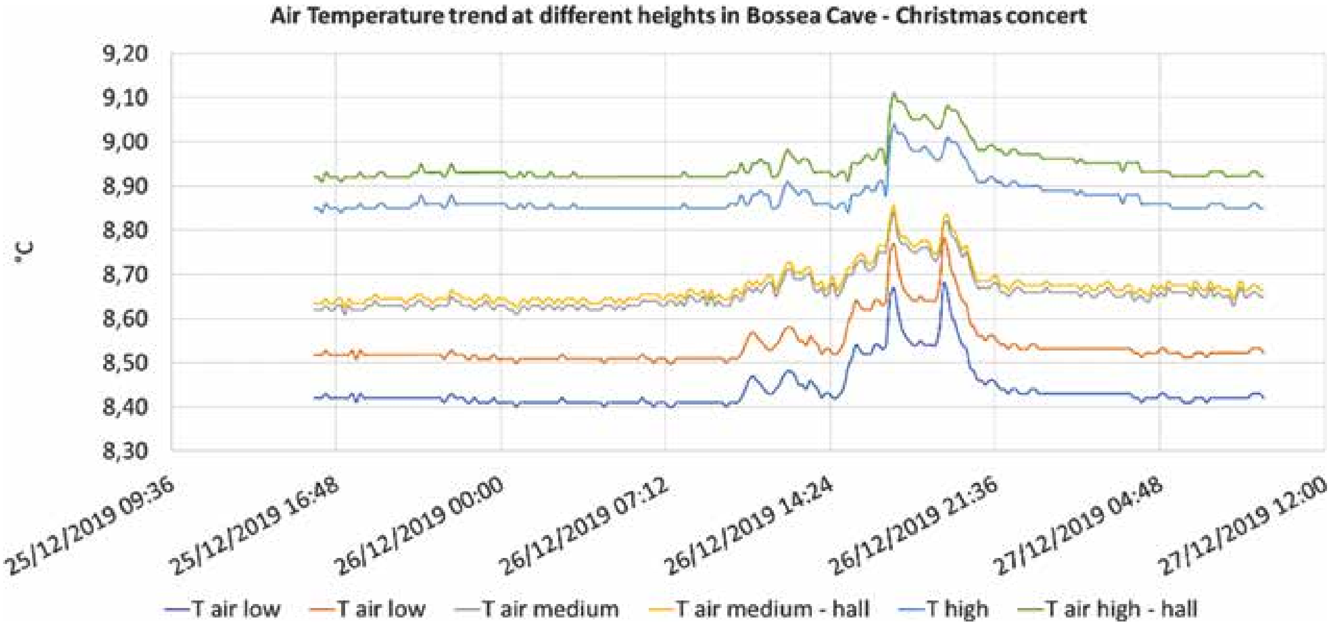

Fig. 3 – Air temperature trend in the central part of the Bossea Cave, at different heights, conditioned by tourist presence during Christmas concert.

4.2. Environmental parameters in Toirano Caves

The Toirano Caves have the entrances placed at an altitude difference of only 15 m. Therefore, this inlets altimetric difference favors an air circulation, slowed down by a series of doors placed at the entrances and in the artificial tunnel. However, these doors allow the passage of air through the crowning spaces between the walls and the artificial structures.

The temperature detectors, located at different heights and along the entire route, highlight the progressive heating of the air conditioned by the rock cluster T which is constant throughout the year. In the winter period the warm air inside the cavities (constant T around 15.6 °C) tends to come out from the entrance of Lower Santa Lucia Cave, consequently, a same volume of cold air enters from the Bàsura Cave. The surface air T heavily conditions underground circulation: in the winter period (especially at night) Lower Santa Lucia cave entrance have a T around 14.5 °C while Bàsura Cave entrance T values drop down to 8.6 °C (Fig. 4). The minimum surface air T value was reached on 14/02/2021 (-0.01 °C) while at the entrance of the Bàsura Cave there was a value of 4.5 °C and at the entrance of Lower Santa Lucia of 14.2 °C. A convective cell is present in the first part of Lower Santa Lucia Cave, characterized by a large tunnel with an evident stratification of the air.

