SUBTERRANEAN ECOSYSTEMS Macroecological and Conservation perspective

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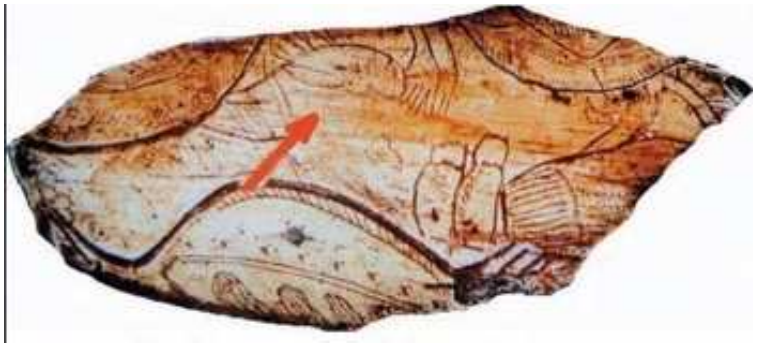
Subterranean environment and human history

- **12.000 B.C. (Magdalenian)**

(*Troglophilus* ou *Dolichopoda)*

Grotte des Trois Frères, Ariège (France)



Bone of *Bos primigenius* (Auroch)

Subterranean environment and human history

- **Greek Mythology**

Rhea “Mouther of Mountains”, gives birth to *Zeus*, in Dicte Cave.

Hades - king of the underworld

Subterranean environment and human history

Japanese Mythology

Amaterasu, the goddess of the sun, hides daily in a cave, circadian rhythm.

Subterranean environment and human history

- **Middle Ages**

Caves were considered the gates of hell, guarded by Cerberus.

Cérbero, William Blake (1757-1827)
National Gallery of Victoria, Australia

Inhabited by fantastic creatures, including dragons, rooted in religious thought.

