Appendix 1

THE PROBLEM OF LAMPENFLORA IN SHOW CAVES

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Abstract: Lampenflora is a typical problem of show caves, because the light that is necessary for the visitors supplies enough energy to some plants, mainly algae and mosses, which may grow to the point of defacing and damaging seriously the cave itself.
After a description of the main characteristics of lampenflora and a detailed list of the environmental conditions contributing to its development, the best methodology to control such a development with particular attention to an easy and successful implementation is here described.

Key words: lampenflora, lighting, control of lampenflora.

INTRODUCTION

In a wild cave the flora, i.e. any kind of plants, exists only in a part close to a natural entrance where the outside light reaches the cave environment. According to the species, the plants may grow inside a cave until the light intensity ranges between one to three orders of magnitude less than outside.

Most of the show caves are fitted with a lighting system and in an area more or less around a lamp plants can develop. In general these plants are algae or mosses but sometimes also ferns till superior plants may develop and grow. This phenomenon was firstly studied mainly by Austrian scientists (Kyrle, 1923; Morton & Gams, 1925) and, later, in France (De Virville, 1928). A rather exhaustive book on the cave flora, with many references dating back to the XVIII century, is that due to Morton & Gams (1925).

Only in 1963 the word “lampenflora” (a German word which means “plants of the lamp”) was firstly introduced by Dobàt (1963) and is presently adopted everywhere in the world to identify any kind of plants growing in the vicinity of lamps.

WHAT IS LAMPENFLORA AND HOW IT DEVELOPS

The plants classified as lampenflora range, in general, from cyanobacteria (also known as blue-green algae), algae, lichens, mosses to ferns. Cyanobacteria, green algae and mosses are the most common components of the lampenflora in show caves, their abundance varies from cave to cave (Padisàk *et al.*, 1984; Grobbelaar, 2000; Aley, 2004). Algae and cyanobacteria exist in wild caves (Claus 1962, 1964; Hajdu, 1966; Kol, 1967) also in the dark sections. This means that a release of spores brought in by the visitors is not strictly necessary for a successive growth of these algae. When a cave is developed as a show cave the algae proliferate in the vicinity of the light sources thanks to the energy released by the lamps.

In general the lampenflora is firstly composed by algae at the beginning of its development, to be followed by mosses, ferns and sometimes by vascular plants (Mulec & Kosi, 2009). The negative effects of lampenflora is due to the fact that plants may produce weak organic acids, which in time can corrode both limestone and formations (Aley, 2004). When a prehistoric cave is concerned the paintings may be seriously damaged as happened in Lascaux cave in France (Ruspoli, 1986). In addition, without any intervention the lampenflora spread rather quickly (e.g. in Baradla cave, Hungary (Hazslinszky, 2002), lampenflora doubled in 7 years) and may become an important source to colonise wide areas. A typical example is observed in Cango Caves, South Africa, where large surfaces of coral-like formations far away from the lighted section of the cave are covered by green algae.

Lampenflora's growth and distribution depend on light intensity, temperature, moisture and substratus.

The lux (symbol: lx) is the unit of illuminance and it is used to measure the intensity of the light, as perceived by the human eye that hits a surface. As a rough indication of the light intensity resulting in the development of 85 % of the lampenflora, a value around 40 lux was measured when the light was switched on for most or all the time that the caves were open. A continuous lighting yields more lampenflora growth than short periods of lighting for the same length of time because the adaptation of plants to light and dark phases requires both time and plant energy (Aley, 2004). The established lampenflora populations can survive long periods of very low levels of illumination or total darkness (Johnson, 1979).

Chlorophyll (types a and b) has two absorption peaks, in the ranges 430 – 490 nm and 640 – 690 nm. Therefore if a lamp has an emission spectrum in the range 500 to 630 nm the contribution to the photosynthesis process of green algae is reduced without important aesthetic problems. In Mammoth Cave, USA, lighting with LED at an intensity of 49.5 lx and a yellow light (595 nm) prevented regrowth for 1.5 years after complete lampenflora removal (Olson, 2002).

Sometimes a UV irradiation was used to suppress the lampenflora on account of its germicidal effect (Mulec & Kosi, 2009). Recently in Grotta Gigante, Trieste, Italy, a new set of germicidal lamps, provided with an electronic starter, which obtained the *2008 Green certificate*, in order to inhibit the development of lampenflora and to ensure an environmentally-friendly use of the cave were installed. These lamps, whose use aims at keeping under control the development of lampenflora, turn on when all the other lights in the cave are turned off (Fabbricatore, 2009).