The two CO_2 probes present in the Bàsura Cave show reduced carbon dioxide levels characterized by oscillations between 390 ppm and 500 ppm. These values seem to be mainly influenced by the natural circulation of incoming air flows, since the cavity is closed to the public now.

The groundwater circulation in the two cavities is very small and limited to droplets that usually increase only during particularly humid periods.

4.3. Environmental parameters in Borgio Verezzi Cave

On the basis of the new data acquired, the Borgio Verezzi Cave seem to be characterized by a particular genesis linked to the mixing of fresh water above the salt water of the saline wedge. The cave, located at a distance of only 550 m from the coast line, is made up of a large collapse hall that reaches an altitude of only 5 m a.s.l. where there are a series of freshwater lakes that seem to belong to an extended karst aquifer above sea salt water. Within three months of monitoring, the multiparametric probe positioned in the main reservoir (Gulliver Lake) showed a significant change in water levels related to precipitation and remarkable values of electrical conductivity and water temperatures constancy, emphasizing the presence of an important karst aquifer.

This cavity has a significant air circulation linked to the presence of three low entrances (tourist entrance, 32 m a.s.l, entrance of children, 34 m a.s.l, and paleontological entrance, 36 m a.s.l.). In the cold season these entrances aspire important volumes of air which quickly warm up circulating in the cavity (Fig. 5). A fourth entrance (British Entry, 36 m a.s.l.) acts as a high entrance that seems to expel only a small part of the incoming air. Evidently there are