Draco helveticus, in "Mundus subterraneus" (1678)
Athanasius Kircher

First studies cave biodiversity

Jørgen Matthias Christian **Schiødte**

Prof. Zoological Museum, University of Copenhagen

1839 **“Bidrag til den underjordiske Fauna”**

1851 **“Specimen faunae subterraneae”**


SPECIMEN FAUNÆ SUBTERRANEÆ

Bidrag

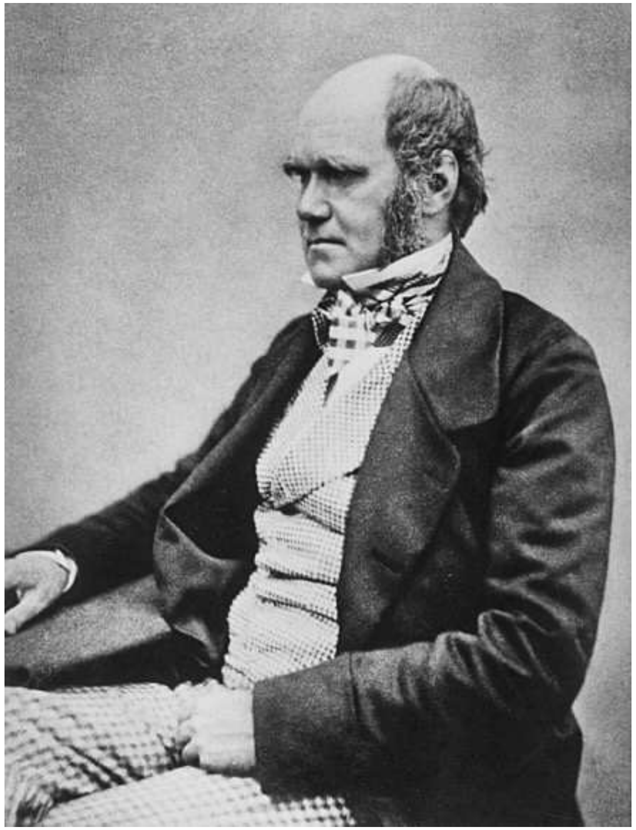
den underjordiske Fauna

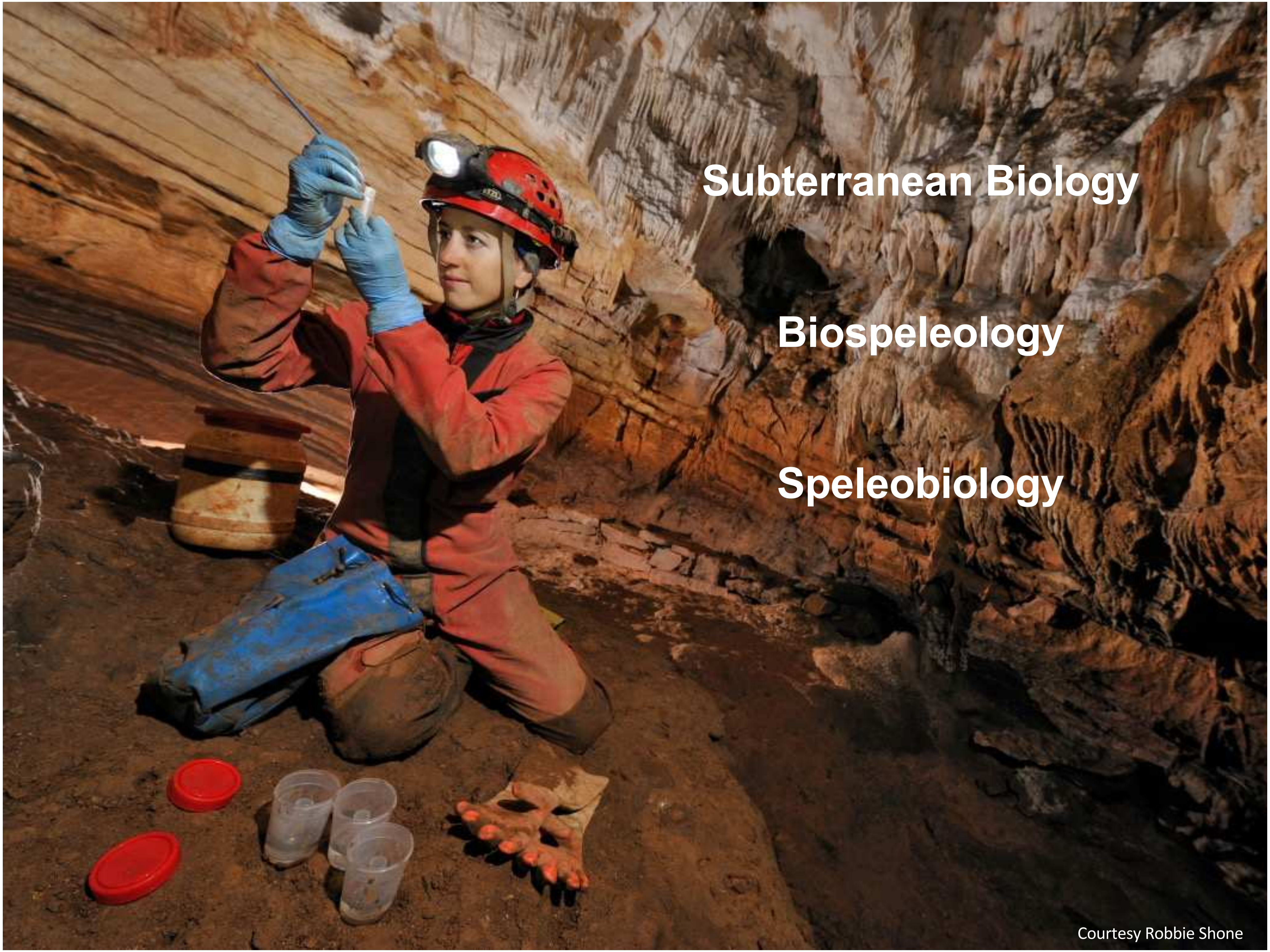
UNIVERSITETETS
ZOOLOGISKE MUSEUM

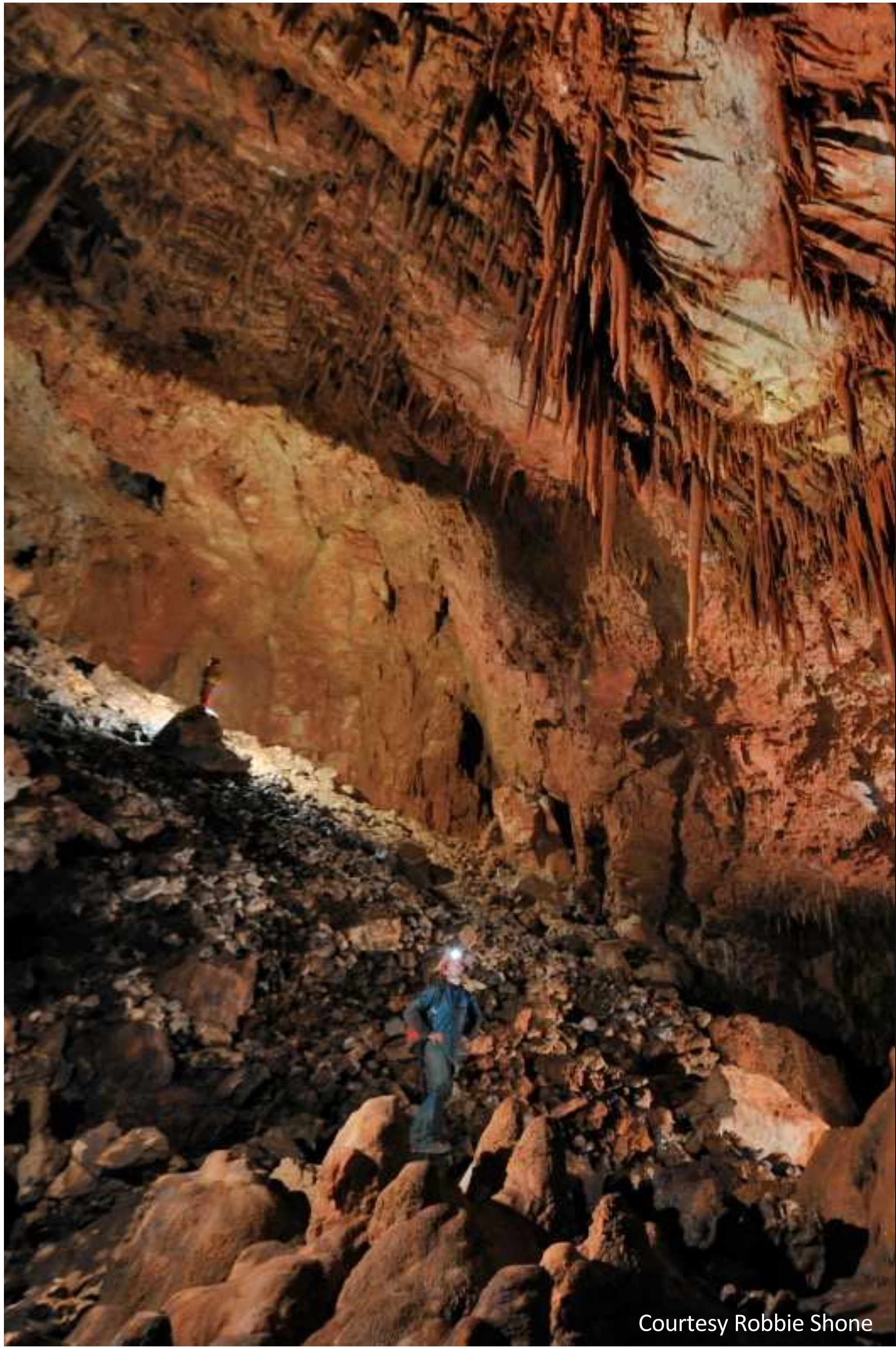
First studies cave biodiversity

"We accordingly look upon the subterranean faunas as small ramifications which have penetrated into the Earth from the geographically limited faunas of the adjacent tracts, and which, as they extended themselves into darkness, have been accommodated to surrounding circumstances. **Animals not far remote from ordinary forms, prepare the transition from light to darkness.** Next follow those that are constructed for twilight; and, last of all, those destined for total darkness, and whose formation is quite peculiar.' **These remarks of Schiodte's it should be understood, apply not to the same, but to distinct species**."

In: Charles Darwin (1859) *On the Origin of Species*.



