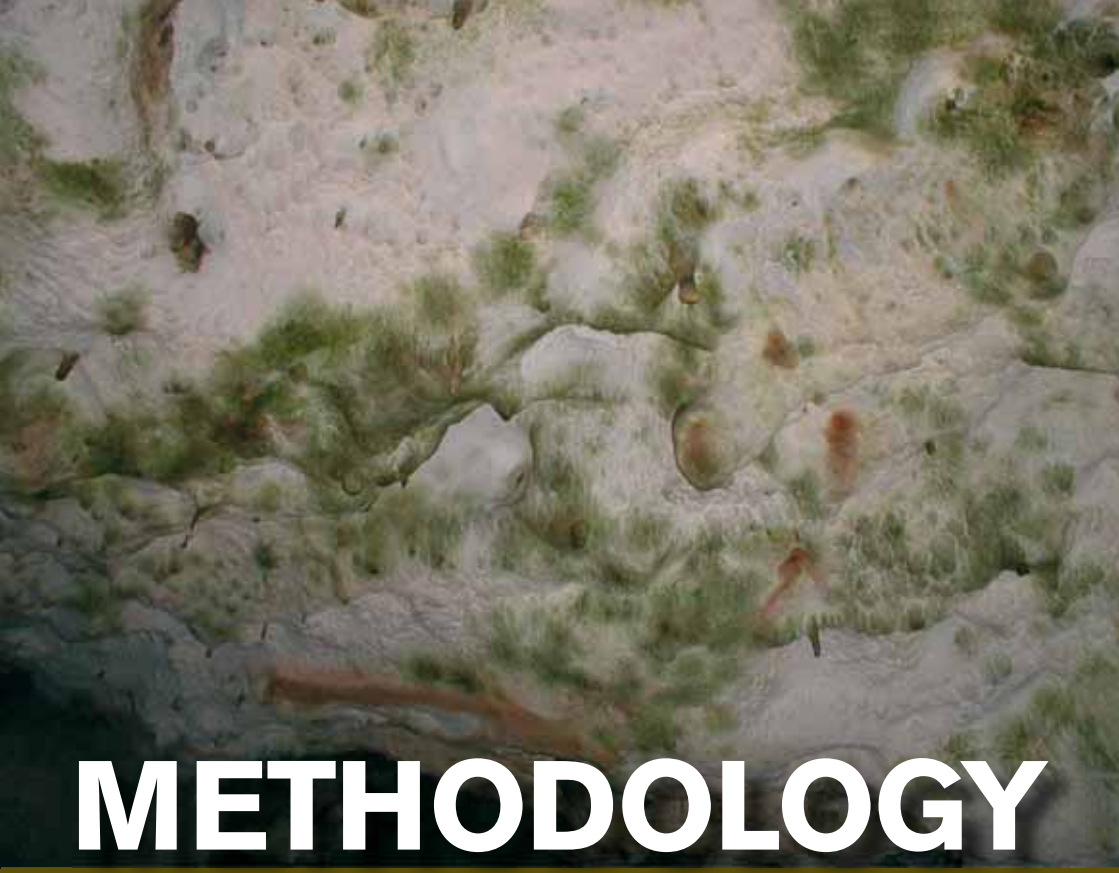

METHODOLOGY
OF LAMPENFLORA REMOVAL IN CAVES ACCESSIBLE FOR TOURISTS

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METHODOLOGY OF LAMPENFLORA REMOVAL IN CAVES ACCESSIBLE FOR TOURISTS

The methodology provides a summary of suitable procedures and preventive measures to remove and control the growth of undesirable flora growths, which turns up near light sources in caves accessible for tourists. The internationally accepted term for these stands is lampenflora. The methodology is compiled on the basis of more than 30 years of experience with removing lampenflora in accessible caves of the Moravský kras, Czech Republic, and also abroad. Adhering to recommended procedures and preventive measures quoted in this methodology can fairly solve the problem of vegetation around cave lamps.