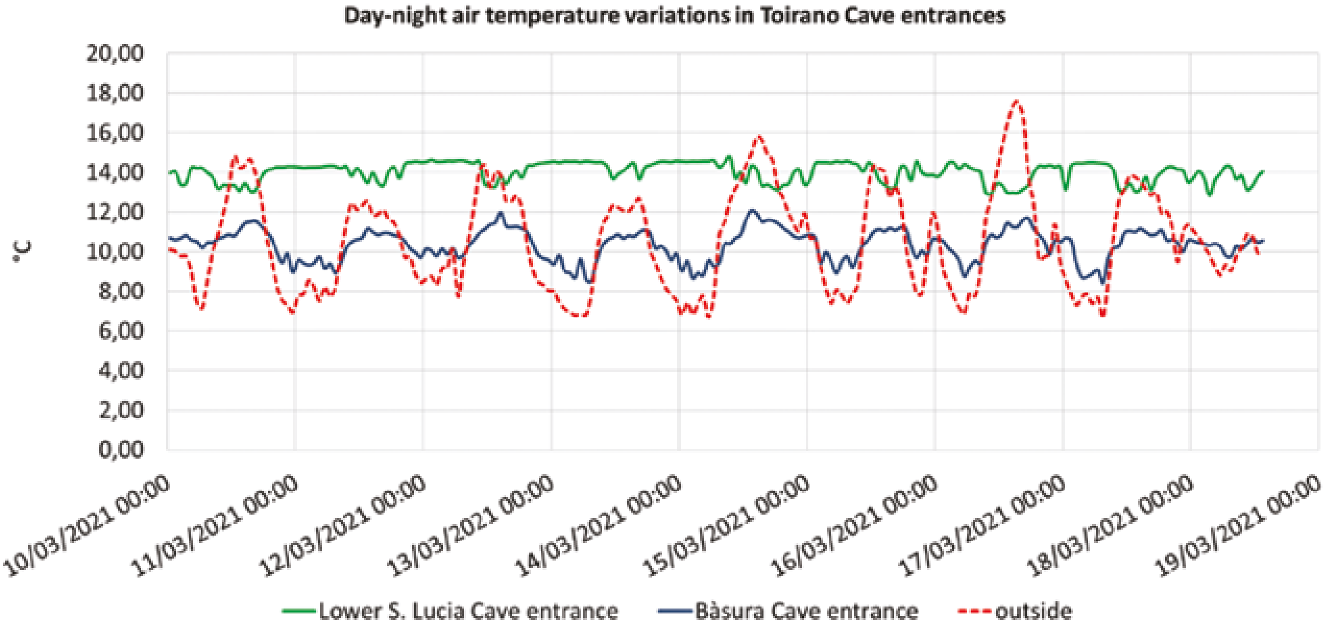

Fig. 4 – Daily air temperature trend outside the Bàsura Cave and at the Bàsura Cave and Lower Santa Lucia Cave entrances.

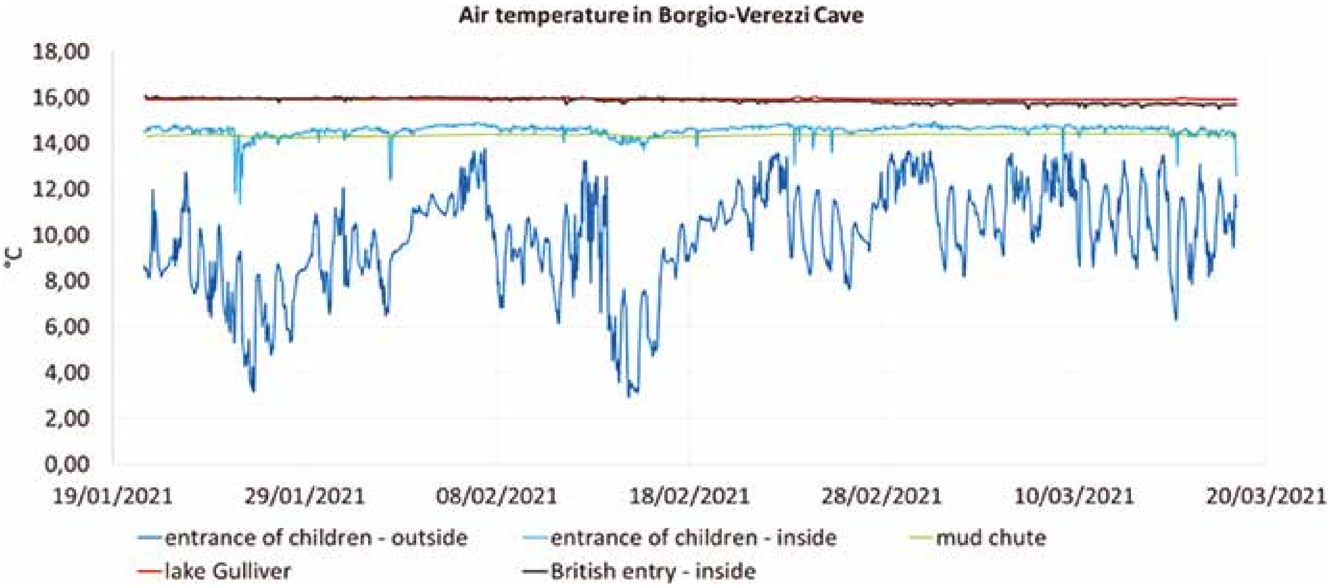

Fig. 5 – Progressive air heating in Borgio Verezzi Cave, from entrance of children (lower entrance) to inner parts of the cavity.

other outputs not yet identified to balance the total volumes circulating in the cavity.

The CO_2 concentration data are significant and characterized by clear multi-day fluctuations of values between 450 ppm and 650 ppm highlighting a singular contribution of natural origin (Fig. 6). These data well describe the environmental situation not affected by tourist use, being the cave closed for the entire monitoring period.

4.4. Geomatic surveys in Borgio Verezzi Cave

The Borgio Verezzi Cave was surveyed with the instruments and methods described in the paragraph 3.2. The external survey was done with a DJI Phantom4 drone flight with 396 frames, to obtain a transverse and across coverage greater than 80 %. The characteristics of the flight and the sensors are shown in Table 1.