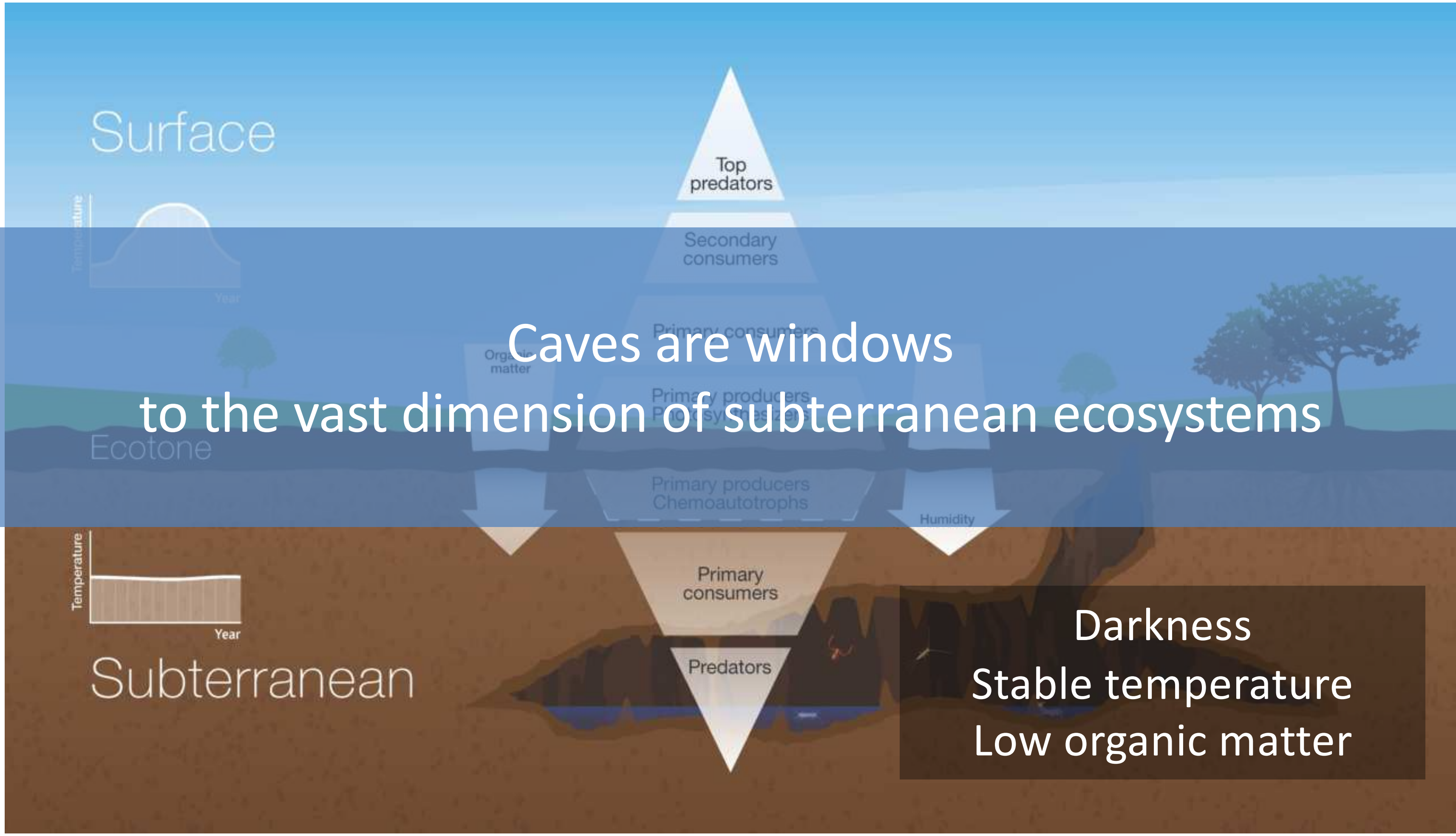

Subterranean Biology
Biospeleology
Speleobiology
Courtesy Robbie Shone



Courtesy Robbie Shone

Courtesy Jean-Paul Sounier

Subterranean vs. surface ecosystems

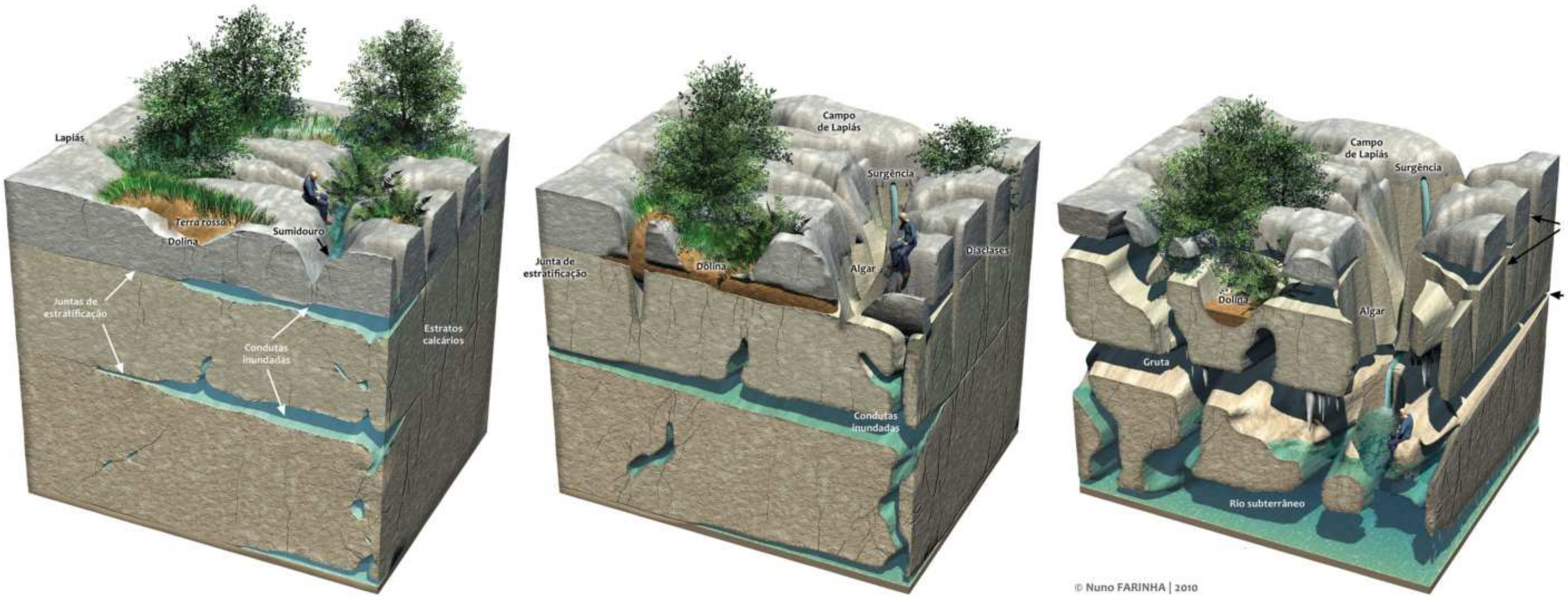


Caves are windows
to the vast dimension of subterranean ecosystems

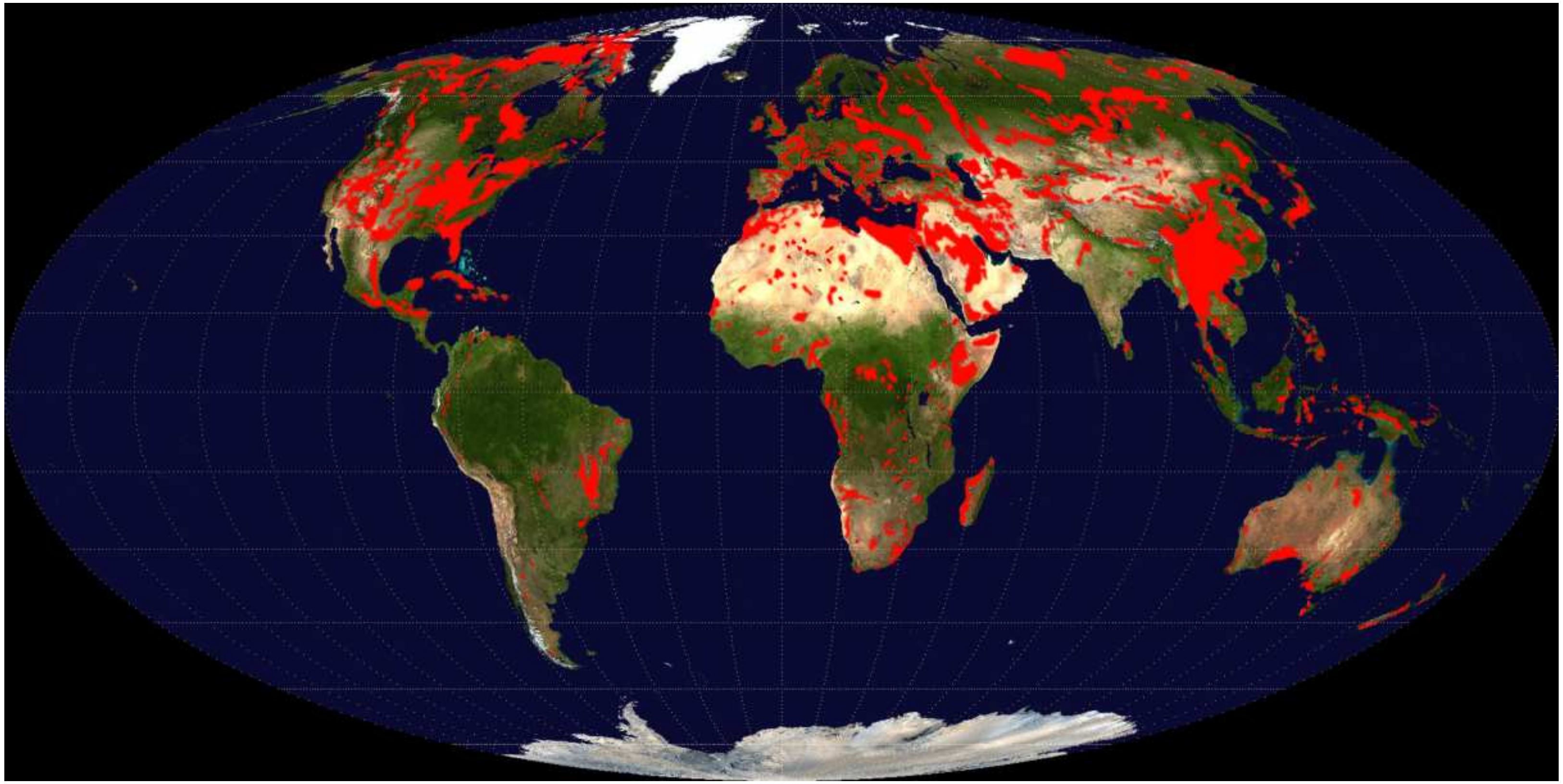
Darkness
Stable temperature
Low organic matter

Castaño-Sánchez, Hose & Reboleira (2020) https://doi.org/10.1016/j.chemosphere.2019.125422

