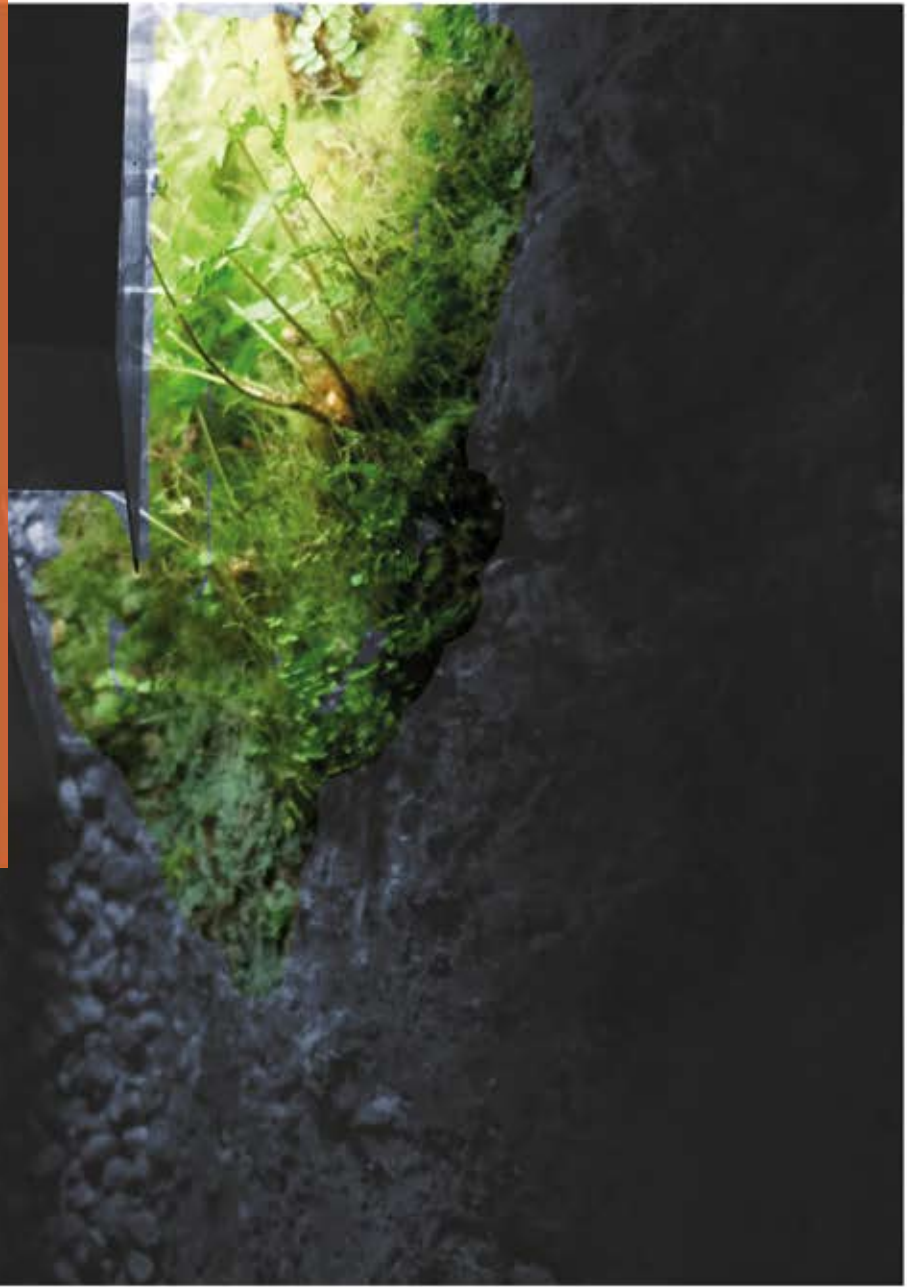


LAMPEN FLORA IN SHOW CAVES



SPECIALIST REPORT LAMPENFLORA
DEFINITION, DEVELOPMENT AND
PREVENTION



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ABSTRACT

AS LONG AS THERE ARE ARTIFICIALLY ILLUMINATED SHOW CAVES, THERE WILL ALWAYS BE THE SO-CALLED LAMPENFLORA, ALSO KNOWN AS LAMP FLORA. THOUGH THE UNDESIRABLE GROWTH OF ALGAE, MOSSES AND FERNS IN ILLUMINATED AREAS CAN BE REDUCED TO SOME EXTENT WITH MODERN LED TECHNOLOGY, PRECISE ALIGNMENT OF THE LUMINAIRES, AVAILABLE SWITCH OPTIONS AND ILLUMINATION TIME ADJUSTMENT ETC., A COMPREHENSIVE SOLUTION TO THE PROBLEM HAS NOT BEEN FOUND YET.

AT FIRST, RESEARCH FOCUSED ON MANUAL OR CHEMICAL REMOVAL OF LAMPENFLORA. LATER, IT FOCUSED ON FINDING OUT WHICH WAVELENGTHS ARE REQUIRED FOR PHOTOSYNTHESIS. TODAY, A SHOW CAVE IS REGARDED AS AN OVERALL HABITAT (BIOTOPE) IN NEED OF PROTECTION.