Incandescent lamps produce an increase of the temperature and a decrease of the humidity. Within some tens of centimetres from the lamp the increase of temperature may be of the order of 10°C and the decrease of the relative humidity to 70 – 80 %, this condition results in an algal growth unless the decrease of humidity is excessive and the algae cannot proliferate (Mulec & Kosi, 2009). In fact lampenflora develops on moist or damp surfaces and therefore soft surfaces as cave sediments and moonmilch provide higher moisture storage than hard surfaces with the chance of luxuriant growths (Aley, 2004).

HOW TO CONTROL LAMPENFLORA

The most obvious action is the reduction of energy supply by both a reduction of the light emitted and the adoption of a light spectrum with a low emission in the wavelength absorbed for growth the lampenflora (Smith & Olson, 2007). Unfortunately such an action

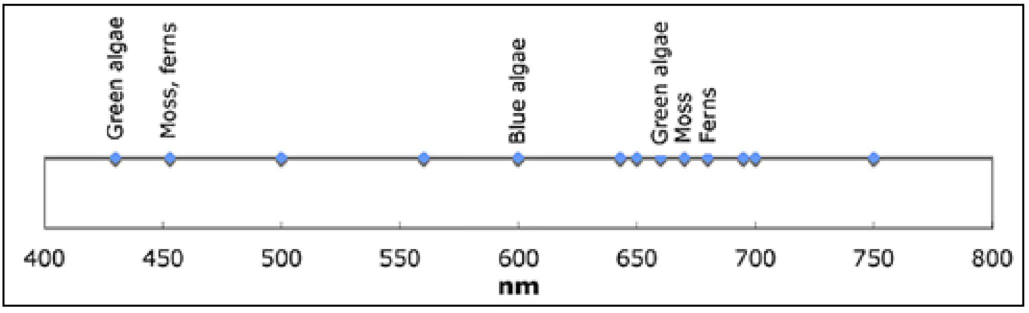

Fig. 1 – The most important absorption peaks of lampenflora (from Caumartin 1994, modified).

is not enough effective to solve the problem. Nevertheless it is convenient to use lamps with an emission spectrum poor of the wavelength mostly absorbed by lampenflora. In Fig. 1 its is reported a graph where the maximum of the absorption peaks are reported. The frequencies with the maxima from 460 to 453 nm around 600 nm and from 653 to 700 (particularly the latter) are the most dangerous for the proliferation (Caumartin, 1994). Preliminary experiments with cold cathode lamps reached a reduction of the growth of a green alga (*Dunaliella salina*) down to 57 % of the control (Antrox, 2009).

The technique of switching out the light for a prolonged time interval (e.g. one month) counteracts the proliferation of photosynthetic organisms in caves but may favour the diffusion of especially resilient organisms as *Phormidium autumnale* (and generically cyanobacteria) by reducing competition (Montechiaro & Giordano, 2006).

It must be stressed that, notwithstanding the reduction of light plays a positive role in reducing the proliferation of lampenflora, sometimes a moss intertwined with cyanobacteria may cover relatively wide areas which were only occasionally illuminated (Giordano *et al*., 2001).

When lampenflora proliferates, it is necessary to destroy it with chemical compounds. The herbicides have the disadvantage of being sometimes highly toxic for cave fauna and also the personnel must pay a special care. For this reason these biocides as DCMU, Atrazine, Simazine, Karmex, etc., are absolutely inappropriate in caves (Mulec & Kosi, 2009).

A comparison among an herbicide, sodium hypochlorite and sodium chlorate at the following concentrations:

Karmex™ Du Pont	3 g/L water
Sodium hypochlorite	2.75 % Cl
Sodium chlorate	30 g/m^2

gave similar results, but sodium hypochlorite had a faster effect while the results obtained with sodium chlorate were less homogeneous. The runoff of the solution should preferably be collected and disposed outside the cave. In any case after the treatment the surface should be rinsed with water.