With the dual frequency GNSS receiver on board the drone, the position of the projection centers of digital camera at the time of shooting were determined in RTK mode, with an accuracy of 1-2 cm (Teppati Losè *et al.*, 2020). It is theoretically possible to directly orient the photogrammetric block with only the coordinates of the projection centers but it is always better to use some GCPs to improve the accuracy and reliability of the solution (Casella & Franzini, 2016).

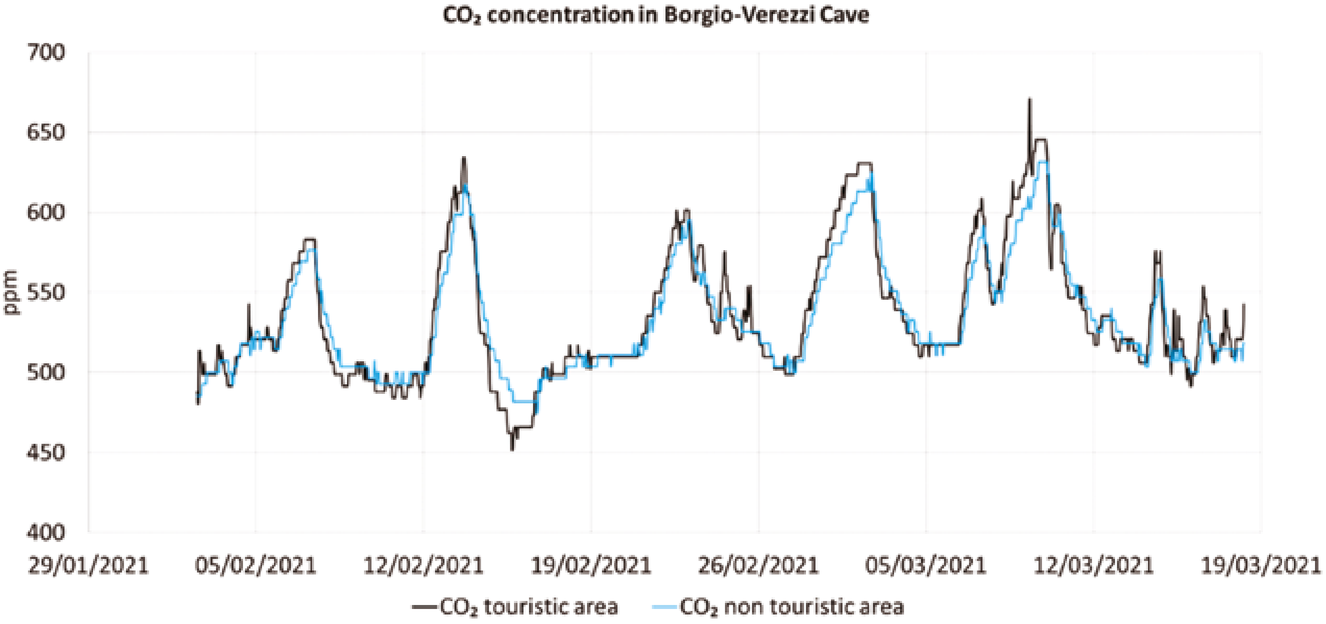

Fig. 6 – CO_2 air concentration trend in a touristic and non-touristic part of the Borgio Verezzi Cave.

Tab. 1 – Camera and flight parameter used in Borgio Verezzi Cave survey.

Camera	Sensor size and memory 1'': 20 M pixel
	Pixel size = 2.4 μm
	Principal distance = 8.8 mm (24 mm FF)
The fly	Relative height average on the ground = 50 m
	Average scale of photos = 1:5680
	Ground Sample Dimension of 1 pixel (GSD) = 1.4 cm
	Number of photos: 246
	Ground size of photos 90 m x 60 m
	Coverage: along track > 80%, across track 80%
Area Measured at ground RPAS	54'800 m^2 5 GCP (5 markers) DJI PH4 (Phantom 4 RTK)

Tab. 2 – Camera projection centers and GCP Errors.