ULTIMATELY, THERE ARE HARDLY ANY LEDS AVAILABLE ON THE MARKET WHICH COMPLETELY AVOID THE GROWTH OF LAMPENFLORA. AS SOON AS ARTIFICIAL LIGHT ENTERS AN ORIGINALLY COMPLETELY DARK AND RATHER NUTRIENT-POOR HABITAT, THE ENVIRONMENTAL CONDITIONS WITHIN THE CAVE CHANGE AND LAMPENFLORA BEGINS TO GROW IN ILLUMINATED AREAS.



IN THE FOLLOWING, WE WILL SHOW HOW LAMPENFLORA DEVELOPS AND HOW IT CAN BE REDUCED.

DEFINITION & DEVELOPMENT

DEFINITION

“LAMPENFLORA” DESIGNATES THE TOTALITY OF ALL AUTOTROPHIC PLANTS (SOME BACTERIA AS WELL AS ALGAE, MOSSES AND FERNS) OCCURRING IN PROXIMITY TO PERMANENTLY INSTALLED LIGHT SOURCES IN CAVES AND MINING GALLERIES.

THE TERM “LAMPENFLORA” WAS COINED BY KLAUS DOBRANT (UNIVERSITY OF TÜBINGEN, 1963) WHO WROTE THE FIRST SCIENTIFIC WORK ON THIS TOPIC. ALREADY IN 1922, THE AUSTRIANS KYRLE AND MORTON DESCRIBED THE PHENOMENON OF PLANT GROWTH IN SHOW CAVES.

BEING HETEROTROPHIC ORGANISMS AND LIVING ON NUTRIENTS SUCH AS WOOD, LEAVES, FOOD ETC., FUNGI ARE NOT CLASSIFIED AS LAMPENFLORA. THE FLORA OCCURRING NEAR THE ENTRANCE OF A CAVE IS GENERATED THROUGH SUNLIGHT AND HAS NOTHING TO DO WITH LAMPENFLORA.

WHAT CAUSES LAMPENFLORA?

AUTOTROPHY (AUTO = SELF, TROPH = NUTRITION) IS THE CAPABILITY OF ORGANISMS TO PRODUCE THEIR COMPOUNDS (AND ORGANIC RESERVES) EXCLUSIVELY FROM INORGANIC SUBSTANCES, GENERALLY USING HEAT OR LIGHT AS A SOURCE OF ENERGY.

IN SHOW CAVES THIS ENERGY IS GENERATED BY ARTIFICIAL LIGHT, WHICH ALLOWS LAMPENFLORA TO GROW.

BUT ALSO THE CO₂ CONTENT OF THE CAVE AIR AS WELL AS MINERALS IN THE CAVE SOIL OR NITROGEN IN THE CAVERN WATER (E.G. BY FERTILIZERS USED ON FIELDS AND MEADOWS ABOVE THE CAVE) MAY LEAD TO A CORRESPONDING INCREASE, ESPECIALLY FOR GREEN AND BLUE ALGAE.

LAMPENFLORA

SUFFICIENT LIGHT AND MOISTURE AS WELL AS GERMS, SEEDS OR SPORES ARE A PRECONDITION FOR THE FORMATION AND DEVELOPMENT OF LAMPENFLORA. THEY ARE TRANSFERRED BY WATER, AIR, ANIMALS AND PRIMARILY BY VISITORS TO THE CAVE.

INITIALLY, BLUE-GREEN ALGAE AND DIATOMS GROW WITH BLUE-BLACK, GREEN OR BROWN COATINGS. HERE, PRIMARILY CYANOBACTERIA (ALEY 2004) PLAY A DECISIVE ROLE. IN THE ADVANCED STAGES, MOSSES AND FERNS DEVELOP, SIMILAR TO THOSE FOUND NEAR THE ENTRANCE AREA.

LAMPENFLORA IS NOT AN ENRICHMENT TO A CAVE. AT HIGH ILLUMINANCE LEVELS OR IN CASE OF HIGH VISITOR NUMBERS AND CONSTANT LIGHTING, LAMPENFLORA MAY HAVE A NEGATIVE IMPACT ON THE APPEARANCE OF THE SHOW CAVE (DRIP STONES AND SINTER AREAS). FURTHERMORE, LAMPENFLORA MAY DESTROY CAVE PAINTINGS AND IS THEREFORE ABSOLUTELY UNDESIRABLE.



AFTER CONVERSION TO LED AND IN ORDER TO EXPLAIN THE PROBLEM OF “LAMPENFLORA” TO THE VISITORS AS WELL AS FOR DEMONSTRATION PURPOSES, A LOT OF CAVE OPERATORS LEAVE THE OLD ILLUMINATION IN ONE PLACE OF THE CAVE (STURMANNSHÖHLE, CHARLOTTENHÖHLE ETC.). ON THE WHOLE, CAVE OPERATORS WOULD LIKE TO AVOID LAMPENFLORA BECAUSE THE GROWTH OF ALGAE ETC. IMPAIRS THE ATTRACTIVENESS OF THE CAVE.

