The conservation of the Nerja Cave: preserving anthropogenic impact in a tourist cave

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ABSTRACT: The Nerja Cave is developed within dolomitic marbles belonging to Sierra Almijara, some four kilometres East of Nerja in the province of Malaga (Spain). The cave, with a nearly horizontal development, has a total surface of 35,000 m^2. It was discovered in 1959 and open to visits one year later. With about 450,000 visitors per year, the Nerja Cave represents a very important natural and cultural resource for the tourism industry of the region where it is located. The important archaeological site of the cavity motivated its declaration as Good of Cultural Interest with the category of Archaeological Zone. In addition, Nerja Cave is internationally recognized as Heritage Sight of Geological Relevance. Moreover, animal endemism and singular speleothems raise the Nerja Cave as highlight of the Natural Heritage of Andalusia. Since it was discovered, many research projects have been carried out in the cave, on geology, hydrogeology, microclimate and microbiota, among others. The results allowed the identification of natural or anthropogenic elements which can be a risk for the conservation of the cultural and natural heritage of the Nerja Cave and also the design and application of the most appropriate preservation protocols. Among these, delimitation of the protection area, assessment of the anthropogenic impact in the cave and the gradual replacement of unsuitable materials previously used in the tourist track. Additionally, specific protocols are being developed to reduce the photosynthetic biofilms which cause biodeterioration and/or aesthetic damage to surfaces.

1 INTRODUCTION AND SITE DESCRIPTION

Caves may answer question related to the biology, geology and archaeology of the subterranean environment. These fragile ecosystems can be disturbed by many anthropogenic and/or natural factors. In tourist caves, visitors or the introduction of foreign materials to facilitate the visit, induce the anthropogenic impact and, generally, this alteration uses to be higher than natural alteration. Therefore, one of the main goals of the managers of tourist caves is to control the human impact, according to their conservation.

The Nerja Cave, a Good of Cultural Interest, in the category of Archaeological Site and an internationally recognized Heritage Sight of Geological Relevance, is one of the most important tourist caves in Spain, with 485,541 visitors annually for the period 1988-2013. The cave was discovered in 1959 and opened to the public one year later. It has a volume of 300,000 m^3, and about a third of the cave, the Tourist Galleries, is open to tourists while other parts, the High and New Galleries, is only visited by researchers and reduced groups of tourists (Fig. 1).

The cave saves a chronocultural and paleoenvironmental sequence between, at least, 25,000 and 3,600 years before present, which makes possible to carry out many interesting interpretations of prehistoric settings (Jordá Pardo 1986, Pellicer & Morales 1995, Pellicer & Acosta 1997). This Cultural Heritage has also more than three hundred catalogued rock art paintings, belonging to the Upper Paleolithic and Late Prehistory, so the cave is one of the richest archaeological sites in prehistoric art forms of Southern Iberian peninsula (Giménez Reyna 1962, Sanchidrián 1994). Moreover, the cave has endemic species (Barranco et al. 2004, del Rosal et al. 2009) and excepcional geological formations, which have enabled the reconstruction of paleoclimate and paleoearthquakes (Durán et al. 1993) and constitute the natural Heritage of the Nerja Cave (Carrasco et al. 1998).

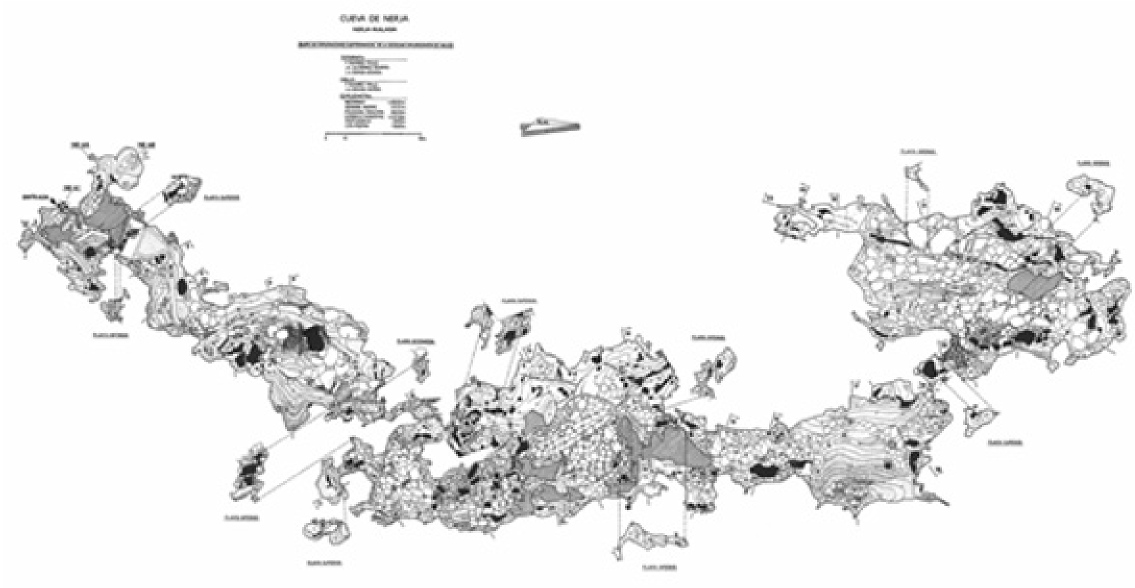

Figure 1. Map of the Nerja Cave (SEM 1985).