Speleogenesis – Karst

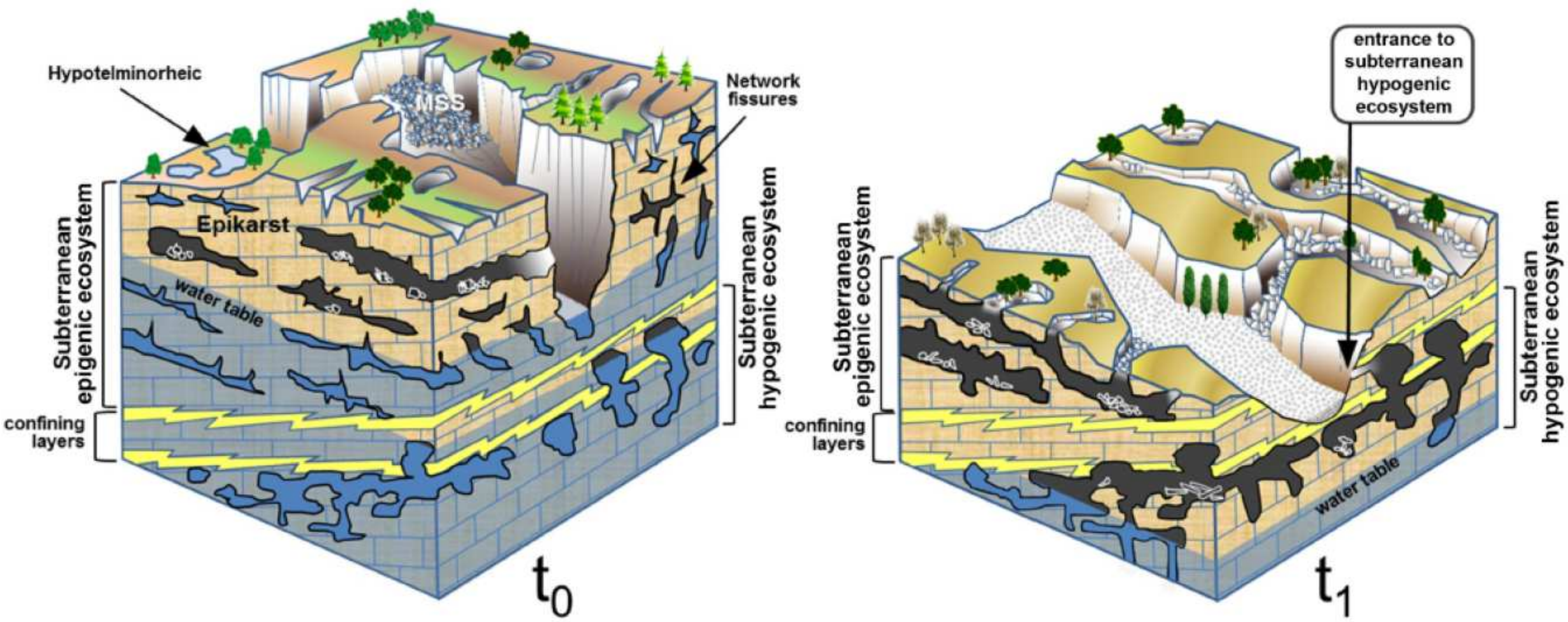


Karst areas occupy 15% of Earth's surface



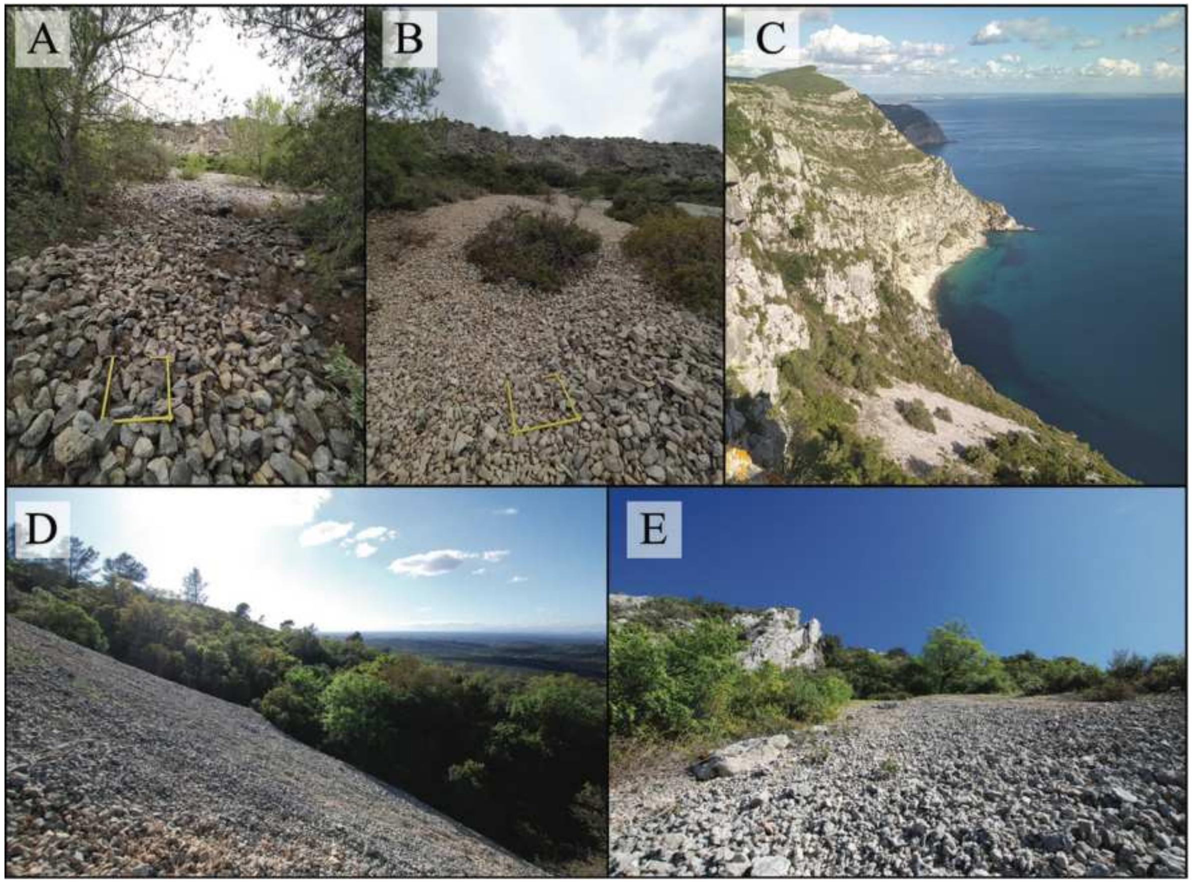
Source: Ford & Williams, 2007

Speleogenesis – Hypogenic/epigenic



Sendra et al. (2014) http://dx.doi.org/10.5038/1827-806X.43.3.2

Mesovoid Shallow Substrate (MSS) – Colluvium/Alluvium

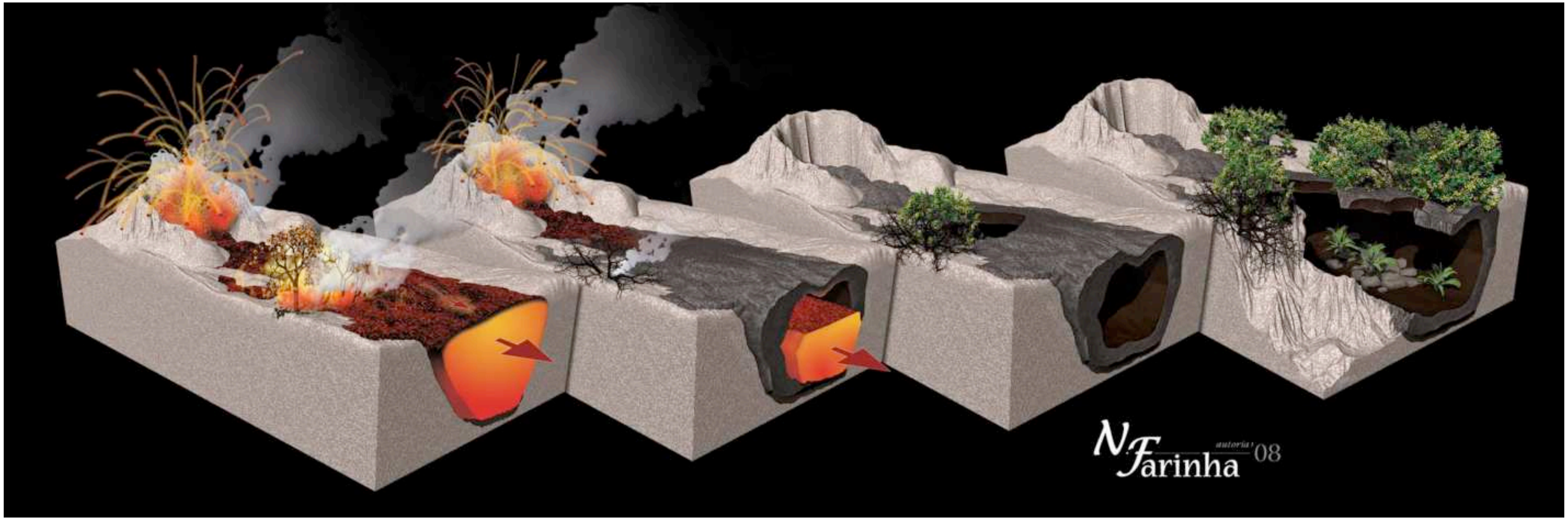


Eusébio et al. (2021/2023). https://doi.org/10.1016/j.zool.2021.125931, https://doi.org/10.3897/subtbiol.45.96332