PHOTOAUTOTROPHISM

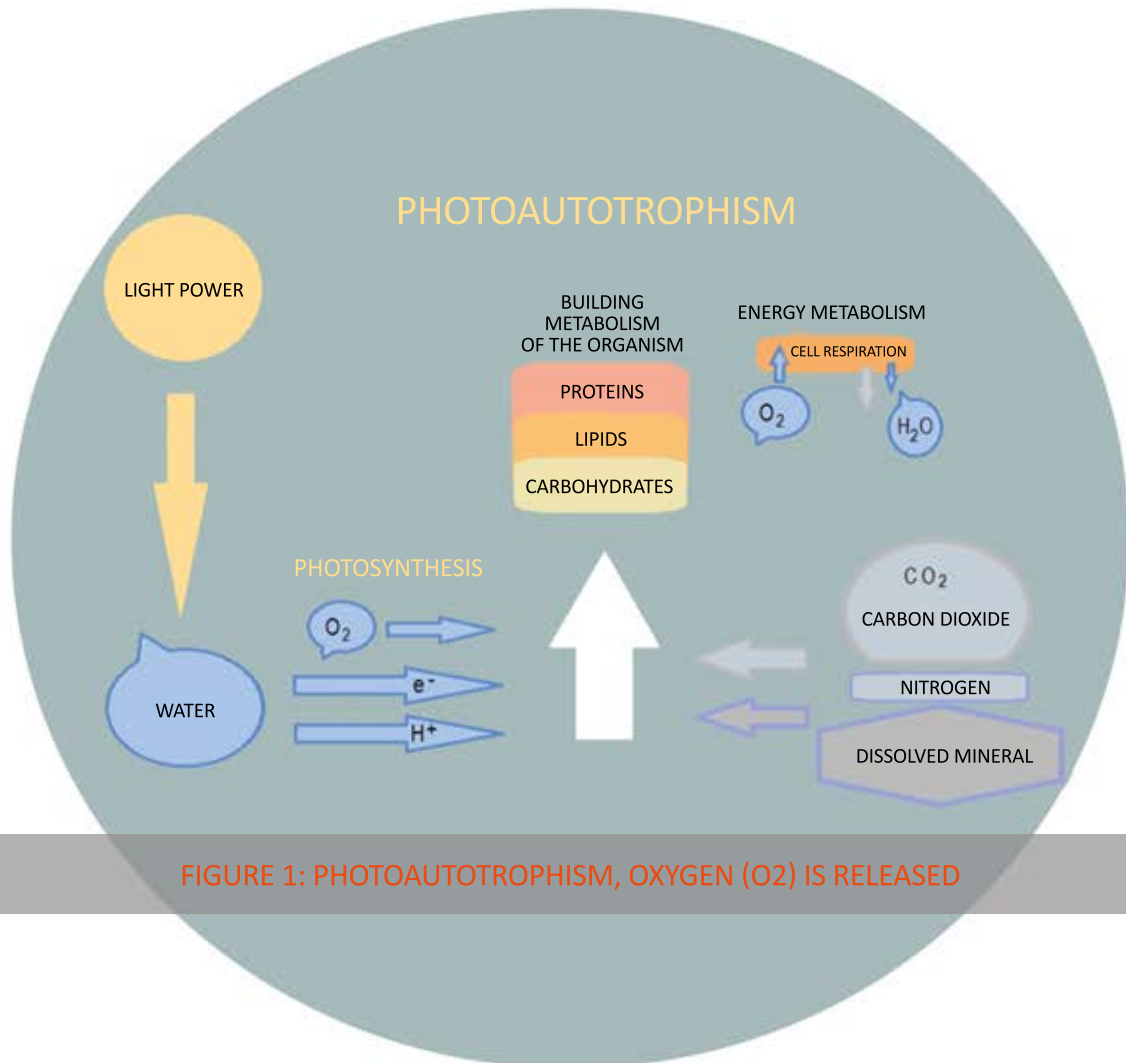


FIGURE 1: PHOTOAUTOTROPHISM, OXYGEN (O₂) IS RELEASED

PLANTS ARE AUTOTROPHIC ORGANISMS USING PHOTOSYNTHESIS. THEY USE THE ARTIFICIAL LIGHT OF A CAVE ILLUMINATION AS AN ENERGY SOURCE (PHOTOAUTOTROPHISM). A LOT OF ORGANISMS, IN PARTICULAR BACTERIA, CAN ALSO USE CHEMICAL SUBSTANCE CONVERSIONS AS ENERGY SOURCES (CHEMOAUTOTROPHISM).

HETEROTROPHY EVOLVED ON THE BASIS OF BIOMASS PRODUCTION BY AUTOTROPHIC ORGANISMS. HETEROTROPHIC ORGANISMS USE ORGANIC COMPOUNDS TO MANUFACTURE THEIR OWN NUTRIENTS. ANIMALS, FUNGI, MANY BACTERIA AND ARCHAEA (PRIMORDIAL BACTERIA) ARE HETEROTROPHIC ORGANISMS. EITHER THEY SUBSIST AS CONSUMERS OR THEY ARE REMINERALIZERS, I.E. THEY CONVERT ORGANIC SUBSTANCES INTO INORGANIC SUBSTANCES.

MICROBES AND BACTERIA

THE TOPIC OF BACTERIA AND MICROBES WITHIN CAVES IS HIGHLY COMPLEX: RESEARCH RESULTS ARE MOSTLY LIMITED TO A FEW INVESTIGATIONS CARRIED OUT IN THE RESPECTIVE CAVE AND ARE AS A WHOLE VERY DNA-BASED. OVERALL, IT IS VERY DIFFICULT TO MAKE GENERAL STATEMENTS ON SHOW CAVES IN THIS CONTEXT BECAUSE EACH CAVE MAY HAVE DIFFERENT ENVIRONMENTAL CONDITIONS, E. G. IN TERMS OF MOISTURE AND TEMPERATURE WHICH ARE ALSO DECISIVE FACTORS.