A test to evaluate the corrosive action of sodium hypochlorite was carried out on some broken formations. After 10 minutes of treatment about 41 mg/m^2 were dissolved without any further increase over 17 hours (Bertolani et al., 1991). For this reason the treatment with sodium hypochlorite is currently adopted in the Frasassi Caves, Italy, since many decades with no disadvantages for the formations, which are as shining as when, they were discovered. But according some authors (Faimon et al., 2003; Mulec & Kosi, 2009) it represents a burden for the cave environment.

Therefore hydrogen peroxide, which is an environmentally friendly agent was proposed (Grobbelaar, 2000). The threshold concentration for the destruction of lampenflora was found to be 15 % vol. but the solution attacked the carbonates with a dissolution rate around $2*10^{-2}$ mol m^{-2} h^{-1}. In order to avoid such an effect a preliminary peroxide saturation was obtained by adding of few limestone fragments into the peroxide solution at least 10 hours prior to its application (Faimon et al., 2003).

CONCLUSION

There are different actions to control the development of lampenflora in show caves. First of all, there is the reduction of energy introduced into the cave by the lighting:

- Lights switched on when necessary only
- Minimum distance of indicatively 1 m between lamp and cave wall or formations
- Emission spectrum with minima in the ranges 430 – 490 nm and 640 – 690 nm
- UV lamps switched on when visitors are absent

These actions can be implemented together or each one according to the local situation and possibilities. Obviously the lamps switched on only when the visitors are present in their vicinity reduce the energy release as well as the cost of electric energy. Since the amount of radiation emitted from a lamp decreases as the inverse of the square of the distance, it is always convenient to avoid the placement of lamps too close to walls or formations also because the temperature increase can interfere with the growth of formations. A spectrum poor of the wave length mostly absorbed by lampenflora can be easily obtained with discharge lamps (cold cathode lamps) or LED. The effect of UV irradiation was found to have only a transitory suppressing effect (Dobat, 1998). In addition the effective range is between 50 and 70 cm for a 30 W lamp and therefore in order to have a wider area treated to a distance, e.g. of 3 m, a 400 W lamp would be required or a multiple low power lamps (Kermode, 1975). Some experiments are being carried on presently, as in Grotta Gigante (Trieste, Italy) where the whole electrical system has been replaced recently (Fabbricatore, 2009). The result of the UV irradiation will be appraised in the very next future. In particular its effects should be considered with reference to the expenses of installation and maintenance.

Once the lampenflora is present, it is necessary to avoid its further development and destroy it by chemical methods:

No herbicides! Too toxic for the cave environment
Sodium hypochlorite 5 %
Hydrogen peroxide 15 % vol

Herbicides, used frequently in agriculture, must be avoided because their degradation in the cave environment is rather slow and their toxicity may affects seriously the cave fauna. Sodium hypochlorite treatment releases gaseous chlorine, which may have bad side effects on the cave fauna. Some air circulation may avoid such bad effects. Hydrogen peroxide, once it is saturated with calcium carbonate, is surely the most "friendly" chemical compound, but its use required some precautions by the personnel, while the personnel can apply the sodium hypochlorite without special attention.

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References.

Aley T., 2004. Tourist Caves: Algae and Lampenflora. In: Gunn J. (Ed.) – *Encyclopedia of Caves and Karst Science*, Taylor and Francis-Routledge, New York: 733–734.

Antrox, 2009. Personal communication by Daniele Traferro, President, Antrox srl., Via Fioretti 10, 60131 Ancona – Italy

Bertolani M., Cigna A. A., Macciò S., Morbidelli L. & Sighinolfi G.P., 1991. The karst system "Grotta grande del vento-Grotta del Fiume" and the conservation of its environment. *Proc. Int. Environmental Changes in Karst Areas* – I.G.U.-U.I.S., Italy, 15 – 27 Sept. 1991, Quaderno Dip. Geografia N. 13, Univ. of Padova: 289–298. Also as: ENEA Report RT/AMB/92/19.

Caumartin V., 1994. *Reflexion sur la conservation des grottes amenagées pour la visite touristique.*. ANECAT, Paris.

Claus, G. 1962. Data on the ecology of the algae of Peace Cave in Hungary. *Nova Hedwigia,* 4(1): 55–79

Claus, G. 1964. Algae and their mode of life in the Baradla Cave at Aggtelek II. *International Journal of Speleology,* 1:13–2

De Virville D., 1928. *Influence de la lumière électrique discontinue sur la flore d'une grotte.* Imp. Libr. Goupil., Laval.

