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# Diatom flora in subterranean ecosystems: a review

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**Abstract:** Subterranean ecosystems are often severely oligotrophic settings with low supplies of degradable organic matter from the surface due to a lack of light and primary producers. Intense tourism and recreational caving are the greatest human direct influences on cave ecosystems, which significantly modify the entire subterranean ecology. Exocellular polymeric substances (EPSs), which are made of polysaccharides, proteins, lipids, and nucleic acids, are produced by autotrophic organisms (the so-called lampenflora), which are mostly composed of cyanobacteria, diatoms, chlorophytes, mosses, and ferns. The adsorption of cations and dissolved organic molecules from the cave formations is facilitated by the anionic EPSs matrix, which also participates in chemical interactions with the substratum (speleothems). This effect may cause the mineral surfaces to corrode when combined with the metabolic activities of the heterotrophic bacteria colonizing such layer (biofilm). In this paper, we explore how artificial lighting affects speleothems by causing biofilms to grow, particularly diatom-dominated ones. When artificial or natural light enters the subterranean habitat, a significant number of diatom species may in fact colonize it. The ideal substrates are typically cave openings, artificially lit walls, and speleothems inside the cave. This review summarizes the data found in all the scientific studies published from 1900 to the present and focuses on the diatom flora colonizing subterranean settings.

**Keywords:** Diatom, Cyanobacteria, Indonesia

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## 1. Introduction

Natural sciences (from Earth to biological sciences), medical and engineering sciences, as well as the cultural history of mankind, find in caves an idealized intersection where several fields collide, enriching our knowledge of the past of our planet. In addition to examining unusual and extreme environments, research into the biology of caves is essential to our comprehension of the delicate ecological balances on Earth (Lee et al., 2012).

Subterranean ecosystems frequently have lower levels of diversity and number of creatures than surface ecosystems, and the abiotic conditions in the deeper portions of caves are typically more stable. In the lack of light and primary producers, cave ecosystems are typically quite oligotrophic and receive insufficient amounts of organic materials that can be broken down. Some types of bacteria, fungi, and protozoa rely on inorganic sulfur, ammonium, and ferrous iron compounds as well as other energy sources. Some subterranean microorganisms appear to have acquired the ability to produce specialized chemical compounds, or poisons, in order to fend off competing microbes, as a result of their extended isolation from the surface and the lack of nutrition. This is the case with a collection of chemolitotrophic bacteria that were found by Haak et al. (2002) in the most subterranean area of the Mammoth Cave (Kentucky, USA) and which create a substance with alleged anti-cancer activity.

Viruses, bacteria, fungus, algae, protozoa, plants, and animals of various kinds have been discovered in a variety of underground settings, particularly in caves. pools, boulders, springs, cave walls, or even scattered throughout the air (Culver & Pipan, 2009; Romero, 2009). In general, the coexistence of resident and non-resident creatures (accidentals) defines cave biological communities (Culver & Pipan, 2009). Accidental entry into caves can occur through water, silt, wind, air, spores, or even animals, including men.

Accidentals may have a significant impact on the local "genuine" troglobiont populations, and in the worst-case scenario, they may even displace the native populations and communities, depending on their actions and length of stay in the cave (Saiz-Jimenez, 2010).

## 2. Materials and Methods

The data was obtained through a review of existing literature, mainly peer-reviewed papers, articles and research reports, but also from government reports and assessments and other literature on the world's diatoms. We use this data to analyze lethal tourism waste and categorize it into different levels. Finally, this data will be made into a conclusion in determining the status of diatoms.

## 3. Results

Changes in the natural light gradient caused by human activities in subterranean habitats may have a significant impact on the diversity of biotic groups inside caves. Lampenflora might be classified as invasive in this situation (Mazina & Maximov, 2011). Tourists who visit underground ecosystems are responsible for the transfer of algae, which causes unintended biological pollution and encourages the colonization of bacteria and fungi at the same time (Albertano et al., 2003). As a result, changing the show caves' natural environmental conditions may likewise change the diatom communities. The cave's temperature and CO2 concentration rise as a result of visitors, accelerating wall degradation. The majority of the diatom species discovered in underground systems are global, despite the possibility that these unusual conditions could encourage the colonization of tropical species. Diatoms are mostly introduced into the subsurface environment through air circulation and are often regarded as incidental organisms. Algae are only found in the liminar and subliminal zones under natural conditions, where their quantity is tightly correlated with the availability of light. Despite this, curiosity in the algal "darkflora" peaked in the scientific community in 1950, when it was discovered that numerous algae strains could endure complete darkness. If the cave is illuminated, the cave's size has a significant impact on air flow, which in turn affects the diversity of the diatoms in the deeper areas of the cave. The diversity of diatoms is typically correlated with proximity to the entrance. The richest diatom communities are typically found in caves' liminal and subliminal zones, perhaps as a result of the effect of the environment and its daily and seasonal variations. Although variations in light and humidity are associated to changes in diatom composition and richness, interspecific competition and the role of the substratum cannot be completely disregarded. Light is significant and can be linked to the diversity of the cave population in show caves that are temporarily closed to the public (and consequently dark for several months).