2 A BRIEF HISTORY OF THE RESEARCH IN THE NERJA CAVE

The works of conditioning and adaptation the cave for tourists and visitors started eight months after the discovery. At the same time, some members of the Board of Archaeological Excavations in Malaga visited the cave and were impressed by the extraordinary richness of the archaeological site and scientific relevance. This entity instructed Manuel Pellicer, professor of Prehistory at the University of Granada, the direction of the archaeological excavation and Simeón Giménez Reyna the rock art prospecting. Thus, archaeological research in the cave was started with a two-fold aim: scientific and touristic. Due to the importance of the archaeological results the cave was declared a Historical Artistic Monument in 1961. The same year, Antonio Cobos conducted the first biological research into the cave and described as endemism the coleoptera *Platyderus speleus* (Cobos 1961). The study of the geological heritage of the cave started in 1979, conducted by Manuel Hoyos, a researcher of CSIC (Spanish National Research Council). In 1979 a Nerja Cave Scientific Advisory Board was set up, constituted by the archaeologists Manuel Pellicer Catalán and Francisco Jordá Cerdá and the geologist Manuel Hoyos. The aim of this board was to advise the Foundation in areas related to research and conservation of the cave and heritage, considering the social economic function and the rational and sustainable exploitation of the Nerja Cave. The constitution of the Nerja Cave Research Institute, in 1999, gave renewed support to the cavity research. The aims included research, preservation, and diffusion of both the natural and cultural heritage of the Nerja Cave and its surroundings. A year after, in 2000, a Guiding Plan was elaborated (Garrido et al. 2009), which states the model, methodology and activities to preserve the cave heritage. Nowadays, Nerja Cave research are being carried out in the framework of a project called Interdisciplinary Research Project to preserve the Nerja Cave, directed by José Luis Sanchidrián (University of Cordoba) and authorized by the Junta de Andalucía, that includes, among the objectives, the specific preservation of rock art, the study of the deteriorating factors in the cave and the development of a dissemination plan. Finally, the project will design a management system based on research, preservation and dissemination.

3 RESEARCH APPLIED TO THE CONSERVATION OF THE CAVE OF NERJA

Researches conducted in the Nerja Cave, since the discovery, are numerous and developed in various scientific disciplines (www.cuevadenerja.es). This paper relates some of them whose results have been used in the management of the cavity for a proper conservation. It is noteworthy that the Nerja Cave is one of the most visited tourist cave of Spain, so it is very important to know the human impact. To evaluate the anthropogenic influence on microclimate, hydrochemistry and microbiology on a tourist cavity is necessary characterizing the microclimate of the cave, defining the physico-chemical parameters of the groundwater, analyzing the hydrogeological behaviour and quantifying the microbial populations, establishing its interaction with the substratum.

3.1 *Geological characterization*

Studies carried out on the Nerja Cave have allowed to establish the main geological features of the cavity and surroundings: outcropping lithologies and geological structure (Sanz de Galdeano 1986, Jordá Pardo 1992, Andreo et al. 1993, Guerra-Merchán & Serrano 1993), geomorphologic features (Benavente & Almécija 1993, Guerra-Mechán et al. 2004, Jiménez-Sánchez et al. 2004), directions fracturing in wall rock and speleothems (Sanz de Galdeano 1986, Durán et al. 1998a,b, Gumiel et al. 1999, 2003), mineralogy and petrology of wall rock (López Sánchez-Vizcaíno & Gómez-Pugnaire 1993), mineralogy of speleothems from the cavity (Reyes et al. 1993, Caballero et al. 1995, Casas et al. 2001, 2002, Jiménez de Cisneros et al. 2003, 2006, Durán et al. 2006), chemical and isotopical composition of speleothems (Reyes et al. 1993, Vadillo et al. 1998, 2002, Durán 1996, Jiménez de Cisneros et al. 2006, Jiménez de Cisneros & Caballero, 2010), age of speleothems (Durán et al. 1993, 2006), or indirect location of cavities nearby to the Nerja Cave (ADARO, 1991), among others.

From a geological standpoint, the cave is located in the Almijara Unit, belonging to the Alpujarride Complex of the Internal Zone of the Betic Cordillera. The Almijara Unit has two lithological formations. The lower formation is made up of metapelites (schists and quarzites) of Paleozoic age. The upper formation is carbonated: white dolomitic marbles towards the base and blue calcareous marbles towards the top, with discontinuous metapelitic intercalations, dating from the middle-upper Triassic. The cave is developed in highly fractured dolomitic marbles. Outside the cave, detrital Neogene deposits outcrop discordantly over the Alpujarride materials. Although the structure of the Alpujarride complex is very complicated on a regional scale, in the surrounding of the cave is fairly simple because the marbles have an almost tabular arrangement, dipping 15-20º to the South. The outcroping of Alpujarride marbles are limited to the south by faults, which have caused significant vertical movements since Pliocene. These faults and associated diaclases systems have played an important role in karstification of the massif. Thus, there is a preferential dissolution of the marbles in the NE-SW to NNE-SSW directions and NW-SE to NNW-SSE that are similar to the directions of the main halls and galleries of the Nerja Cave.