IT IS A FACT THAT BACTERIA AND MICROBES DO NOT REQUIRE LIGHT FOR GROWTH: THEY PARTLY SUBSIST ON ROCK(S) OR THEY SURVIVE BY CONVERTING CO₂ FROM CARBONATE, IRON, MANGANESE AND PHOSPHORUS EVEN IN REGIONS UP TO 5 KM BELOW GROUND.

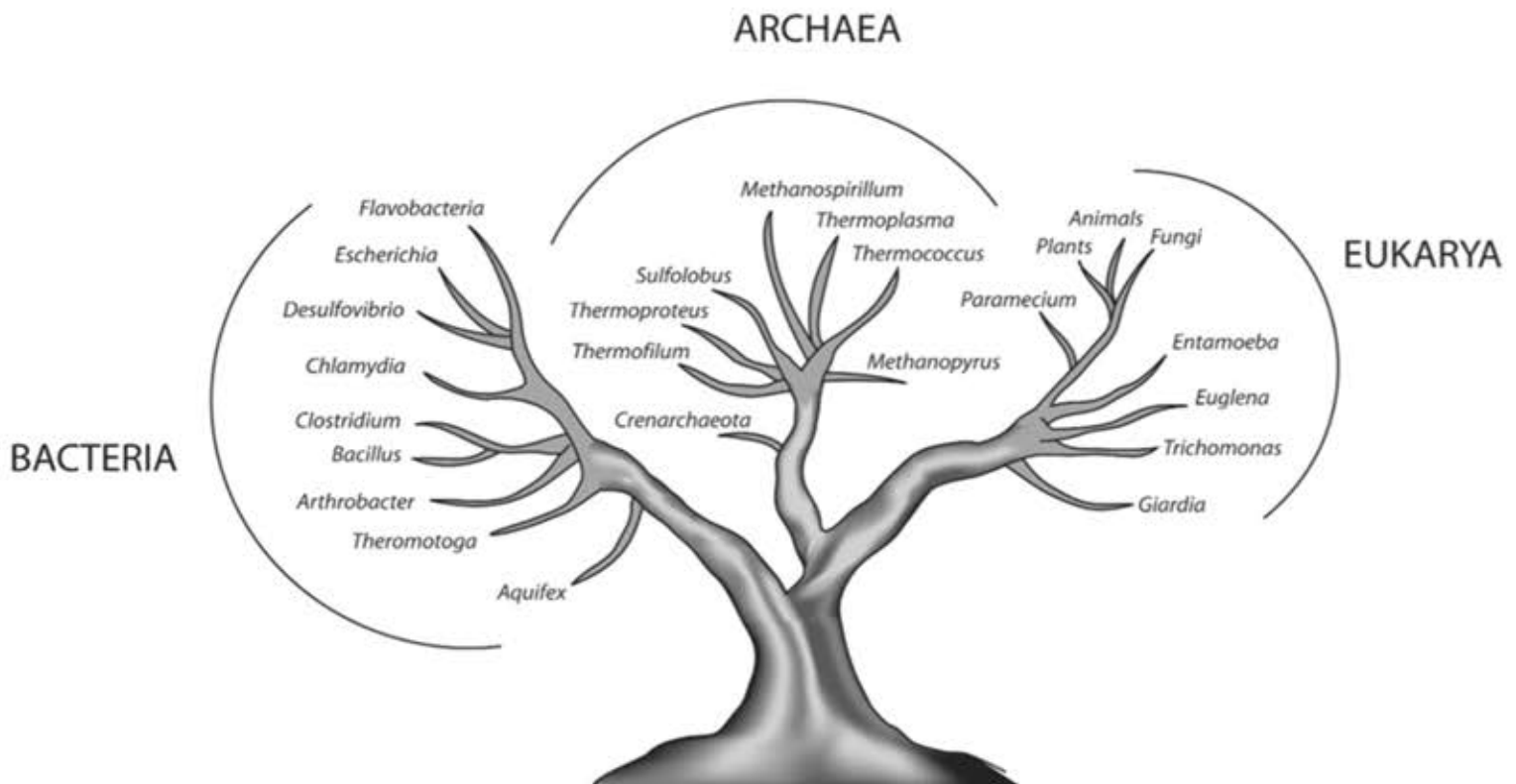


FIGURE 3: THE TREE OF "LIFE" ACCORDING TO WOESE AND FOX (1977), FURTHER DEVELOPED BY PACE (1997). THE TREE IS BASED ON THE "ROOT" OR ON THE LAST COMMON ANCESTOR OF LIFE. IT IS DIVIDED INTO THREE MAIN DOMAINS OF LIFE: BACTERIA, ARCHAEABACTERIA AND EUKARYA (CELLS WITH NUCLEUS).

MICROBES AND BACTERIA

IN CONTRAST TO NON-TOURISTIC CAVES AND DUE TO HUMAN INTERVENTION, THERE ARE MANY MICROBES SUCH AS BACTERIA FOUND IN SHOW CAVES, ESPECIALLY ON AND NEAR PATHS AND NEAR LIGHTING FIXTURES.