	X error (cm)	Y error (cm)	Z error (cm)
Average Camera location error (396 camera projection center)	1.2	0.8	1.1
Estimated Gorund Control Point RMS (5 marker)	2.1	1.0	1.6

5 GCPs were detected, made with markers clearly visible on the frames and detected with GNSS RTK. The operations of alignment of the frames and compensation of the AT is done with the software AGISOFT Metashape. The residuals of the least square adjustment on the projection center of the digital camera and 5 GCP are a maximum of a couple of cm, consistent with the size of the GSD (Tab. 2).

From the orientation of the frames, estimated from the positions of the GCPs and the projection centers of camera, it is possible to derive cartographic products such as DSM with 3 cm resolution (Fig. 7) and orthophotos with 2 cm resolution (Notti *et al.*, 2021). The DSM refers to ellipsoidal heights: to obtain the orthometric heights, the undulation of the geoid must be subtracted. It can be estimated using the ITALGEO model to be 47.43 m, without appreciable differences in the area considered.

The internal survey of the cave is referred to a polygon of 18 points. This is the most delicate and important part of the survey, where precision is strongly conditioned by the length of the visuals between the collimation points. On views of only a few meters, as in the case of this cave, small centering and collimation errors on the signal strongly propagate the angular measurement error. The lack of an external "closing" ground control point does not allow to compensate for these errors. Figure 7 shows the polygon with 95% error ellipses, with an amplification factor = 100. The measurement of the differences in height was made with total station from the reciprocal stations. The accuracy (standard deviation 68%) obtained for the dimensions is a maximum of 1.3 cm on the last point of the polygon.

The polygonal allowed to georeference 15 scans performed with Lidar Polaris Optec, on the whole tourist route of the cave. The acquisition was made in short range mode since the distances generally