3.2 *Hydrogeological researches*

The Triassic carbonate materials that outcrop in Sierra Almijara constitute an aquifer of regional importance (IGME 1983, SGOP 1991, Andreo & Carrasco, 1993a, Pérez & Andreo, 2007) whose recharge is mainly by precipitation infiltration. The aquifer discharge is through a series of springs, where Maro spring is the most important (Liñán et al. 2000a) and by boreholes.

The cave is actually in the vadose zone of the aquifer, several metres above the water table, because of the neotectonic activity of the fault which limits the aquifer at the South. The thickness of the marbles above the cavity is highly variable: from 4 to 50 m in the tourist area, and exceeding 90 m in the non-visitable area. Rainfall and water used to irrigation of the gardens located on a small part of the cavity infiltrate through fissures and fractures in the marbles, and drips from the roof of the cave (Andreo & Carrasco 1993b, Carrasco et al. 1995, Liñán et al. 2008).

From 1991, a systematic study of the hydrodynamic, the hydrochemistry (principal components), the isotopic content ($\delta^{18}O$ and $\delta^{2}H$) and the physico-chemical characteristics (pH, temperature and electrical conductivity) of the water obtained both outside the cave (rainwater recorded at the weather station) and within it (dripwater) has been made. The volume of precipitation above the cave, measured at the weather station, and the volume of dripwater within the cavity have been analyzed.

The dripwater flow within the cavity is, in general, very low, around 10-100 m^3/year under average pluviometric conditions. At one of the drip point in the Tourist Galleries, the natural responses respect to precipitation reveals the existence of two types of infiltration through the epikarst in the unsaturated zone (Carrasco et al. 1996, Liñán et al. 1999, 2000b, Andreo et al. 2005): a slow one predominates throughout the year, while the fast (or, rather, less slow) only occurs sporadically, when recharge levels are very important in magnitude or intensity.

The residence time of the rainwater in the epikarst in the unsaturated zone until it appears at the drip point in the Tourist Galleries is 2-8 months (rapid and slow infiltration, respectively), as calculated from the hydrogram obtained at the drip point, from the results of correlatory and spectral analysis (Andreo et al. 2002), from the time lag between entry and exit flows of K+ and $\delta^{18}O$ (Carrasco et al. 1996, Andreo et al. 2002, Liñán et al. 2002, Mudry et al. 2008) and from the temporal evolution of the total organic carbon content (Batiot et al. 2003).

The evolution of the flow in drip water points of High and New Galleries shows a different seasonal variation observed in the tourism sector (Liñán et al. 2008), with maximum flow values in autumn-winter and minimum in spring-summer. Hydrograph analysis follows a lower residence time of water in the epikarst and infiltration in the unsaturated zone and a faster response to rainfall in this part of the cavity.

Within the cave there are two main types of water: one of them, obtained closest to the entrance, and the other one, in the rest of the cavity (Andreo et al. 1993a,b). The first one, with a calcium-magnesium-bicarbonate-sulphate facies, an average level of electrical conductivity of 1150 μS/cm and a PCO_2 of 0.43%, is obtained from a nearby borehole, is used to irrigate the garden and after it seeps into the cave. The second type, with a calcium-magnesium-bicarbonate facies, an average level of electrical conductivity of 468 μS/cm and a PCO_2 of 0.15% (Carrasco et al. 1996), has a meteoric origin, as evidenced by its chemical and isotopic composition (Cardenal et al. 1999, Liñán et al. 1999). The water inside the cave is supersaturated in calcite throughout the year, and deposits calcium carbonate.

3.3 *Microclimate studies*

The first microclimatic net in the cave was installed by Manuel Hoyos and was operating since 1986 until 1990. It consisted of five air CO_2 sensors, eleven air temperature sensors and eleven air relative humidity sensors which measures every hour. The few published results (Hoyos & Soler 1993) reported an increase in air temperature and a decrease in relative humidity from the entrance to the deeper part of the Tourist Galleries, as well as an excessive rate of visitors during, at least, five months a year, depending on the night time recovery observed in the cavity. In 1991, Francisco Carrasco installs a meteorological station outside the cave, for rainfall and temperature control and for chemical and isotopic sampling. In 1993, a new monitoring net was installed, both outside (temperature, air relative humidity and atmospheric pressure) and inside the cave (temperature, relative humidity and CO_2 in the air, atmospheric pressure and temperature of the rock) with an hourly frequency measurement (Carrasco et al. 1999). In this decade starts the study on the cave ventilation, based on the gas ^{222}Rn concentration (Cañete 1997, Dueñas et al. 1999, del Rosal et al. 2010b).