LAMPENFLORA IN THE AREA OF GUIDE PATHS AND LIGHTING

APART FROM A FEW EUROPEAN, AUSTRALIAN AND CHINESE INSTITUTES, THE KARST INSTITUTE IN POSTOJNA, IN COOPERATION WITH MAMMOTH CAVE IN THE UNITED STATES, PLAYS A LEADING ROLE WORLDWIDE IN THE FIELD OF LAMPENFLORA AND BACTERIA. IN GENERAL, NEW FINDINGS (MULKEC AT AL., 2008, 2009, 2010, 2012) FIRST POINTED TOWARDS THE ILLUMINATION SPECTRUM (YELLOW, AMBER, ORANGE) IN ORDER TO AVOID THE GROWTH OF LAMPENFLORA ENTIRELY, OR, AS PREVIOUSLY, TOWARDS ADVISING HOW TO REMOVE LAMPENFLORA (GENTLY, BUT EFFICIENTLY). IN THIS CONTEXT, THE BIOLOGY OF THE CAVE TO BE PROTECTED WAS MENTIONED, BUT IT WAS NOT CONSIDERED IN THE STUDIES - FOR THIS, CAVE BIOLOGISTS (BIOSPELEOLOGISTS) WOULD BE NEEDED.

THE FULL COMPLEXITY OF THE TOPIC OF BACTERIA AND MICROBES IS CLEARLY ILLUSTRATED IN THE GRAPHIC ABOVE. THIS MEANS THAT LIFE IN CAVES, IN WHATEVER FORM, IS GIVEN BY NATURE. HOWEVER, THE PHENOMENON OF LAMPENFLORA IS EXCLUSIVELY CAUSED BY ARTIFICIAL LIGHT INFLUX.