Punkevní caves, 1981

Table of contents

1. Introduction

All over the world caves open for public and furnished by an electric illumination are faced with the issue of occurrence and spread of various types of predominantly non-vascular flora around lamps. This includes namely algae, blue-green algae, bryophytes, ferns and rarely also seed plants. Depending on the type of used light source, type of substrate, its humidity and other factors, these plants can appear at a distance of several centimetres up to several dozen meters from the source of light and may cover large areas of the cave and stalactite decoration. Lampenflora growths change the habit of stalactite decoration and produce humic acid which may irreversibly damage the decoration. In publicly accessible caves flora patches create alien element whitch do not appear in spaces without artificial illumination. As we wish to preserve caves in their original state before an illumination introduction, we are faced with the problem of removing existing lampenflora patches and preventing further growth without negatively affecting cave geoecosystems.

2. Overview of existing research and practical experience

The Documentation Department of the *Moravský kras* State Agency under the authority of Dr. O. Štecl first began to deal with the problem of lampenflora removal in 1978. At first, mechanical removal methods were used (brushes, pressurized water) – the effectiveness of which was very low and on the long-term, these methods brought no positive results. Therefore these methods had been abandoned and new methods utilizing ultraviolet radiation were tested. New methods showed sufficient results at a short range only and not for large growths. It has been discovered that the most suitable means of removing lampenflora are compounds within the zone of chlorine-based disinfection agents. Research utilizing these agents was carried out in 1970s in Waitamo Caves, New Zealand. Two hypochlorite compounds were used as active substances: Calcium hypochlorite ($Ca(ClO)_2$ x $2H_2O$) and sodium hypochlorite (NaClO).

In *Moravský kras*, tests using hypochlorite began in 1978/79. Obtaining pure calcium hypochlorite was difficult since it was not available in the Czechoslovak Socialist Republic at that time. Chlorinated lime was used as a substitute for hypochlorite – it is a mix of calcium hypochlorite ($Ca(ClO)_2$ x $2H_2O$) and calcium chloride ($CaCl_2$). Compared to pure calcium hypochlorite, this mix is less soluble in water. At first, tests were performed at small areas of 20 x 20 cm. In order to achieve complete removal the area had to be sprayed with 2–4 % solution of chlorinated lime 3 times in a row. For further application on larger areas (1 x 1 m) in the Sloupsko-Šošůvské caves the concentration of chlorinated lime was therefore increased to 4–10 %. This concentration had proven to be effective and was used for the whole lampenflora removal in all show caves in area Moravský kras between 1980 and 1983. The concentration of released chlorine, as measured by the Regional Hygiene Station in Blansko was below the registration limit of measure instruments. Two problems arose during the application of chlorinated lime. At first a low water solubility appeared, which caused clogging of spray nozzles. Second problem was a white film remained after the application on treated areas – coagulated residues of the used chemicals had to be later removed by pressurized water. Due to given reasons tests of again a new substance from the zone of disinfection agents – chloramine-T – were initiated in 1984. Chloramine T is *N*-chloro 4-methylbenzenesulfonamide, sodium salt. Unlike chlorinated lime, it is less toxic and better soluble in water. Due to the lower toxicity of chloramine-T, its concentration had to be increased to 10–15 %. In comparison to chlorinated lime, the perishing period of lampenflora appeared significantly longer – up to weeks. This method was used until 1990.

At the beginning of 1991, 2–4 % solution of sodium hypochlorite was tested in caves of Moravský kras. Tests were performed similar way as those with the chlorinated lime. Results showed that between all available substances of sodium hypochlorite seems to be the most suitable chemical substance removing lampenflora.

In 1996 the author started experimenting with removing lampenflora in the Sloupsko-šošůvské caves with hydrogen peroxide (H_2O_2), which is much friendlier towards a cave environment. Since the method had been new its verification was carried out and optimum pH concentration or possible negative effects were assessed in cooperation with

members of the Faculty of Science, Masaryk University in Brno (RNDr. Jindřich Štelcl, CSc.; Ing. Jiří Faimon, Dr.; Mgr. Svatava Kubešová) and from the Faculty of Science, Palacký University in Olomouc (Doc.RNDr. Jiří Zimák, CSc.) who further developed the method (Faimon et al. 2002).