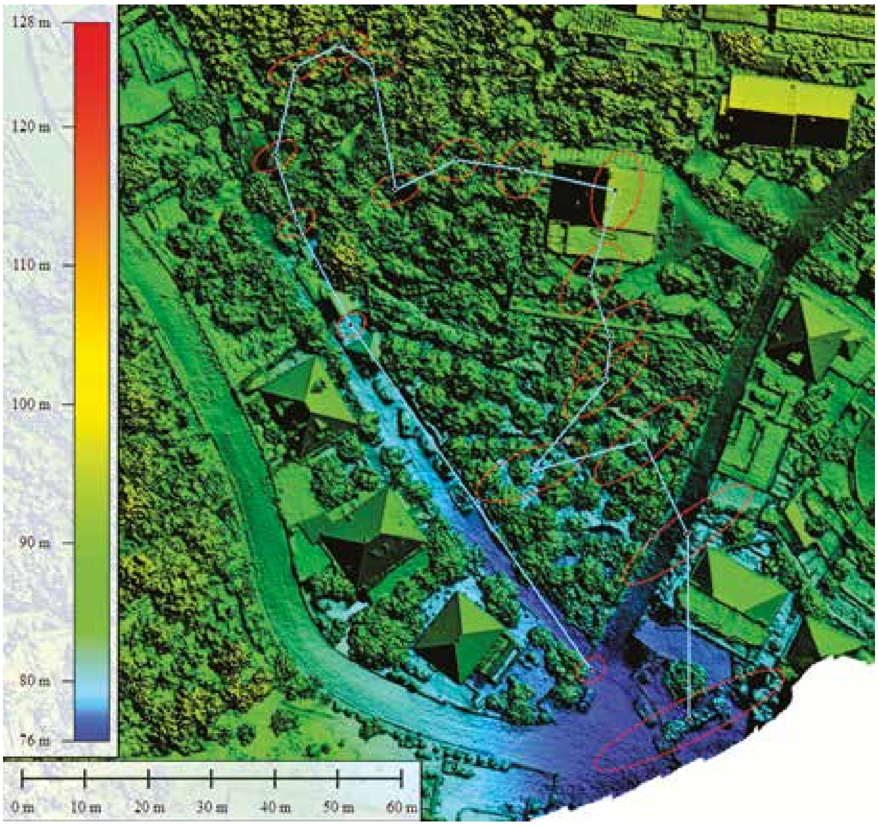

Fig. 7 – Ellipsoidal Digital Elevation Model (DEM resolution = 3 cm) and polygonal inside Borgio Verezzi cave with 95% error ellipses (ellipsis amplification factor = 100). Undulation of the Geoid = 47.43 m.

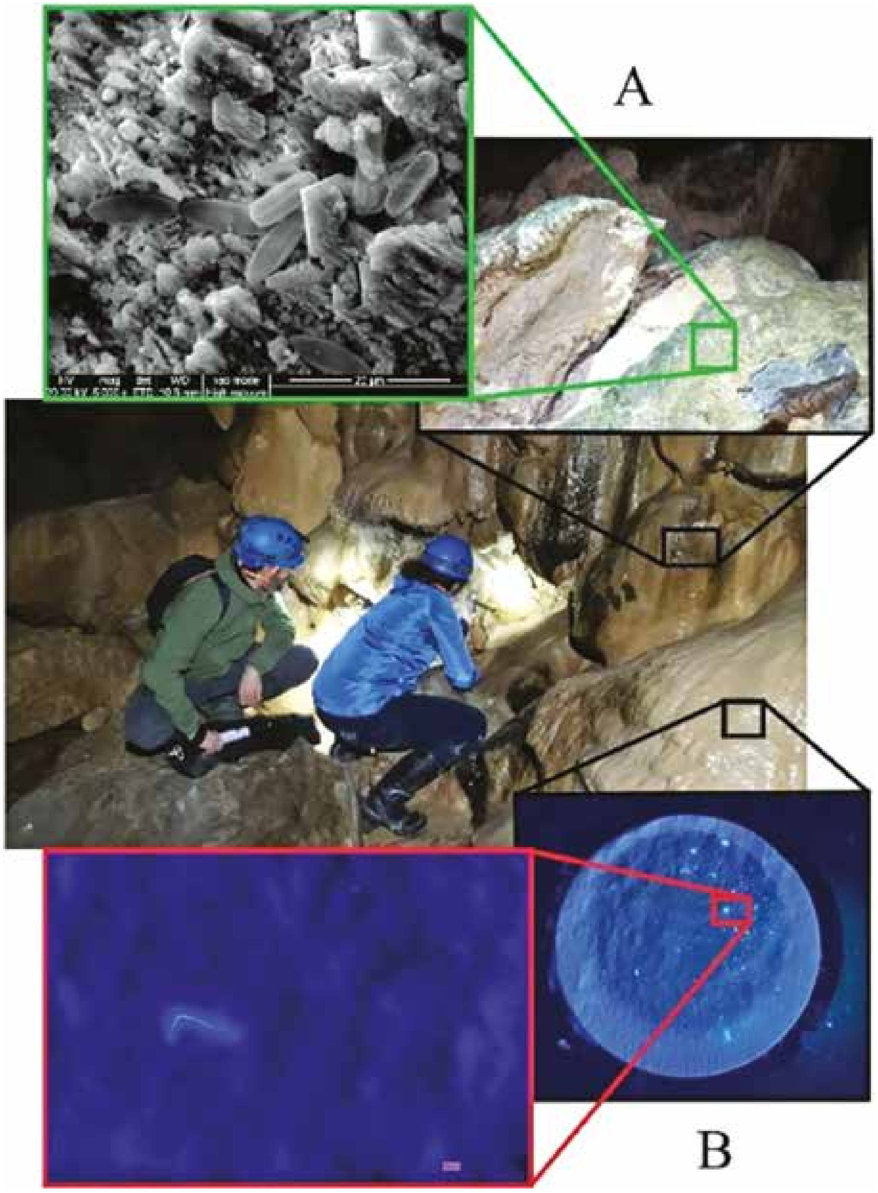

Fig. 8 – Bossea Cave in situ monitoring. A. Lampenflora on speleothem and SEM blow up of diatoms and lampenflora corrosion. B. Microplastic fibers analysis on filter, after sediment separation, and microscopic blow up under UV light.