PHOTOSYNTHESIS AS SOURCE OF LAMPENFLORA

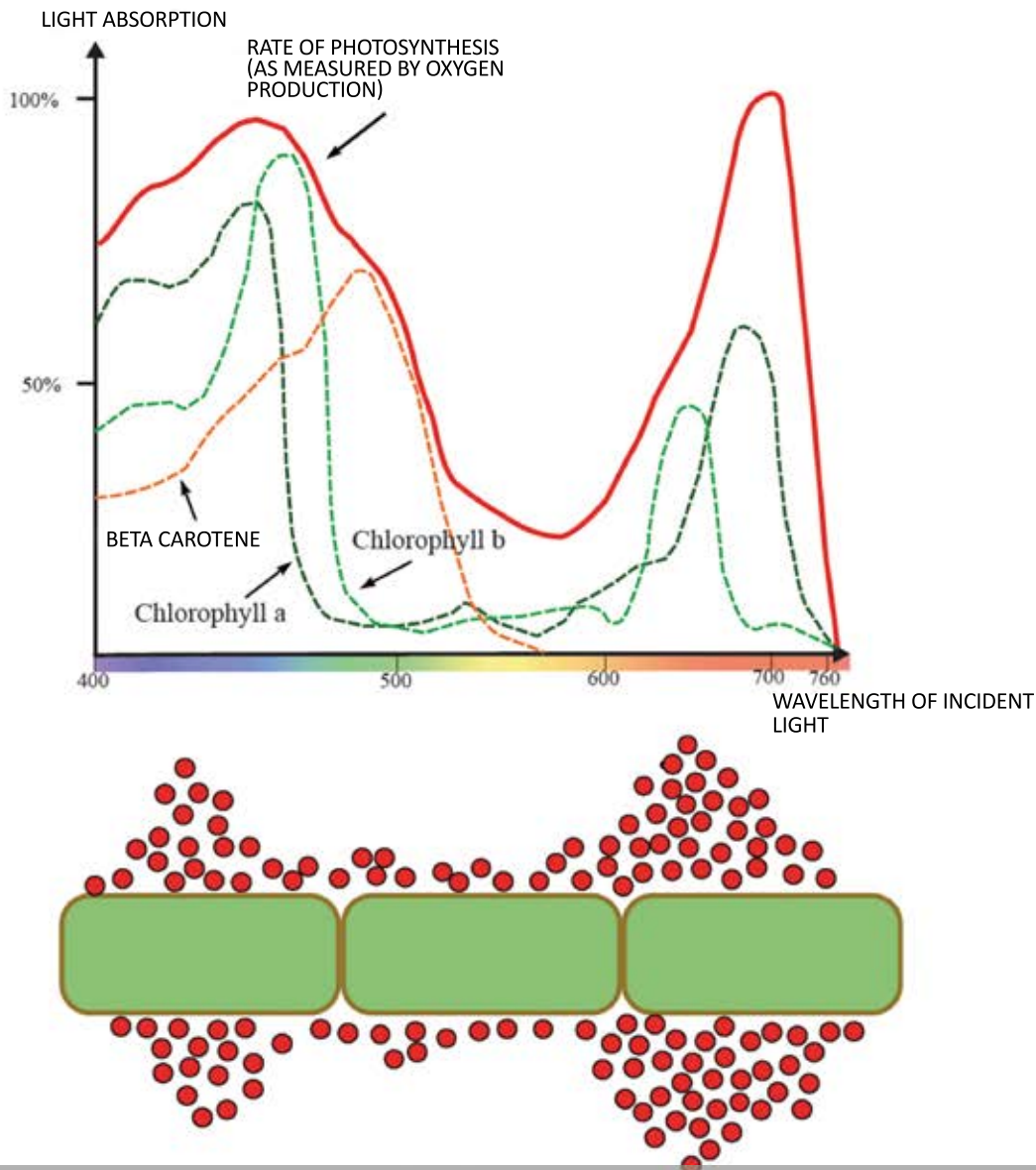


FIGURE 4: ENGELMANN'S BACTERIAL EXPERIMENT

ENGELMANN'S BACTERIAL EXPERIMENT CLEARLY SHOWS THE EFFECTS OF DIFFERENT WAVELENGTHS (COLORS) OF LIGHT (NM) ON PHOTOSYNTHETIC ACTIVITY/THE RATE OF PHOTOSYNTHESIS AS MEASURED BY THE PRODUCTION OF OXYGEN IN RELATION TO BACTERIAL GROWTH. IT IS THUS SHOWN THAT, DUE TO ARTIFICIAL LIGHT IN SHOW CAVES, BACTERIA MULTIPLY TO FORM LAMPENFLORA. DECISIVE FACTORS IN THIS RESPECT ARE BETA CAROTENE, CHLOROPHYLL A AND B.

ROUGHLY SPEAKING, BACTERIAL GROWTH IS THE LOWEST BETWEEN 500NM AND 600NM. THIS CORRESPONDS TO A LIGHT COLOUR BETWEEN GREEN AND ORANGE. HOWEVER, A DECISIVE FACTOR FOR THE GROWTH OF LAMPENFLORA ARE ALSO THE TWO PEAKS BETWEEN 430 AND 470NM (BLUE) AND BETWEEN 600 AND 650NM (ORANGE/RED).

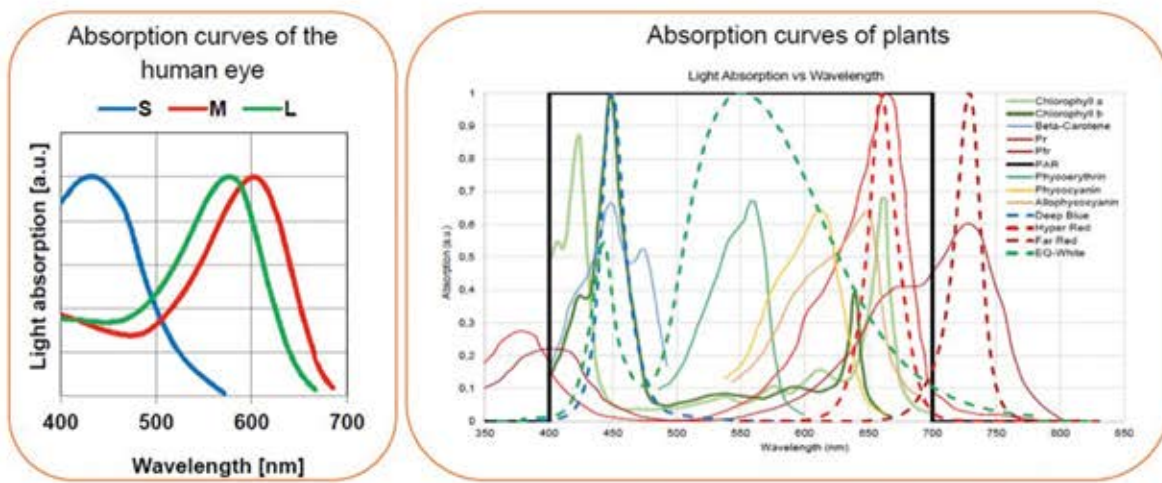


FIGURE 6.: ABSORPTION CURVES OF THE HUMAN EYE AND OF PLANTS

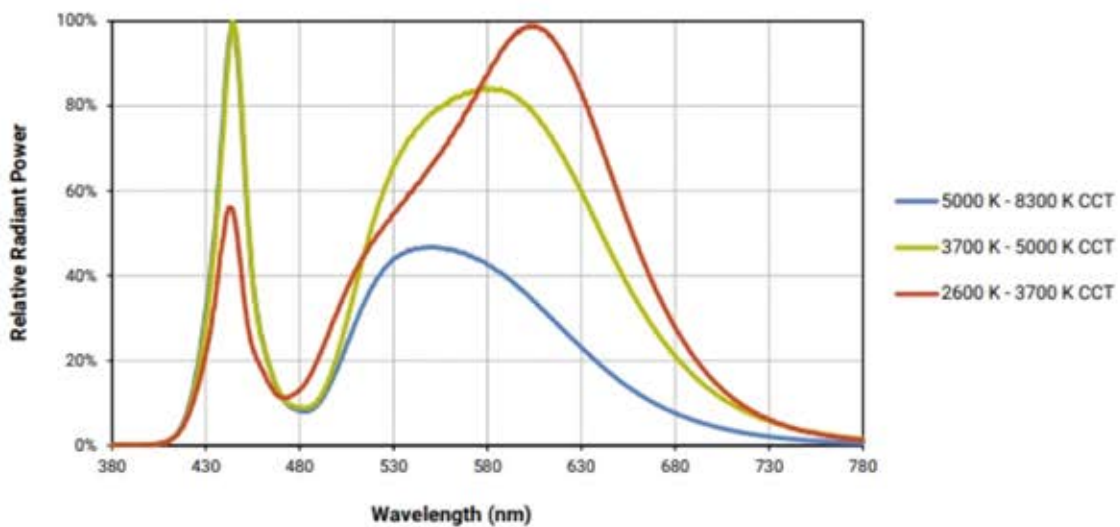


FIGURE 5.: RELATIVE SPECTRAL POWER CURVE BY CAVE LIGHTING LEDs (CREE XPG2)