Subsequent tests carried out in the caves of Moravský kras have shown that hydrogen peroxide was far from attaining the effectiveness of hypochlorite compounds. Hydrogen peroxide suffices for removing molds; to remove moss and algae the application must be repeated and the results are not guaranteed.

Koněprusy caves' staff inspired by the one of Moravský kras, addressed the problem in 1980. First chlorinated lime had been tested but did not bring satisfactory results and was replaced by chloramines. Hydrogen peroxide (H_2O_2) proved to be effective just to remove molds, organic sedimentation and blue-green algae.

Fig 1 – removal of lampenflora in the Kateřina cave

3. Overview of selected methods for lampenflora removal

3.1. Mechanical methods

The use of mechanical methods (brushes and compressed water) is questionable. The effectiveness of these methods is very low or negligible on a long-term basis. Mechanical methods pose a serious danger of further lampenflora spreading to the surrounding so-far unaffected areas as well as damaging walls and sinters.

3.2. Methods using ultraviolet radiation

Methods are highly-effective within a short range and have minimum side effects. Perished lampenflora turns reddish brown and has to be removed by one of mechanical methods. Application limits of the UV method involve its short range. Ultraviolet radiation from a 30 W lamp is effective within approximately 50–70 cm range, whereas lampenflora grows into distances exceeding 15 meters from the light source. Therefore methods have not proven useful in the Moravský kras – they could be applied only in smaller caves. As another disadvantage it appears that in areas with rich stalactite decoration and narrow cracks the shadows significantly reduce or inhibit the effect of UV radiation.

3.3. Chemical methods

Chemical methods represent another way to remove undesirable lampenflora. However, these methods – if inappropriate chemicals are used – can cause more trouble and damage than mechanical methods. When searching for and testing a new suitable substance, its ecological acceptability and safety for both staff and visitors has to be taken in account due to uninterrupted performance of a cave. Compounds containing highly poisonous chemicals, such as arsenic, cyanide, lead or mercury, as well as mildly poisonous substances, which do not decompose quickly enough and could accumulate in the caves – such as chlorinating hydrocarbons or other carbonate compounds – must be excluded. Also aromatic compounds (formaldehyde) and other phytotoxic agents whose possible negative effects on cave ecosystems are not well known must be excluded. Compounds within the zone of chlorine-based disinfection agents were identified as the most suitable substances for removing lampenflora. Research using these substances was conducted in the 1970s in Waitamo Caves, New Zealand. Two hypochlorite compounds were used as active substances: Calcium hypochlorite ($Ca(ClO)_2 \times 2H_2O$) and sodium hypochlorite - NaClO. Both hypochlorite compounds have strong oxidation effects. Their solutions are used for disinfection purposes and bleaching in the textile industry. When applying hypochlorite to lampenflora patches, a fast oxidation process occurs, resulting in extinction and bleaching of the patch. Both agents decompose quickly (5 minutes – 12 hours), namely in contact with organic substances. After the use of calcium hypochlorite, white films remain on the background – coagulated residues of applied chemical - which must be removed by pressurized water.

The use of hydrogen peroxide (H_2O_2) is much friendlier towards the cave environment but achieved results come far worse of those of hypochlorite compounds.

4. Recommended procedures and preventive measures to remove and control the growth of undesirable flora

The removal of lampenflora and control of its growth should be approached from two directions:

1) Removal of existing lampenflora

The existing lampenflora can be satisfactorily removed by the use of chemical methods.

2) Controlling further lampenflora growth

Preventive measures to reduce further growth of lampenflora can be divided into four main areas:

- Shortening the light exposure time
- Reducing the light intensity
- Using lights with specific wave-length (experiments using germicidal lamps are conducted lately e.g. in *Grotta Gigante* in Italy)
- Removing all contamination which supports growth of lampenflora from the cave and preventing its further contamination.

Reducing light exposure time is the most effective preventive measure. It affects all autotrophic plants diminishing their development. The measure can be implemented by modifying the illumination circuits connections and control so as to shorten an operation time in specific parts of the cave. It might be advantageous to divide the cave illumination:

1st circuit – lights at the tourist route (pavements) for safe visitors´ passage

2nd circuit – distinctive illumination to emphasize special formations and to be switched on only during limited period when visitors pass or stop nearby.