Dobàt K., 1963. "Höhlenalgen" bedrohen die Eiszeitmalereien von Lascaux. *Die Höhle,* Wien, 14(2): 41–45.

Dobàt K., 1998. Flore de la lumière artificiélle (lampenflora-maladie verte). In: Juberthie C. & Decu V. (Eds.). *Encyclopaedia Biospeleologica* . Tome 2, Société de Biospéologie, Moulis-Bucarest: 1325–1335.

Fabbricatore A. (Ed.), 2009. *Grotta Gigante, tursimo, ambiente, cultura*. Società Alpina delle Giulie, Trieste: 1–24.

Faimon J., Stelcl J., Kubesova S. & Zimak J., 2003. Environmentally acceptable effect pf hydrogen peroxide on cave “lamp-flora”, calcite speleothems and limestones. *Environmental Pollution*, 122: 417–422.

Grobbelaar J. U., 2000. Lithophytic algae: A major threat to the karst formation of show caves. J. Applied Phycology, 12: 309–315.

Giordano M., Mobili F., Pezzoni V., Hein M. K. & Davis J. S., 2001 – Photosynthesis in the caves of Frasassi (Italy). *Phycologia*, 39(5): 384–389.

Hajdu, L. 1966. Algological studies in the cave at Maytas Mount, Budapest, Hungary. *International Journal of Speleology,* 2: 137–149.

Hazslinszky T., 2002. Übersicht der Lampenflorabekämpfung in Ungarn. In Hazslinszky T. (Ed.) *Proc. Int. Conf. on Cave Lighting* , Budapest, Hungary, Hungarian Speleological Society: 41–50.

Johnson K., 1979. Control of Lampenflora at Waitomo Caves, New Zealand. In: Robinson A. A. (Ed.) *Cave Management in Australia III*. Proc.Third Aust, Conf. Cave Tourism and Management, Mt. Gambier, South Australian National Parks and Australian Speleological Federation, Adelaide.

Kermode L., 1975. Glow-worm Cave, Waitomo. Conservation Study. *New Zealand Speleological Bulletin,* 5(91): 329–344.

Kyrle, G. 1923. *Grundgriss der theoretischen Speläologie*. Wien: Österreichischen Staatsdruckerei

Kol, E. 1967. Algal growth experiments in the Baradla Cave at Aggtelek. *International Journal of Speleology,* 2: 457–74.

Montechiaro F. & Giordano M., 2006. Effect of prolonged dark incubation on pigments and photosynthesis of the cave-dwelling cyanobacterium *Phormidium autumnale* (Oscillatoriales, Cyanobacteria). Phycologia, 45 (6): 704–710.

Morton F. & Gams H., 1925. Höhlenpflanzen. *Verlag Eduard Hölzel,* Wien: 1–227 + 10 Tables.

Mulec J. & Kosi G., 2009. Lampenflora algae and methods of growth control. *J. of Cave and Karst Studies*, 71 (2): 109–115.

Olson R:, 2002. Control of lamp flora in Mammoth Cave National Park. In: Hazslinszky T. , Ed., *Proc. Int. Conf. on Cave Lighting* . Budapest, Hungarian Speleological Society: 131–136.

Padisak J., Rajczy M., Paricsy-Komaromy Z. & Hazslinszky T., 1984. Experiments on algae and mosses developing around different lamps in the cave “Pal-Völgyi-Barlang”. *Proc. Int. Colloquium on lamp flora, Budapest, 10 – 13 October 1984*: 83–102.

Ruspoli M., 1986. *The Cave of Lascaux: the Final Photographs*. New York, Abrams and London, Thames and Hudson.

Smith T. & Olson R., 2007. A Taxonomic Survey of Lamp Flora (Algae and Cyanobacteria) in Electrically Lit Passages Within Mammoth Cave National Park, Kentucky. *Int. J. Speleology,* 36(2): 105–114.

Appendix 2

INTERNATIONAL COMMISSION ON PREHISTORY IN SHOW CAVES

Address of Joëlle Darricau – Chairman

At the time of the preparation for the **I.S.C.A. conference in Toulouse in 2008**, I presented my idea to President David Summers for creating a special commission in the Association dealing with prehistory.

I had been feeling a growing concern at our meetings because the prehistoric caves lacked a dimension for prehistory, these highly symbolic and significant places, bearing witness to our Humanity.