FLOWERING PLANTS, FERNS, MOSSES AND ALGAE ESSENTIALLY NEED LIGHT TO GROW. DURING PHOTOSYNTHESIS THEY ABSORB LIGHT ENERGY, TRANSFORM CARBON DIOXIDE FROM THE AIR AND MINERALS FROM THE SOIL INTO ORGANIC COMPOUNDS SUCH AS SUGAR/GLUCOSE AND STARCH.

THUS, ORGANIC COMPOUNDS ARE STORED LIGHT ENERGY AND ALWAYS CONTAIN CARBON DIOXIDE.

GREEN PLANTS CAN ONLY SURVIVE INSIDE A CAVE FOR AS LONG AS THEY HAVE SUFFICIENT LIGHT. THEY ENCROACH INTO THE CAVE TO A DEPTH THAT CORRELATES WITH THEIR SPECIFIC MINIMUM LIGHT REQUIREMENTS. HOWEVER, SPORES ARE ALSO CARRIED FAR INTO THE SHOW CAVE BY VISITORS WALKING ALONG THE FOOTPATHS.

EACH OF THE FOUR GROUPS OF PLANTS LISTED BELOW REQUIRES A SPECIFIC AMOUNT OF LIGHT:

1/200
OF DAYLIGHT
**FLOWERING
PLANTS**

1/300
OF DAYLIGHT
FERNS

1/20000
OF DAYLIGHT
ALGAE

**DIFFERENTLY
VERY
UNDEMANDING
ORGANISMS
MOSSES**

OUTLOOK AND RECOMMENDATIONS

LAMPENFLORA AND THUS VISIBLE ALGAE, CYANOBACTERIA (BLUE-GREEN ALGAE), MOSSES AND FERNS ARE ALWAYS CAUSED BY ARTIFICIAL LIGHTING IN SHOW CAVES.

ALREADY STUDIES FROM THE 1980S PURSUED TWO OBJECTIVES ON THE LEVEL OF LIGHT MANAGEMENT OF A SHOW CAVE:

- ✓ REDUCTION OF LIGHT INTENSITY AND ILLUMINATION DURATION
- ✓ REMOVAL OF LAMPENFLORA BY MECHANIC OR CHEMICAL MEANS



THE REMOVAL OF LAMPENFLORA BY CHEMICAL MEANS IMPLIES CERTAIN CONSEQUENCES FOR THE CAVE BIOTOPE AND IS NOT RECOMMENDED DUE TO UNKNOWN EFFECTS.

IN PRACTICE, HOWEVER, CHEMICAL MEANS ARE STILL OFTEN USED, ESPECIALLY IN SHOW CAVES WITH HIGH VISITOR NUMBERS, LONG OPENING HOURS AND CORRESPONDING LONG ILLUMINATION TIMES.

RED AND BLUE LIGHT COMPONENTS PROMOTE THE GROWTH OF LAMPENFLORA. HOWEVER, THE LIGHT COLOURS YELLOW OR ORANGE RECOMMENDED BY SEVERAL KARST INSTITUTES AS WELL AS “AMBER” ARE NOT ADVISABLE EITHER BECAUSE THEY DO NOT MAKE A CAVE VISUALLY ATTRACTIVE TO VISITORS. IN ADDITION, THE BEAUTIES OF THE CAVE SUCH AS DRIPSTONES AND FLOWSTONE DRAPERIES ARE NO LONGER CLEARLY VISIBLE.

OUTLOOK AND RECOMMENDATIONS

THESE DAYS SHOW CAVES ARE MANAGED IN A MORE ENVIRONMENTALLY FRIENDLY MANNER OVERALL, ESPECIALLY WHEN IT COMES TO DIRT PARTICLES CARRIED INTO THE CAVE BY VISITORS, LED ILLUMINATION (ENERGY SAVING), ILLUMINATION DURATION, LIGHT INTENSITY AND TOUR PROCEDURE.

THE PROTECTIVE COVERS (TARPAULINS) IN GERMANY'S NEWEST SHOW CAVE (HERBSTLABYRINTH IN BREITSCHIED), WHICH HAVE BEEN FIXED BENEATH THE GRATES OF THE PATHWAYS, ARE A PERFECT EXAMPLE THAT IS LITTLE NOTICED.

SOLUTIONS NEED TO BE THOUGHT ABOUT FOR HOW TO PREVENT WASTE WATER FROM THE NECESSARY CLEANING OF THE TOUR PATH FROM ENTERING THE CAVE BECAUSE MOST OF THE BACTERIA AND GERMS BROUGHT IN BY VISITORS ARE TO BE FOUND ON THIS PATH. CONSIDERATION SHOULD ALSO BE GIVEN TO THE AIR EXCHANGE OF A CAVE AND TO THE HEAT OUTPUT OF A LAMP.