### DIATOM ASSEMBLAGES IN SUBTERRANEAN ENVIRONMENTS: SPECIES COMPOSITION

According to Johansen (1999), the majority of diatom communities found in caves are made up of euaerial and pseudoaerial taxa, which are often distinguished by their small size, great resilience to desiccation, specific pH preferences, tolerance of low nutrient levels, and high conductivity. The majority of these taxa are found in the Navicula s.l. genus. Troglophilic taxa, such as Hantzschia amphioxys and Luticola nivalis (Ehrenberg) D.G. Mann in Round, Crawford, and Mann, are examples of aerophilous diatom flora that can thrive on cave walls in low light conditions. No troglobiont diatom species (obligatory occupants of the subterranean habitats that could not live elsewhere) has ever been documented (Hoffmann, 2002). The pH of the wall surface can affect the species composition of diatoms; acid rocks typically support Eunotia or Pinnularia species (such as P. borealis), whereas alkaline substrates are more likely to support Orthoseira roeseana (Rabenhorst) O'Meara. Diadesmis gallica and Orthoseira roeseana populations can be found in mosses and ferns, although epiphytic diatoms like Hantzschia amphioxys, Luticola mutica, and Pinnularia borealis are also frequently seen.

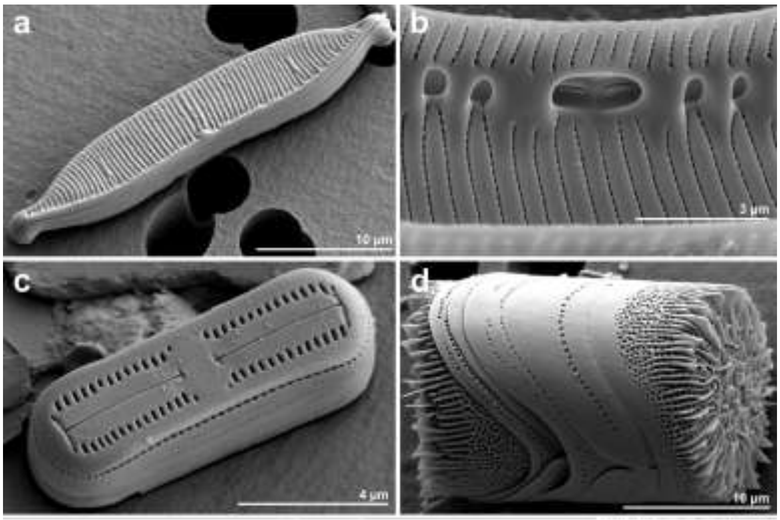


**Fig. 1**. SEM micrographs of common aerophytic diatoms. a-b) Hantzschia amphioxys, external view (a) and internal details of interrupted raphe and fibulae (b). c) Diadesmis contenta, external view. d) Orthoseira roeseana sensu lato, girdle view (d) and inner details of carinoportulae

Amphioxys Hantzschii (Ehrenberg)

Basionym: Ehrenberg's 1843 Eunotia amphioxys

It is one of the most often observed taxa on submerged bryophytes (Germain, 1981; Reichardt, 1985; Van de Vijver & Beyens, 1997) and wet habitats, such as soils and rock crevices. Hantzschia amphioxys is an aerophilous species (Garbacki et al., 1999; Taylor et al., 2007). This species can frequently be found in both arid areas and ad hoc watering holes. In rivers, it is frequently sampled during urgent hydrological circumstances.

Diadesmis satisfied (Grunow ex Van Heurck) Round one: D.G. Mann

Navigational content Grunow ex Van Heurck, 1885

An aerophilous species known as Diadesmis contenta is distinguished by its modest cell size. It exhibits preferences for circumneutral pH, low conductivity, and nutrient content in freshwater settings (Blanco et al., 2010). It is classifiable as a -mesosaprobous, a member of a prestigious guild, mobile, and capable of establishing colonies.

Orthoseira roeseana Rabenhorst 1875

Biological name: Melosira roeseana 1852 Rabenhorst

Orthoseira roeseana is regarded as xerotic and aerophilous. It frequently grows on moist surfaces like wet walls, moist rocks and stones, mosses, and even the wet banks of riparian plants. A 30% record of this species is found in the literature review (Austria, Belgium, Canada, Czech Republic, France, Germany, Hungary, Poland, Spain, Ukraine and USA). Orthoseira roeseana is typically found in the liminar zone of caves, where it is exposed to natural light, however other writers have discovered it on walls with artificial lighting. Additionally, O. roeseana is regarded as native to Lewis and Clark Caverns in Montana, USA, and was not accidentally introduced there (Lauriol et al., 2006).

## 5. Conclusions

The literature reviewed is about subterranean habitats (mostly caves) in 27 different countries, mostly in Europe and North America (Table 1). Over 230 papers were examined. More than 190 of them concern the algal flora inhabiting subterranean systems, with 82 specifically referring to diatoms and providing a list of recorded species. The literature data span a time span of 113 years, from 1900 to 2013 (Figure 3), and provided information on the diatom flora colonizing primarily wet walls in caves, including touristic caves. The scientific community's interest in this subject has grown over the last few decades, particularly in relation to the impact of biofilm in show caves.

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