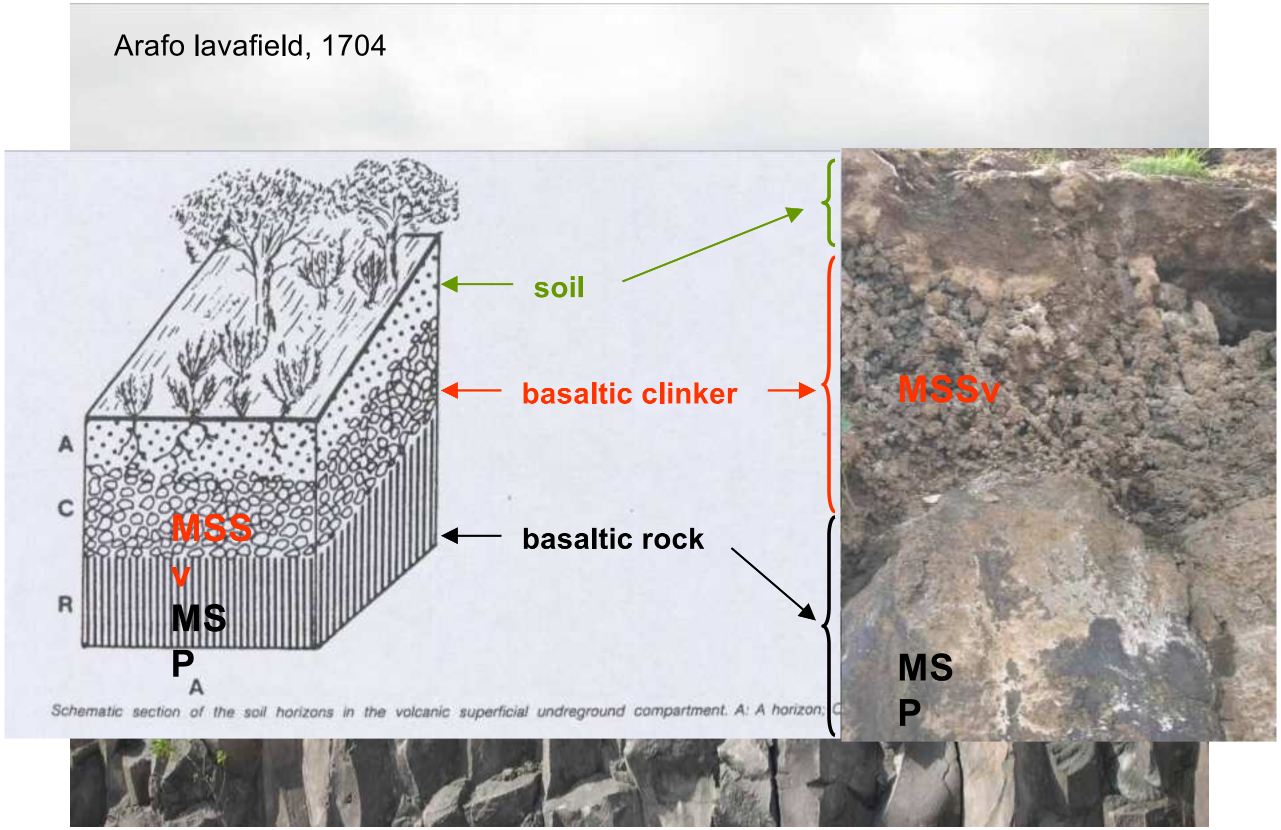
Volcanic territories

Timanfaya, Lanzarote, Canary Islands

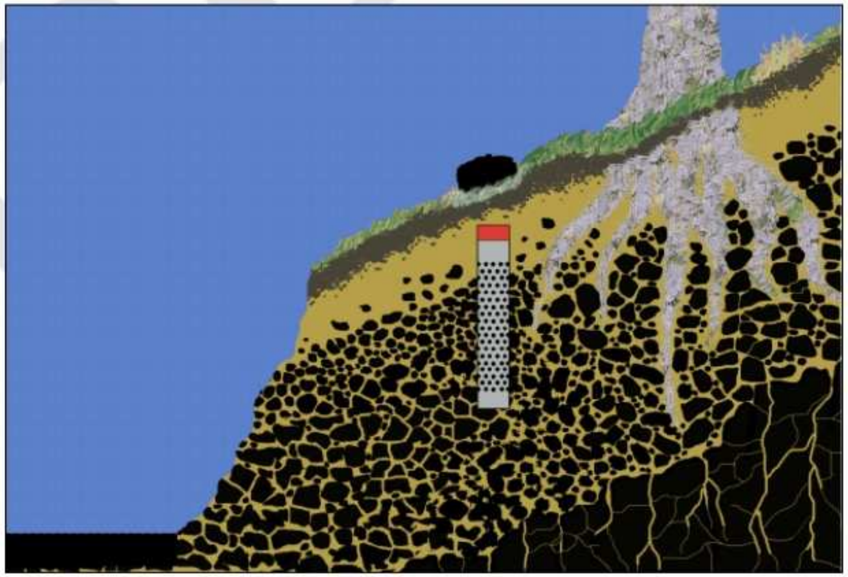
Speleogenesis – Volcanic territories



Shallow Subterranean Habitats



Shallow Subterranean Habitats



Shallow Subterranean Habitats

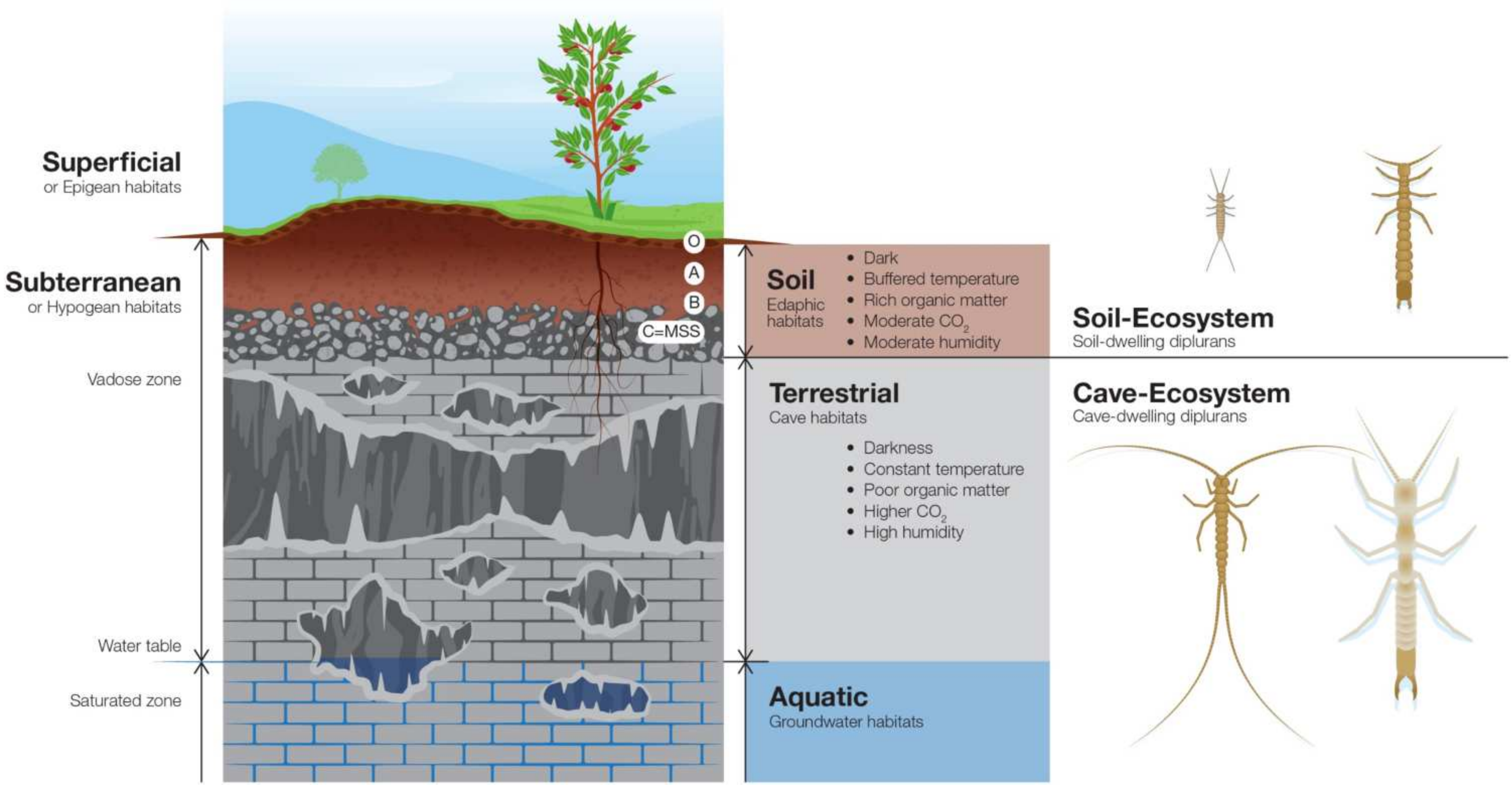