In 1999, the Research Institute of the Nerja Cave starts the continuous monitoring in the High and New Galleries, with the installation of air temperature and relative humidity sensors. This initial net was progressively completed with the addition or replacement of equipment (Liñán et al. 2007). Since 2013, two microclimate stations (temperature, relative humidity and CO_2 concentration in the air and atmospheric pressure) and two hydrogeological stations (drip flow, electrical conductivity and water temperature) measure the subterranean environment, both Tourist and High Galleries.

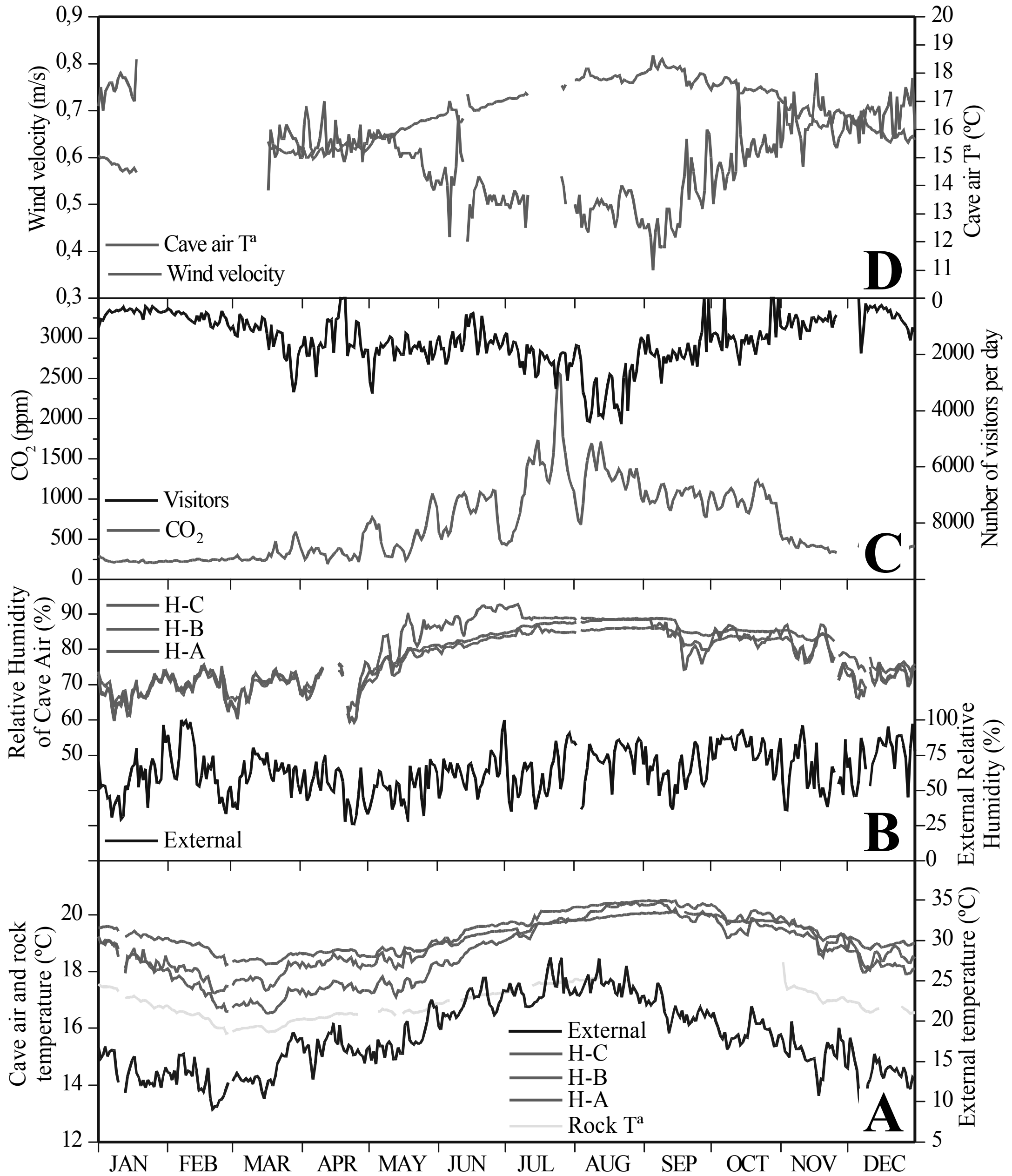

Figure 2. Annual evolution with daily data for environmental parameters during one type year (Tourist Galleries). A: Temporal evolution of temperatures (air, rock and outside); B: Relative humidity inside and outside the cave; C: CO_2 and number of visitors and D: Velocity of the wind and air temperature. H-1: Belen Hall, H-2: Cascada Hall, H-3: Cataclismo Hall (Vadillo et al. 2001).

The analysis of the wide range of environmental data has allowed obtaining valuable information about the natural variation of the controlled parameters and the anthropogenic influences in the cavity (Carrasco et al. 1999, Vadillo et al. 2001, Liñán et al. 2004, 2009). Figure 2 shows the annual evolution for main environmental parameters measured in Nerja Cave during one type year.