Each of these circuits must have a separate control unit; the second circuit should be furnished by infrared (or similar) sensors reacting to movement.

To reduce light intensity just remove strong (namely halogen) spotlights from prominent positions and replace them with less powerful ones (for example LED), obviously with respect to visitors safety.

5. Removing lampenflora with sodium hypochlorite

When applying hypochlorite to lampenflora growths, a fast oxidation process occurs, resulting in extinction and bleaching of the patch. Both agents decompose quickly (5 minutes – 12 hours) in contact with organic substances. During decomposition, gas chlorine is released and might cause incitation of more sensitive persons. Actual concentration of chlorine in the air is still in fact very low.

In an alkaline environment oxidation occurs according to the following equation

$$ClO^- + H_2O + 2e^- = C^- + 2\ OH^-$$

Degree of oxidation abilities is expressed by a high value of the standard redox-potential $E^o = 0.89$ V (Gažo et al. 1974). The whole oxidation process of biomass with formal stoichiometric composition $(CH_2O)_n$ can be expressed by the following summarizing equation

$$(CH_2O)_n + 2n\ ClO^- = n\ CO_2 + 2n\ Cl^- + n\ H_2O$$

The oxidation process produces carbon dioxide, water and chloride ions. Other reactions occur in parallel with the process. In the solution, hypochlorite is completely dissociated to ions

$$NaClO = Na^+ + ClO^-$$

With regards to the fact that hypochlorous acid is a weak acid (pK = 7.47), hypochlorite ions are easily hydrolyzed

$$ClO^- + H_2O = HClO + OH^-$$

Produced hypochlorous acid is unstable and decomposes quickly according to the following equation

$$7\ HClO \rightarrow 3\ Cl_2 + HClO_3 + ½\ O_2 + 3\ H_2O$$ (Faimon et al. 2002)

The effectiveness of this method depends on a) the concentration of hypochlorite (chlorine) in the used solution, b) on the density and type of the plant material, c) on the base at which the lampenflora developed, d) on the amount of trickling water running on the treated surface and last but not least e) on how old is the chemical agent. The effectiveness of 4 % sodium hypochlorite solution in caves in the Moravský kras after one application reached on average 80 % – see Fig 2 and 3.

Fig 2 – Punkevní caves – before application of sodium hypochlorite

Fig 3 – Punkevní caves – after application of sodium hypochlorite

Application of sodium hypochlorite

- Spraying lampenflora growths with sodium hypochlorite solution with 4 % concentration (the concentration may be increased up to 8 % for areas with thick growth)
- Staff must wear protective equipment (rubber boots, rubber gloves, rubber overall with a hood, protective goggles or chemical shield, respirator) – see Fig 1
- Application by using a plastic manual spraying device (small areas) or plastic backpack pump (larger areas) – it is necessary to provide an even humidification of the whole patch
- The application should be performed before the main tourist season starts, still after the end of bats hibernation period; partial and preventive applications can be performed during a daily traffic
- In localities with a sensitive surface (e.g. moonmilk), agents should be tested at a small area of 10 x 10 cm prior to the overall application
- Apply carefully and with a consideration towards the surrounding habitat
- Do not apply during the period of heavy water trickling
- After the application, ensure the best possible ventilation of the released gas chlorine from the cave (e.g. by opening doors)
- In caves with extensive areas of lampenflora patches and insufficient ventilation, the application zone should be split up into several smaller areas to be mended within a range of several consecutive weeks rather than applying to the whole cave in one go
- Do not allow tourists into the cave for at least 12 hours after the application
- Check the treated areas in 2 to 5 days after the application and spray once more surviving plants – repeat until the whole growth is removed (approximately 2–3 times)
- Residues of dead lampenflora should be removed after approximately 14 days by spraying with water (best by water from The Cave).

Information about the composition of sodium hypochlorite, its risk hazards, first aid principles, storing, etc. is included in the Safety Sheet processed in accordance with the Regulation (EC) No. 1907/2006 (REACH) – see annex No. 1. This safety sheet can be obtained when purchasing the agent or on the internet.