did not exceed 50 m. The adopted resolution is 1 cm on 50m with acquisition time of about 10 minutes per station. The resolution of the scans allows not only the calculation of the volumes of the underground rooms but has sufficient detail for the observation of the speleothems. An external 24 MPx digital camera allows you to color the point cloud with higher quality than the internal camera of the instrument. The processing of LiDAR measurements is in progress.

4.5. Corrosion of speleothems

Evidences of CO_2 corrosion on different speleothems in all examined caves have been found as well as the presence of lampenflora near tourist paths and lights.

SEM analysis on speleothems samples with lampenflora have been done to better understand the level of corrosion on their shallows. Presence on diatoms has been detected on the speleothems with lampenflora alteration. (Fig. 8A). Environmental factors influencing the presence and the growth of lampenflora in Bossea Cave have been previously investigated (Piano *et al.*, 2015). First sampling in this cave has been made to estimate the alteration of speleothems by lampenflora in different part of tourist path. The micro samples will be analyzed by SEM, looking for an analytic method to quantify the decay and correlate it with the presence of Diatoms, Cyanobacteria and green algae in collaboration with DBios – Università di Torino.

Evident CO_2 corrosion damages on speleothems are present in the Toirano Caves and Borgio Verezzi Cave. These phenomena are linked to different processes as high CO_2 concentrations in the air or the presence of undersaturated water. These processes can be linked to natural origins but also visitors and lighting along tourist paths can cause significant increasing in air T and CO_2 concentration.

4.6. Microplastics pollution

MPs pollution has been observed both on sediments and on speleothems and in all examined caves. Different laboratory tests have been performed on cave sediments samples, in order to identify the correct method to separate MPs from cave sediments and quantify them (Balestra & Bellopede, 2021). To assess the presence of MPs, UV light has been used in situ and in lab simultaneously with visual identification (Fig. 8B). Advanced microscope techniques as Raman and FTIR microscopy (which, however, still need to be optimized, considering the complexity of the sample examined) have been used to confirm MPs presence and typology.

Visual identification and different photographic techniques, in association with different software have been used to count and measure MPs in cave sediments. After the validation of laboratory technique, the goal to apply the quantification of MPS in situ by means of proper photographic technique will be carried out.

5. Discussion and conclusions

The first results of the study related to the monitoring of the three cavities examined highlighted the environmental parameters (air temperatures and CO_2 concentration) variations, related to the air and groundwater circulation. Following the closure of the tourist caves for Covid pandemic, it was possible to acquire useful information on the natural environmental of the cave, without tourism influence (tourists and lights). Usually, these data are unfortunately not recorded in cave before public opening; however, they are essential to understand the following environmental tourist impact (Calaforra *et al.*, 2003; Cigna & Burri, 2000; Cigna & Forti, 2013).

Geomatic survey, yet started for Borgio Verezzi Cave, allowed to estimate the subjacency of the cave with the respect to the urbanized territory and to obtain a georeferenced survey of underground cave with a proper resolution.

The identification of altered speleothems is essential to link the in situ survey with the laboratory research. At microscope level the assessment of the CO_2 and lampenflora corrosion on speleothems and MPs pollution in cave sediment should be done with the aim to give back an indirect index of cave conditions and different indexes useful for cave management and protection.

The integrated use of environmental parameters monitoring, geomatic survey and laboratory analysis will define the proper methodology to assess the tourism impact and the threshold value to minimize pollution in caves and the speleothems decay, and to preserve natural heritage in show caves.

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