3.4 *Microbiological studies*

Microbiological studies carried out in the Nerja Cave started in 1982, directed by Fernando Marín as a member of the Nerja Cave Scientific Advisory Board. They were focused on the study of airborne microbiota and photosynthetic biofilms on speleothems or rock, known as *lampenflora* (Carrasco & Marín 1991). Therefore, work carried out in the framework of heritage conservation also aim to control and maintain a healthy environment, that is, free from risk factors for the health of workers and visitors.

In indoor places where a high number of people are concentrated, such as the Nerja Cave, is recommended to carry out an environmental microbiological control to prevent the existence of risk factors for public health. Thus, the indoor air microbiota in the cavity has been analyzed by using two methods, one based on colony forming units (Cañaveras et al. 2004) and the other, on fungal spores (Docampo 2008, Docampo et al. 2011). For the analysis of colony forming units an air impact sensor, SAS type (Surface Air System), was used and samples were taken every two weeks, over several years. The organisms analyzed (mesophilic cultivable heterotrophic) provided information on environmental microbiota and were also used as indicator of human pathogens presence, so that the samples were incubated at room temperature (between 18 and 22ºC) and 37ºC respectively. Bacteria of the genus *Staphylococcus* were the most abundant obtained at 37°C, while members of the genus *Bacillus* and the *Actinobacteria* class were the most abundant at room temperature, in high and low visiting periods respectively. Other identified genera were *Alcaligenes*, *Flavobacterium*, *Acinetobacter, Aerococcus, Sporosarcina*, *Sphingobacterium*, *Micrococcus*, *Rothia* and *Arthrobacter.* This methodology was also used for the specific analysis of fungi and the genera *Aspergillus*, *Cladosporium*, *Penicillium* and *Fusarium* were detected. This work also allowed establishing mathematical models for predicting microorganism concentration. For the statistical analysis were used temperature, carbon dioxide concentration and relative humidity in the air, presence of visitors during sampling, total visitors the previous day and presence of wood for building the stage and the dressing rooms (used at the events that take place inside the cave), in addition to the microbial groups analyzed, as explicative variables. The models pointed to a significant association between mesophilic aerobic microorganism groups concentrations, with air relative humidity and with visitor presence during sampling. The specific model for fungi, pointed an exponential relationship between fungi concentration and the wood and visitors inside the cave during the sampling.

The study of fungal spores in the air was carried out with the aid of two Hirst type volumetric spore traps (Hirst 1952), with a constant suction flow of 10 l/min. One of them was installed near the entrance and the other one in the deep area of the Tourist Galleries. Most of the results were named Imperfect Fungi like the genera *Alternaria*, *Aspergillus*/*Penicillium*, *Cladosporium* and *Septoria* among others. The similar distribution patterns, the positive correlations shown between the concentrations of certain spore types inside and outside the Nerja Cave, as well as the negative gradient established from the cave entrance to the deep part, lead us to think that most fungal spores detected inside the cave, excluding *Aspergillus*/*Penicillium* type, come from outside. This work also revealed the relationship between the presence of wood into the cave and a high concentration of *Aspergillus/Penicillium*, whose concentration reached over 100,000 spores/m^3 (Docampo 2008, Docampo et al. 2011).

Studies concerning phototrophic microorganisms in the Nerja Cave have been few so far, despite the visible development of greenish patinas (del Rosal et al. 2010a). When light is available, cave surfaces host a diversity of microorganisms that develop in accordance to environmental conditions and the physico-chemical parameters of the substratum. This development of photosynthetic biofilms on walls and speleothems causes patinas and discoloured stains and can induce deterioration.

Since the famous study of green sickness, which affected the Palaeolithic paintings in the Cave of Lascaux, France (Lefèvre 1974), the presence of photosynthetic microorganisms in the walls and paintings of other caves and monuments has been reported. Their growth is organized in biofilms. A biofilm is any body of microorganisms in which cells stick to each other on a surface. These adherent cells are frequently embedded within a self-produced matrix of extracellular polymeric substance or EPS (Hall-Stoodley et al. 2004).

Biofilms can contain many prokaryotic types, algae, mosses, fungi, protozoa and even plants. Among them occur complex interactions that give the biofilm an enhanced protection against external factors, which can exceed the sum of the individual abilities of each of the species.

Despite dryness or nutrient-poor conditions, the colonies of microorganisms in a biofilm find cooperative ways to survive. It would then be imprecise to directly extrapolate characteristics of a single species grown in the lab with a multispecies biofilm occurring in environmental habitats (Albertano 2012). For this reason, and due to difficulties in accurately mimicking the complex interactions that exist between the component microorganisms and the substratum, it is best to conduct research *in situ* (Hernandez-Mariné et al. 1999, 2003, Roldán et al. 2004a,b).