A LOT OF FACTORS PROVIDE FAVORABLE CONDITIONS FOR THE GROWTH OF LAMPENFLORA AND EACH SHOW CAVE IS DIFFERENT IN TERMS OF VISITOR NUMBERS, ILLUMINATION DURATION, TEMPERATURE, CO₂ CONTENT, ILLUMINATION INSTALLATION AND CAVE MANAGEMENT.



OUTLOOK AND RECOMMENDATIONS



TO ILLUMINATE A CAVE IN SCIENTIFICALLY RECOMMENDED LIGHT COLORS DOES NOT MAKE IT SO MUCH MORE ATTRACTIVE AND IT PROMOTES THE GROWTH OF OTHER BACTERIA AND ALGAE. THUS, THE PERCENTAGE OF ALGAE, BACTERIA AND MOSSES IS ONLY SHIFTED AND THE REAL PROBLEM IS NOT SOLVED, EVEN IF THE QUANTITY AND EXPANSION OF LAMPENFLORA AND UNDESIRED VEGETATION GROWTH CAN THUS SIGNIFICANTLY BE REDUCED.

THANKS TO MODERN LED TECHNOLOGY COMBINED WITH GOOD CAVE MANAGEMENT REGARDING ILLUMINATION DURATION AND LIGHT INTENSITY, THE GROWTH OF LAMPENFLORA CAN BE CONSIDERABLY REDUCED. IN REALITY, HOWEVER, LAMPENFLORA WILL CONTINUE TO FORM/GROW, BUT IT CAN BE DECREASED IF THESE TWO IMPORTANT FACTORS ARE TAKEN INTO ACCOUNT.

IMPORTANT MEASURES FOR AVOIDING LAMPENFLORA

CONSEQUENTLY, THE FOLLOWING CRITERIA FOR REINSTALLATION OR CONVERSION TO LED TECHNOLOGY IN SHOW CAVES AND MINING GALLERIES SHOULD BE STRICTLY RESPECTED.

- ✓ REDUCTION OF LIGHT INTENSITY (E.G. BY MEANS OF CONTINUOUSLY ADJUSTABLE LED ILLUMINATION)
- ✓ REDUCTION OF TOTAL ILLUMINATION DURATION. LIGHT SHOULD ONLY BE SWITCHED ON WHERE VISITORS MAY BE
- ✓ SENSITIVE AREAS SHOULD NOT BE ILLUMINATED AT ALL, OR ONLY LOCALLY (LOCAL SWITCHING)
- ✓ DIFFERENTIATION BETWEEN CAVE LIGHT (TO INCREASE ATTRACTIVENESS) AND PATH LIGHTING (SAFETY LIGHTING) IN ORDER TO AVOID EXCESSIVE LIGHTING IN SHOW CAVES
- ✓ DIVIDING THE CAVES INTO ILLUMINATION ZONES CORRESPONDING TO THE GUIDED TOURS
- ✓ CENTRAL CONTROL UNIT FOR LIGHT CONTROL AND MONITORING
- ✓ DISTANCE BETWEEN LIGHTING FIXTURE AND LIGHTING OBJECT SHOULD BE LARGE ENOUGH (2M)

IMPORTANT MEASURES FOR AVOIDING LAMPENFLORA

- ✓ SELECTION OF APPROPRIATE OPTICS WITH LEDS
- ✓ EXPERT LIGHT DESIGN TO AVOID LAMPENFLORA
- ✓ MEANS FOR COLLECTING AND DRAINING CLEANING WATER

- ✓ REGARDING GRATE CONSTRUCTION: DIRT PARTICLE COLLECTION AND SUBSEQUENT CONTAMINATION THROUGH VISITORS CAN BE PREVENTED BY INSTALLING PROTECTIVE COVERS (TARPAULINS) BENEATH THE PATHWAYS AND REGULARLY CLEANING THEM

- ✓ TRAINING OF CAVE GUIDES REGARDING THE ILLUMINATION SYSTEM TO MAKE SURE THAT AVAILABLE SWITCH OPTIONS ARE ACTUALLY USED

- ✓ ENVIRONMENTALLY FRIENDLY REMOVAL OF LAMPENFLORA (A BIOSPELEOLOGICAL EXPERT ADVICE SHOULD BE OBTAINED BEFOREHAND)

RÉSUMÉ



TO A SMALL EXTENT, THERE WILL ALWAYS BE LAMPENFLORA, ESPECIALLY ALGAE, IN SHOW CAVES BECAUSE THEY GROW UNDER ARTIFICIAL LIGHT IN AN OTHERWISE ABSOLUTELY DARK ENVIRONMENT. IT IS TO BE HOPED, HOWEVER, THAT THE POINTS MENTIONED ABOVE WILL BE TAKEN INTO ACCOUNT IN FUTURE MANAGEMENT PLANS, PARTICULARLY WITH REGARD TO ILLUMINANCE AND LIGHTING DURATION. THE AUTHORS' LONG-TERM EXPERIENCE SHOWS THAT THUS NOT ONLY THE EXPANSION OF LAMPENFLORA CAN BE DECISIVELY REDUCED, BUT ALSO THE LIFETIME OF THE ILLUMINATION SYSTEM CAN BE INCREASED.

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