Shallow Subterranean Habitats

Spatter cones and consolidated cinder cones

Shallow Subterranean Habitats

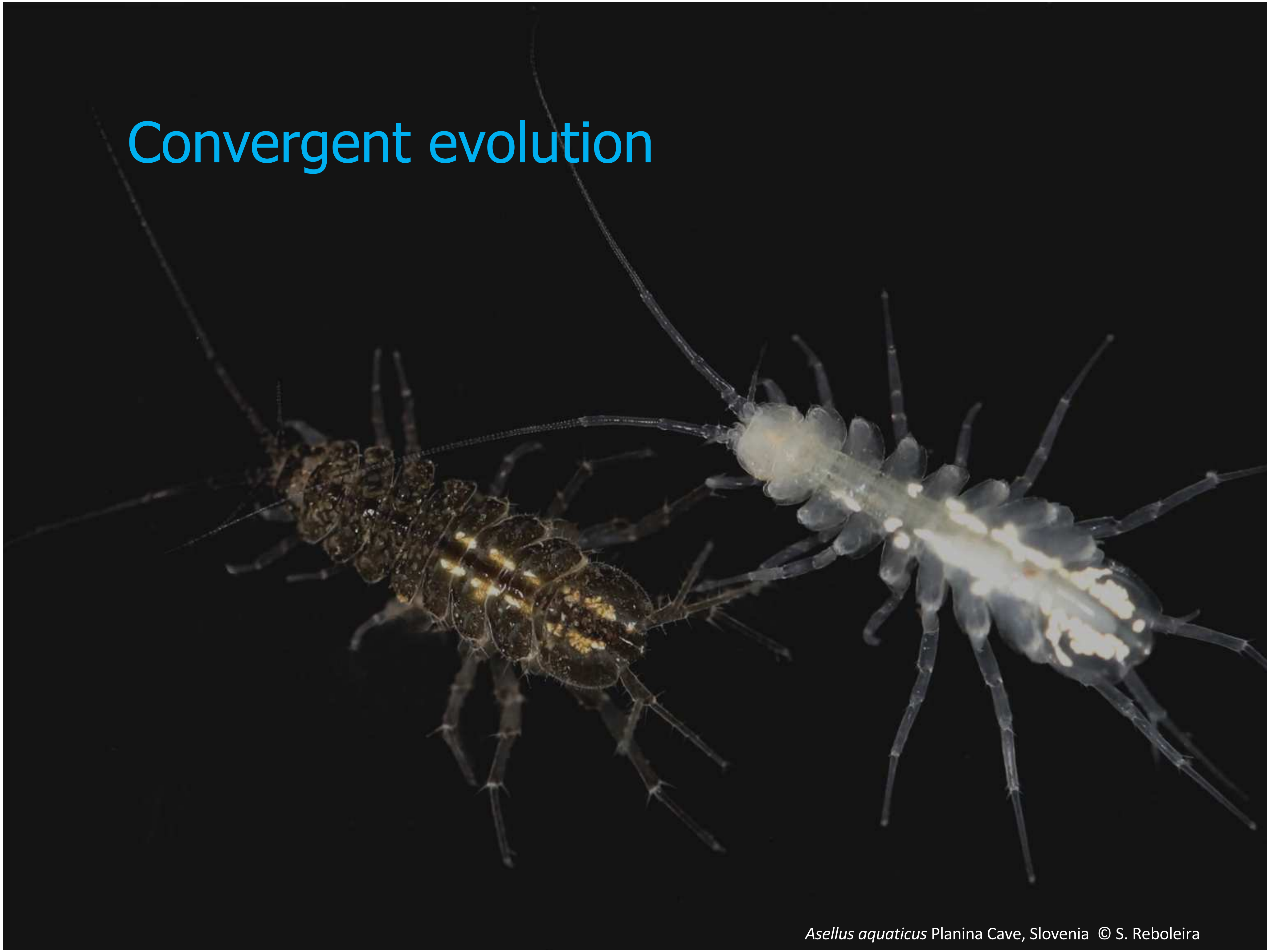
Ash and lapilli fields

Shallow Subterranean Habitats



Sendra A., Palero F., Jimenez-Valverde A. & Reboleira A.S.P.S. (2020) https://doi.org/10.1093/zoolinnean/zlaa116