Limited photosynthetically active radiation (PAR) in the cave provides pressure for selection and is the principal factor to determine whether a biofilm will tend towards autotrophy (i.e. algae and cyanobacteria) or heterotrophy (i.e. fungi and bacteria) as well as of the depth to which a photosynthetic biofilm will penetrate the cave interior and thrive on surfaces near the illuminated areas. Communities of microorganisms organise themselves according to these gradients of light, whether natural or artificial. The quality and type of damage change in relation to the type of individual organisms and the environmental conditions, mainly intensity and quality of light, humidity and the presence of liquid water and air circulation (Potts 1994). Previous results show that in the Nerja Cave the development of photosynthetic microorganisms is limited to the illuminated Tourist Galleries (del Rosal et al. 2010a). Although neither the distribution of organisms nor the balance between autotrophy and heterotrophy within a biofilm is controlled exclusively by light, the damage related to photosynthetic organisms could be reduced by decreasing the intensity of light and the time of lighting and by using wavelengths that hinder their development.

A combination of confocal laser scanning microscopy (CLSM) and spectrophotofluorometric detection (Leica TCS-SP5) have been used to characterise the 3-D structures of intact live biofilms and to identify pigment signatures at a subcellular level, without separating the biofilms from the rock (Roldan et al. 2004a). Moreover, the distinct fluorescence signatures of cells located within a colony could be correlated with cell morphology and individual cell states. The results in the Nerja Cave show the majority presence of coccoid cyanobacteria, as *Chroococcidiopsis* sp., which has good development in cracks and hollows (Fig. 3a), while *Nostoc* sp. (Fig. 3b) is present in areas with natural light or dripping water. These cyanobacteria are highly resistant to extreme environmental conditions, such as drought and excess irradiance (Potts 1974), have a ubiquitous presence in the cave. In the deeper areas, with higher humidity but without runoff on the substratum, we have found *Chalicogloea cavernicola*, *Chroococcidiopsis* sp. and *Leptolyngbya* sp. together with the red alga *Cyanidium caldarium*. More rarely, the cyanobacteria *Geitlerinema* sp., *Aphanothece saxicola* and *Fischerella* sp. have been identified and among the green algae thrive *Bracteococcus minor* and *Desmococcus endolithicus*. The diatom *Diadesmis contenta* is also present in Nerja Cave.

When excited with a 488 nm laser, the cyanobacteria exhibited an emission peak at 657-662 nm due to the overlap of the chlorophyll *a* and phycobiliprotein emissions (phycocyanin peaks at about 640 nm and allophycocyanin peaks at about 650 nm) and, in addition, *Chalicogloea cavernicola*, *Leptolyngbya* sp., *Nostoc* sp., *Aphanothece saxicola* and *Cyanidium caldarium* show emission in the range of 573-590 in which phycoerythrin emits (Roldán et al. 2004a). These spectra indicated the wavelengths required by cyanobacteria to perform photosynthesis, that span over the all-visible spectrum, with the exception of reduced absorbance in narrow bands of the blue and green region (Albertano et al. 2005, Roldán et al. 2004c, 2006, Roldán & Hernández-Mariné 2009). This information identifies a few wavelengths that should inhibit the growth of the cyanobacteria and microalgae. In humid sites, with further development of green algae which have chlorophylls *a* and *b*, simply removing white light and using alternative lights with wavelengths poorly absorbed by them, in the yellow range (around 595 nm) would eliminate much of their development and the subsequent deterioration (Gurnee 1994, Olson 2002, Roldan et al. 2006).