6. Removing lampenflora, organic sedimentation and mold layers using hydrogen peroxide

As already stated above, the use of hydrogen peroxide (H_2O_2) is much friendlier towards cave habitat but achieved results are far from those of hypochlorite compounds. Tests proved the lowest still effective concentration of H_2O_2 appears 10 %. Actually 15 % solution of H_2O_2 has been applied. The effectiveness of hydrogen peroxide is sufficient for removing molds; in case of moss and algae the application must be repeated and results are not guaranteed.

Oxidation properties of H_2O_2 in an alkaline environment are expressed by the following equation

$$HO^{-}2 + H_2O + 2e^{-} = 3\ OH^{-}$$

The value of standard redox-potential Eo = +0.88 V (Gažo et al. 1974) indicates similar oxidation properties as those of hypochlorite. The whole oxidation process of biomass by hydrogen peroxide can be expressed by the following equation

$$(CH_2O)_n + 2n\ HO_2^{-} = n\ CO_2 + n\ H_2O + 2n\ OH^{-}$$

This process does not produce any unnatural by-products burdening the environment. Only water and the equivalent amount of CO_2 are released. (Faimon et al. 2002)

Application of hydrogen peroxide

- Spraying lampenflora patches with hydrogen peroxide solution of 15 % concentration
- Ten hours before applying hydrogen peroxide, preliminary carbonation of the solution by calcite (limestone) is recommended – (Faimon et al. 2002)
- The personnel must be equipped with protective equipment (rubber boots, rubber gloves, rubber overall with a hood, protective goggles or chemical shield, respirator) – see Fig 1
- Application by plastic manual spraying device (small areas) or plastic backpack pump (larger areas) – it is necessary to provide an even humidification of the whole patch
- To be applied out of bats hibernation period
- In localities with a sensitive surface (e.g. moonmilk), agents should be tested at a small area of 10 x 10 cm prior to the overall application
- Apply carefully and with a consideration towards the surrounding habitat
- Do not apply during the period of heavy water trickling
- Do not allow tourists into the cave for at least 4 hours after the application

- Check the treated areas in 2 to 5 days after the application and spray once more surviving plants – repeat until the whole growth is removed (approximately 4–6 times)
- Residues of dead lampenflora should be removed after approximately 14 days by spraying with water (best by water from The Cave).

Information about the composition of hydrogen peroxide, its risk hazards, first aid principles, storing, etc. is included in the Safety Sheet processed in accordance with the Regulation (EC) No. 1907/2006 (REACH) – see annex No. 2. This safety sheet can be obtained when purchasing the agent or on the internet.

Before application

7. Cave care in the following years

- Lampenflora re-appearing after the treatment should be removed in the same way, i.e. by spraying
- Areas where lampenflora growths have been removed need to be monitored for several years and possible re-appearances of lampenflora must be treated immediately (implement the system of quarterly cave inspections to check the re-appearance of lampenflora growths)
- Implement by and by preventive measures described in chapter 4 to check spontaneous further expansion of lampenflora.

After application

8. Conclusion

Thirty years of experience with the application of hypochlorite compounds in four show caves of the Moravský kras indicate the method along with preventive measures provides a satisfactory solution. However, the approach to this problem must be complex. The chemical method can remove the existing lampenflora growth, but due to its low long-term effectiveness given by quick decomposition of hypochlorite substances, the growth re-appears soon. This growth can be stopped by repeated treatment and prevention. In any case spraying cannot be repeated ad infinitum. This opinion does not follow any obvious risks related to ingestion of hypochlorite. It follows a generally accepted opinion that each foreign substance introduced into the cave environment might have long-term effects that may not be visible immediately. For this reason, it is important to implement preventive measures that are more acceptable and suitable in terms of the ecological and economical aspect.

Hydrogen peroxide is suitable for removing molds and organic sedimentation. However, the results for moss and algae are ambiguous and therefore the use of hydrogen peroxide is not recommended..

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Photos from the Sloup-Šošůka Caves (2001) are on the front and back covers.

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