I would like to thank the Board for bringing the specialized subject on prehistory into existence in August 2008

I hope very much that during this congress we will be able **to identify the full member caves that contain evidence of prehistory** in their caves and get to know the people who represent each of them.

This is the greatest difficulty that I have had since the beginning in activating this network. **I need one manager/contact person per each cave containing prehistory, with their E-mail addresses.**

The subjects covered in this commission, are diverse and varied. They cover all of the archaeological sciences. New, and rather surprising research techniques, are now being used at certain prehistoric sites, to better understand the data that exists within them.

I will only mention one of these sciences: **the application of criminal laboratory techniques**.

Other practices are **environmental studies**: climatology, bacteriology.

For archaeological digs: sedimentology, the study of raw materials, the working of bone and stone.

Social anthropology... understanding the social links of a prehistoric economy.

The Introduction of the cognitive sciences: the neurosciences.

Anthroposophy: spiritual science, which leads the spirit that lives in humans towards the spirit that lives in the universe.

Spiritual science, path of knowledge and way of life.

Biomechanics, human behaviour, physical and psychic approaches, the conceptualization of gestures.

Spatialization –Taking a new look at the works: malleability, and **taking into account** the sound and resonance dimension. Cultural links that join all the various ages together.

These are all new forms of research used **to understand** their way of life, **to discover** their know-how, **to imagine** behaviours and then **supposing** their way of thinking.

Perhaps you will think that this list of research techniques – some of them revolutionary – and these new ways of looking at this heritage **do not concern you**, or not very much!

But managers of caves containing example of prehistory must be aware, and be sensitive to these new research techniques.

These new approaches bring us – as the managers of these sites – many things to think about and open up to us. **New outlooks** for the development of an **efficient, innovative, qualitative** offering, made available to **increasingly demanding visitors,** who are hungry for accurate information, who want to discover and understand.

These sites that are open to the public then become **real links** between scientists and the general public, through an appropriate mediation that brings together **these two worlds** that rarely meet.

When I have recently taken part in various International **Symposia:** Lascaux, Ifrao, **network committees**: “Pyrénées Préhistoriques”, “Chemins de l’Art Aurignacien,” and “Caminos de Arte Rupestre”, I am often the only owner-manager of a prehistoric cave site present.

These are the places where **I find new ideas**, where **I nourish my thinking** to be able to explain and think about the site of the caves, **Prehistory to the Present,** in a more original and up-to-date offering... this is also where **I think about our future**... that **I can decide to apply breakthroughs** to move away from obsolete practices, **to be innovating** in terms of presentation, **to gather around me** people with very specific competencies. Also knowing how to talk about others, **about you,** and in the end passing on through this network, **of ours**, everything that we are able to gather from our travels and our reading.

Knowing how to present the specificities of our prehistorical sites with, in the background, **a broader notion of the history of prehistory**.

At the present time we are all fragmented and each of us addresses only a part of our subject.

The committee exists. It will be a place for reflection thanks to the **web site, internet and intra-net** space.

A formidable tool for working and sharing. **It's up to us to make the most of it**.

To achieve this, we must adopt a new way of acting...

Let us create a collective intelligence with the new communication technologies.

Changing our habits, thinking about other people.

Let's be curious about others.

Let's share, exchange, and above all make the time to do it, to create the mechanism of **click and copy, click and send**.

Human beings have survived thanks to exchanges, sharing, in a lived intuition of interdependency of the world of living things and of nature.

Cultural diversity is an enrichment of humanity in motion, we are constantly evolving. **We are the actors.**

Now more than ever, we must **develop a capacity for adaptation**, nourished with substantial and **patient thinking** in making our choices.

I don't have time to go into it now, but I would like us to consider the issue of **tourism for our caves with prehistory**. How far can we go? Again, the management of paradoxes.

What training is needed for our personnel in charge of mediation? The dangers, the notion of fashions, profitability, competency.

Speaking of prehistory...

Like them, let us be **Hunters** of information...

Gatherers of new ideas...

Nomads for a broader vision and sharing that witch will enrich all of us.

Prehistory! Our family history which is far from being finished!!!

Thinking that **the more we think we know, the more we realize that we don't know very much.**

These are the approaches that I would like to explore with you in our future exchanges.

This commission will be **what we are able to build together.**

Thank you – Merci – Gracias – Milesker