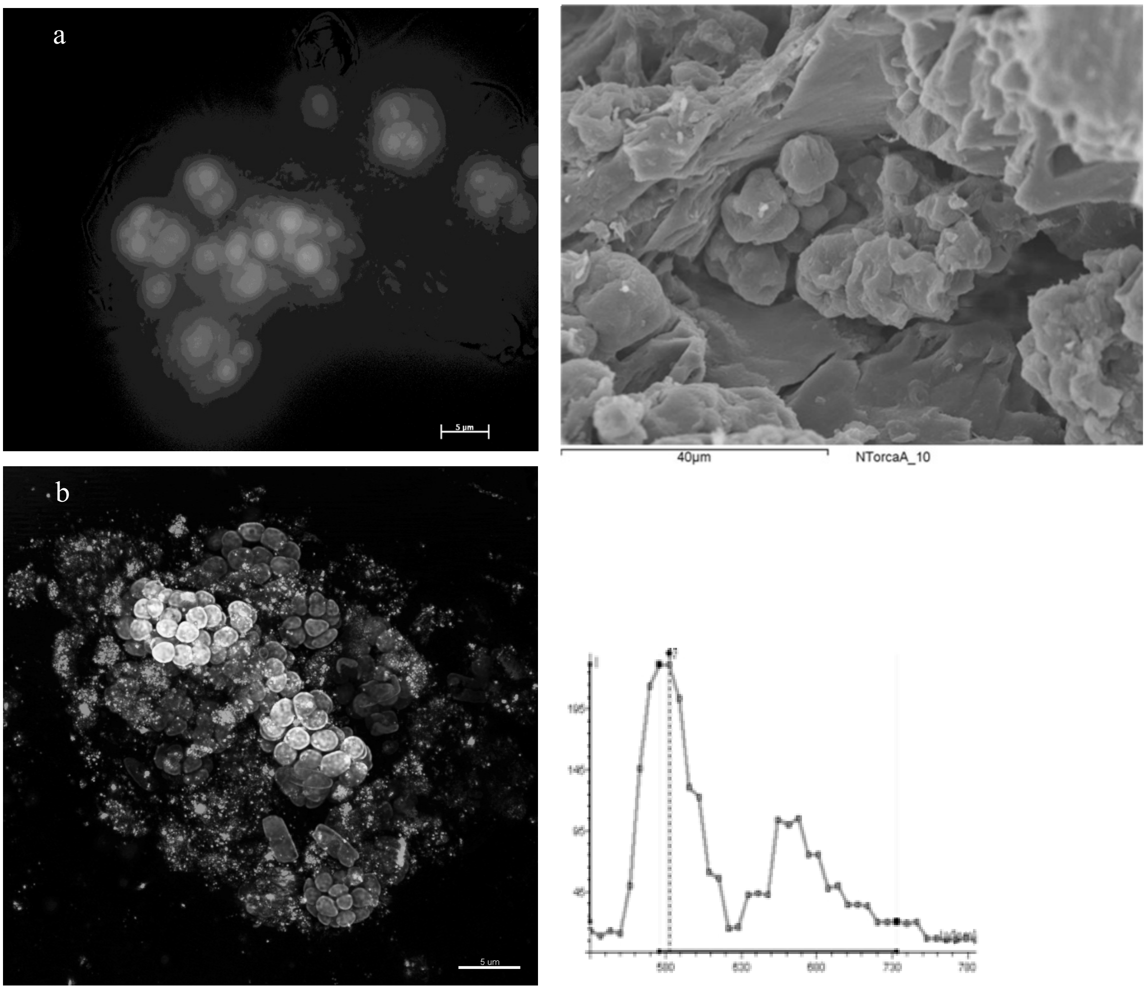

Figure 3. Biofilms collected in Nerja Cave. a: Superimposed image of light-micrograph and epifluorescence showing pigments fluorescence and the sheaths of *Chroococcidiopsis* sp. On the right, SEM micrograph of *Chroococcidiopsis* sp. inside a micro-pit. b: Confocal micrograph of biofilm-forming *Nostoc* sp. Maximum intensity projection showing colonies composed of filaments in a gelatinous sheath and inorganic materials (small white dots). On the right, emission spectra of *Nostoc* sp.

Biofilms in the Nerja Cave, in comparison with those in other caves from temperate damp areas (Albertano 2012, Mulec et al. 2008, Pentecost & Whitton 2012) or in Spanish caves such as Bats Cave in Zuheros (Roldán et al. 2009, Urzì et al. 2010), have a lower number of morphospecies and are thinner, with thickness under one millimetre.

The extent of colonization depends on the time of lighting for visits and on the wavelenghts available for primary production (Albertano & Bruno 2003, Roldán et al. 2004a, Albertano 2012). Unfortunately, the cyanobacteria and algae from caves and hypogean monuments have adapted to dim light. In Nerja Cave they can survive and slowly reproduce at light intensities around 1 µmol photons m^{-2} s^{-1}. This low light intensity has already been reported in other caves with *lampenflora* (Grobbelaar 2000).

4 THE PRESERVATION OF THE NERJA CAVE AND ITS NATURAL AND CULTURAL HERITAGE

The multidisciplinary knowledge of the cavity has allowed the implementation of projects aimed at the preservation of the Nerja Cave and its natural and cultural heritage, including such as those referred:

4.1 *Delimitation of the Good of Cultural Interest Nerja Cave*

After the declaration of the Nerja Cave as Good of Cultural Interest, the delimitation of the protection perimeter of the cave was carried out. This delimitation was mainly based on hydrogeological and geological researches, as for example, extension of the karst network, distribution of permeable and impermeable rocks, piezometric levels, geological structure (dips, faults), drainage network and other neighbouring caves. The Nerja Cave has a full protection area encompassing 1.1 million m^2 and a surrounding protection area of 1.8 million m^2.

4.2 *Visitors studies*

Visitors may cause impacts in the underground environment: variations of the microclimatic parameters, physico-chemical changes or contamination of the groundwater and rock alteration. *Lampenflora* also appears where light and water coexist. Changes are related with the number of visitors and the mean stay time. Others factors inherent to the cave are also very important, as cave volume and natural ventilation.

The Nerja Cave is one of the most visited natural monuments in Spain. The monthly visitor distribution is very similar for different years, with a minimum of visitors in January-February and November-December, between 9,000-33,000 visitors/month, and a maximum in August, between 83,000-119,000 visitors/month (Vadillo et al. 2001). Each day, in the Tourist Galleries, there is an increase in temperature, relative humidity and CO_2 concentration in the air during the opening hours and a decrease during closure, both at midday and during the night (Fig. 4). The main changes related to the visitors are the following (Vadillo et al. 2001): (1) air temperature rises 0.2ºC by 1000 visitors/day; (2) relative air humidity increases between 2-3 % in a day, nearly reaching saturation on summer days; (3) air CO_2 concentration increases up to values between 500-700 ppm during low visiting periods and almost 8 times (2,300 ppm) the natural mean value during high visiting periods and (4) rock temperature rises between 0.02ºC and 0.15ºC/day. In the High and New Galleries the tourism impact has been detected only during high visiting periods in winter (Liñán et al. 2009).

With a very high number of visitors, increases in temperature, relative humidity and air CO_2 concentration are greatest and it is possible to detect cumulative effect in air CO_2 concentration (the cave does not recovery the minimum values during the closed periods). This cumulative effect is punctual and disappears several days after; when the number of visitors is lower (Carrasco et al. 1999). Nowadays, the limit set of visitors (Scientific Advisory Board) is 500 people per hour, with a maximum of 4,000 visitors a day. Furthermore, along the time the Nerja Cave has been open to the public, there have been several changes to their opening hours to reduce the human impact (Carrasco 1996).

The large volume of the cave (300,000 m^3) and the natural ventilation are positive aspects, which allow a high number of visits. The ventilation index of the Nerja Cave, calculated by the air radon concentration in the cavity, is 0.2 m^3/s in spring-summer period, and 2.8 m^3/s in autumn-winter (Cañete 1997, Dueñas et al. 1999). From October to June, the airflow direction is predominantly from the Tourist Galleries to the deeper galleries of the cave. By contrast, in July, August and September, the airflow direction goes from the deeper galleries to the Tourist Galleries (Liñán et al. 2008, Liñán & del Rosal 2014). This general model of airflow circulation facilitates the removal of anthropogenic impact in the Nerja Cave during the summer, the most visited season in the year.

4.3 *Design a new lighting system*

The actions for the prevention and control of *lampenflora* in the Nerja Cave include the design of a new lighting system. This system requires information about pigments of the microorganisms in photosynthetic biofilms and about the rate of active radiation from the lamps. These characteristics allow recommend appropriate lighting wavelengths for the cave, so the development of *lampenflora* is minimal. At present, it is developing a rehabilitation project about the tourist track, which includes the replacement of current lighting system.

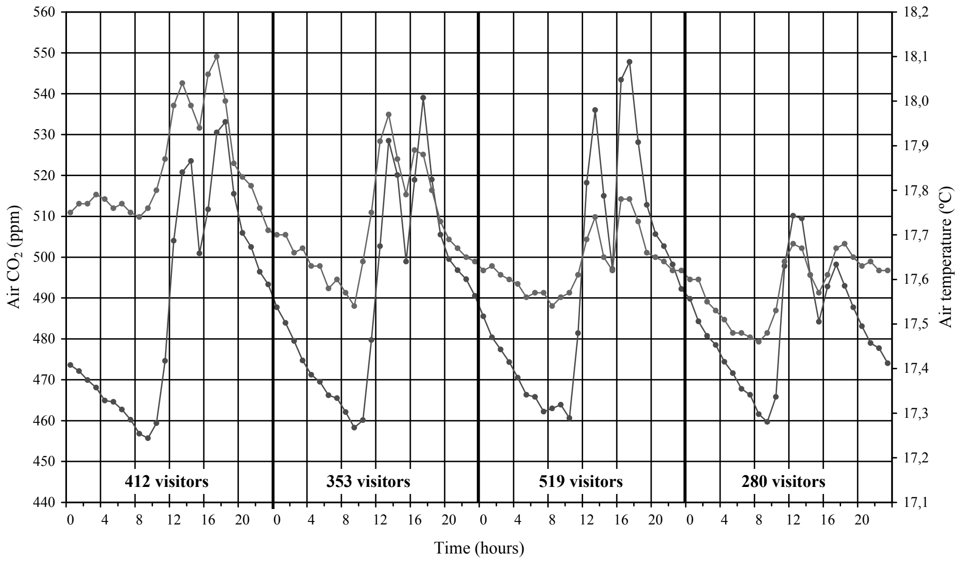

Figure 4. Temporary evolution of the air temperature (upper line) and CO_2 (bottom line) in the Tourist Galleries of Nerja Cave, from February 1st to 4th, 2014 (hourly data).

4.4 *Dissemination activities*

The dissemination activities are considered effective and essential to know, enjoy, respect, protect and preserve the Natural and Cultural Heritage. The dissemination of the Nerja Cave tries to show to the society the importance of the Cultural and Natural Heritage of the cave and to promote the knowledge and understanding of environmental factors affecting the hypogean environment as well as cause a feeling in society to respect and protect this environment by developing attitudes to the conservation of this valuable and fragile legacy. The Research Institute of the Nerja Cave has been responsible for the design and development of dissemination activities. Since 2011, this work is carried out jointly with the Nerja Museum (Liñán et al. 2010). This work integrates activities and materials aimed at different public, which have allowed participants to understand and appreciate the Nerja Cave always keeping as a priority its conservation.

5 CONCLUSIONS

The research, conservation and dissemination carried out by numerous research groups, the Scientific Advisory Board and the Research Institute of the Nerja Cave are a fundamental tool for: (1) the knowledge of "natural" variations of the subterranean environment and anthropogenic modifications of microclimate, hydrochemistry and microbiota of the cavity, (2) reconcile the conservation of the cave and its surroundings with a tourist and cultural use and (3) establish corrective measures required, as changes in visiting arrangements or lighting systems.

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