Convergent evolution



Asellus aquaticus Planina Cave, Slovenia © S. Reboleira

Troglomorphisms

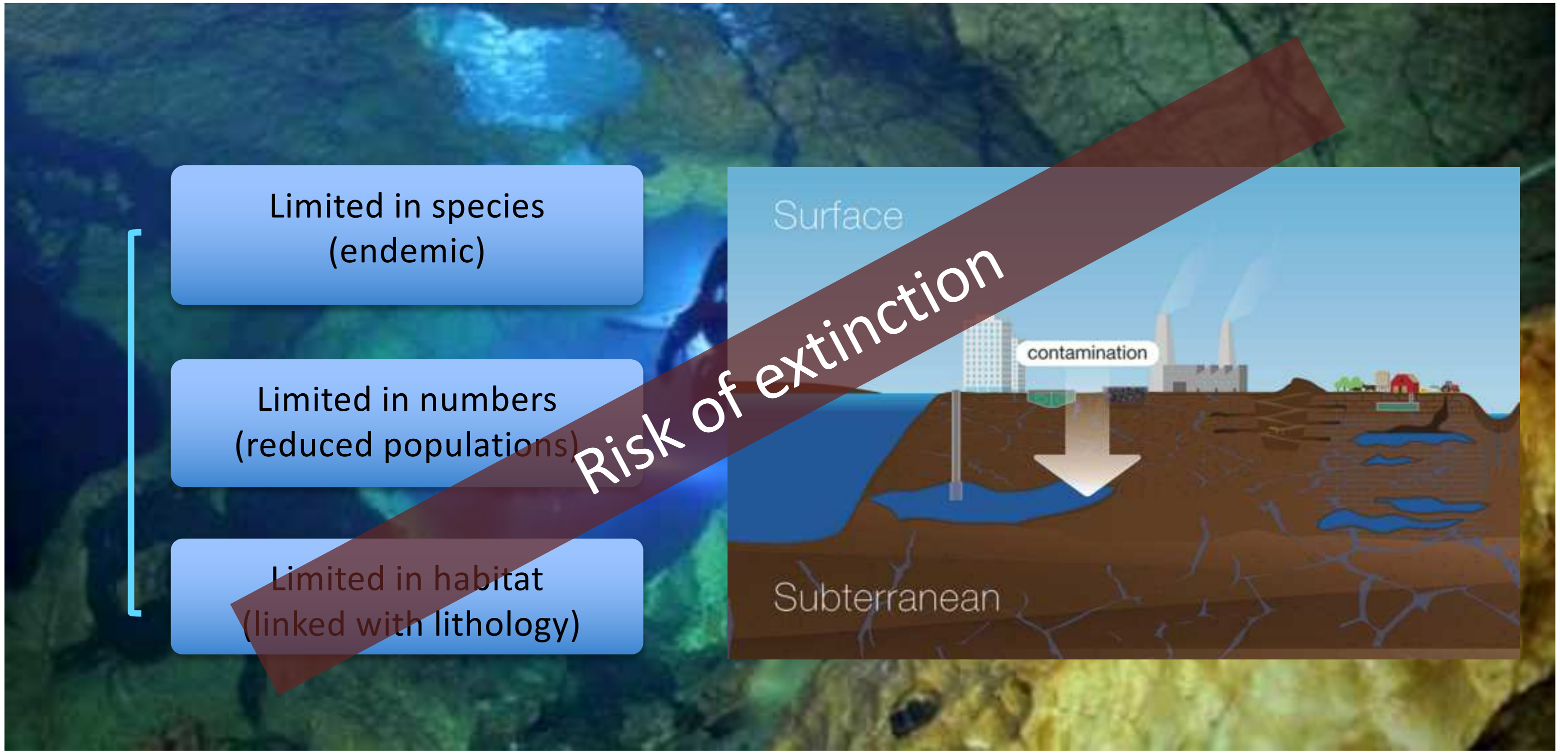
Slow metabolism

Reduced fertility

Lack of circadian rhythm

Domitius lusitanicus (Fage, 1931) © S. Reboleira

Subterranean habitat intrinsic vulnerability

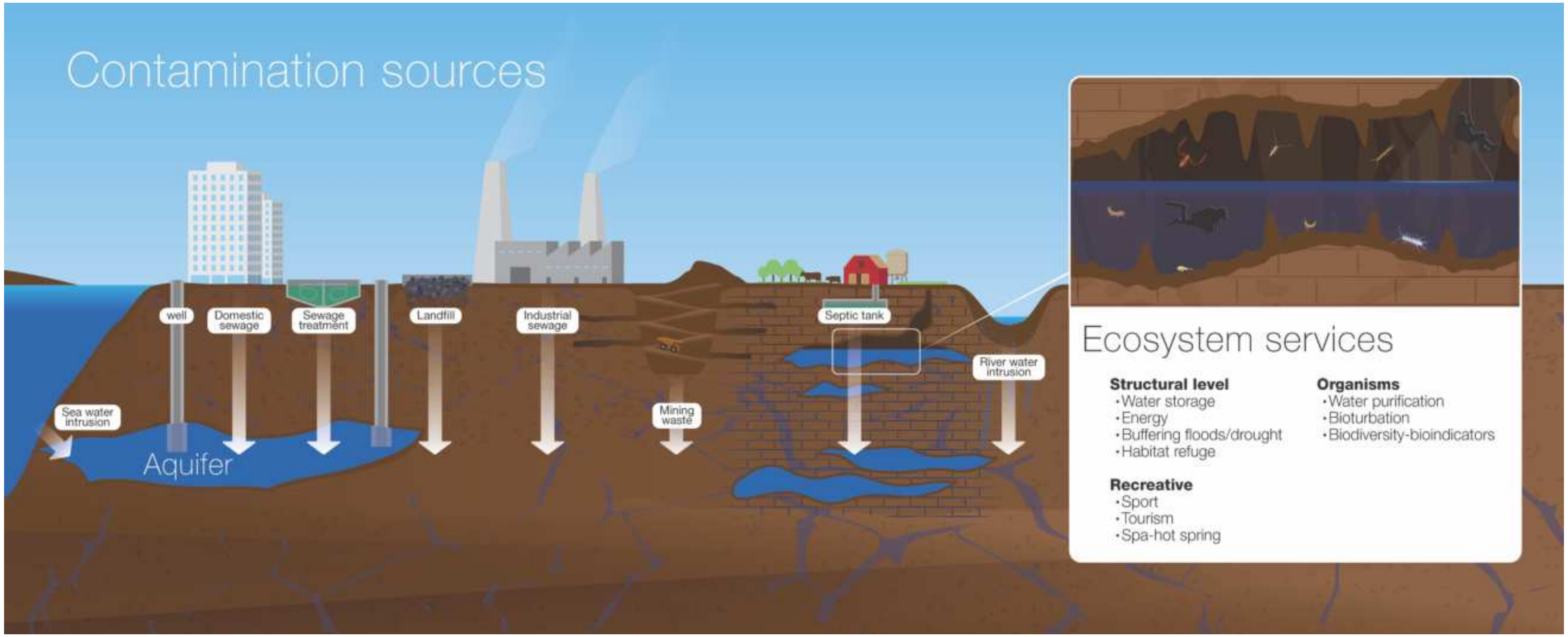


Infiltration

Ecosystem
degradation

Castaño-Sánchez, Hose & Reboleira (2020) https://doi.org/10.1016/j.chemosphere.2019.125422

Ecosystem services, threats and conservation



Castaño-Sánchez, Hose & Reboleira (2020) https://doi.org/10.1016/j.chemosphere.2019.125422

Current level of conservation in Europe

Linkages - synergies WFD, GD and HD?
Synergies with other regulations
(e.g. Nitrates Directive (96/676/EEC), Invasive Alien Species Reg.)

- EU Water Framework Directive
- Groundwater Directive

- Habitats Directive

- Physicocher
- Neglects sub

species

Evaluate ecological state

Establish specific conservation measures

?

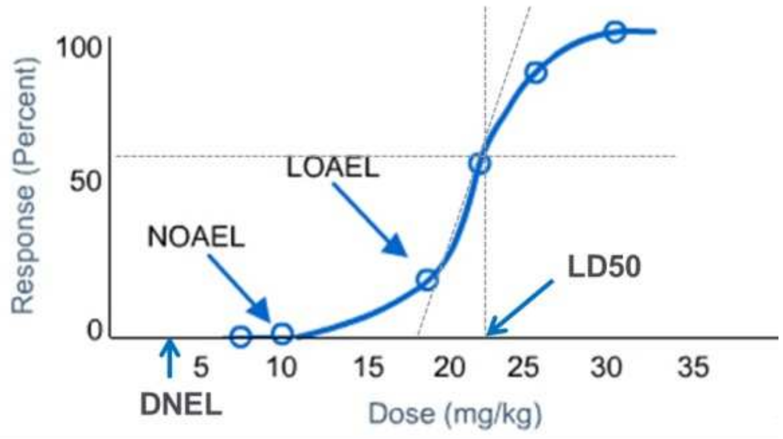
The main challenge:

Evaluate the impact of anthropogenic activities in subterranean ecosystems

Eco(toxico)physiological experiments

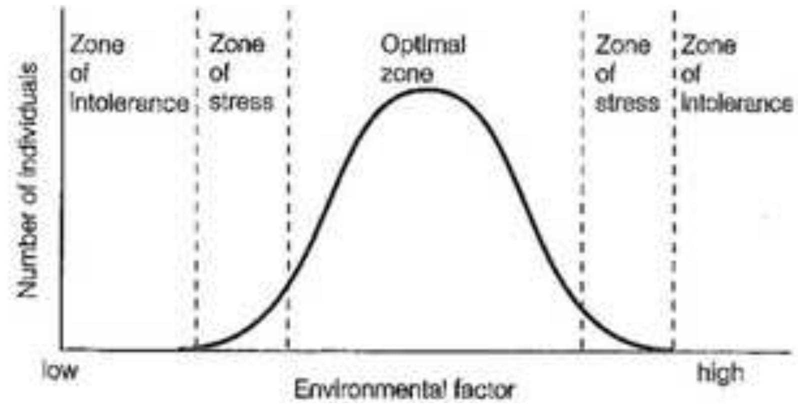
Lethal

End point: mortality

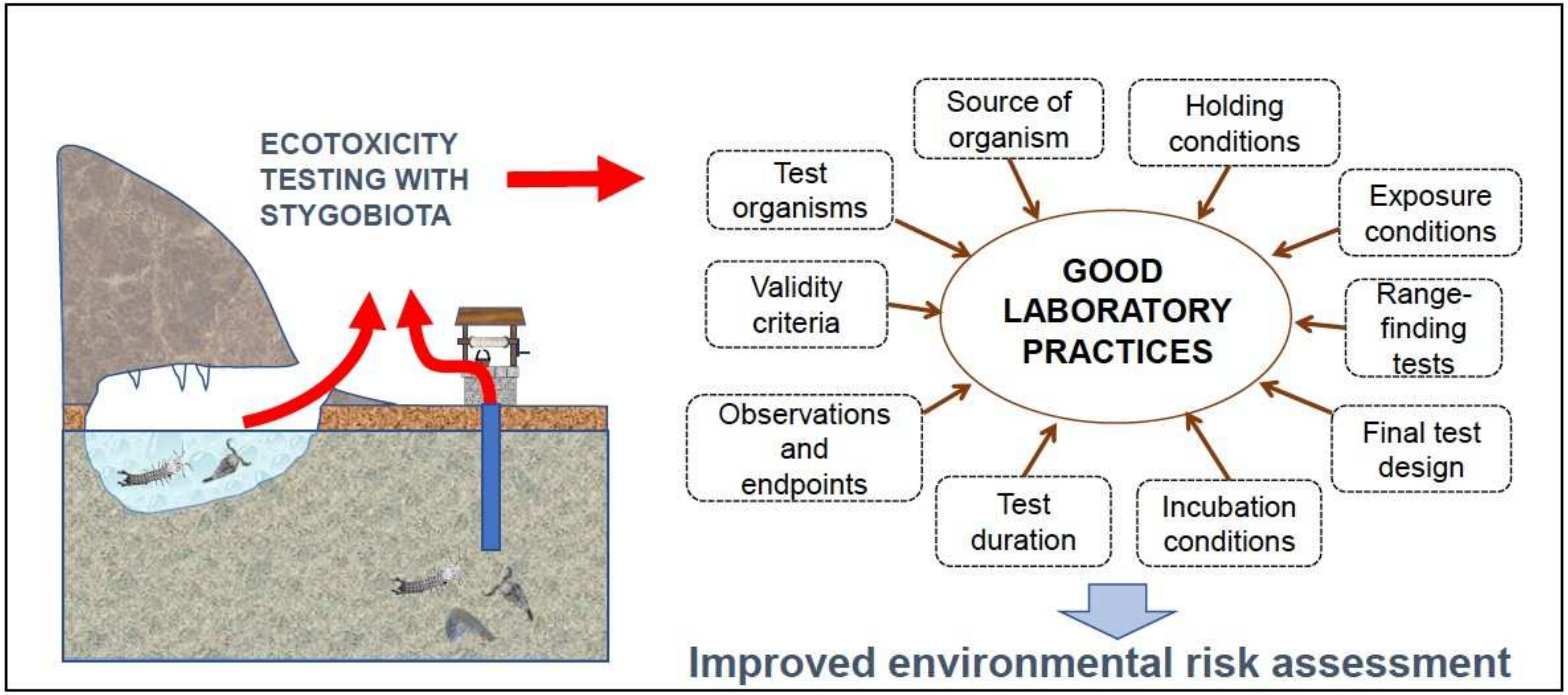


Sub-lethal

End point: physiological response



Recommendations for ecotoxicity testing with stygobiotic species in the framework of groundwater environmental risk assessment

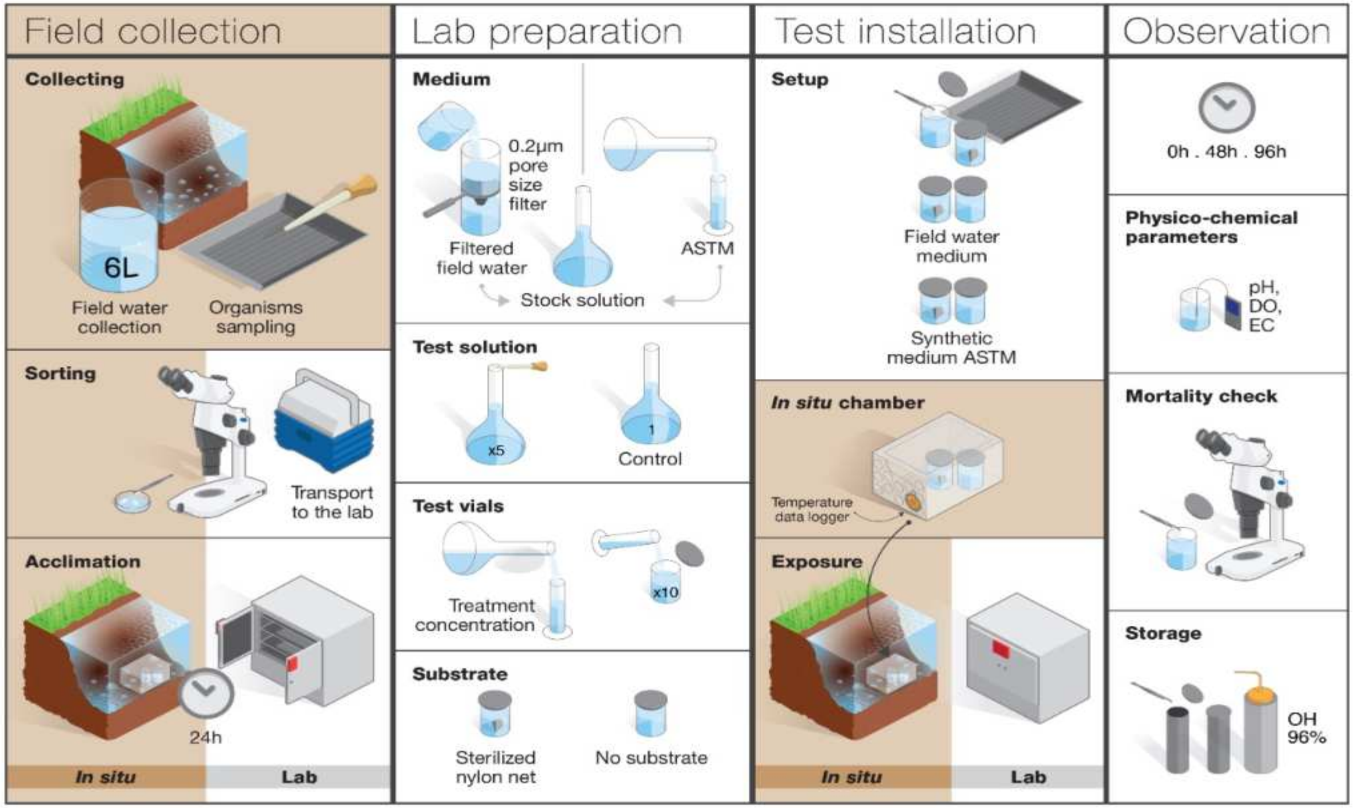


Di Lorenzo et al. (2019) https://doi.org/10.1016/j.scitotenv.2019.05.03

Can’t bring the animals to the Lab?

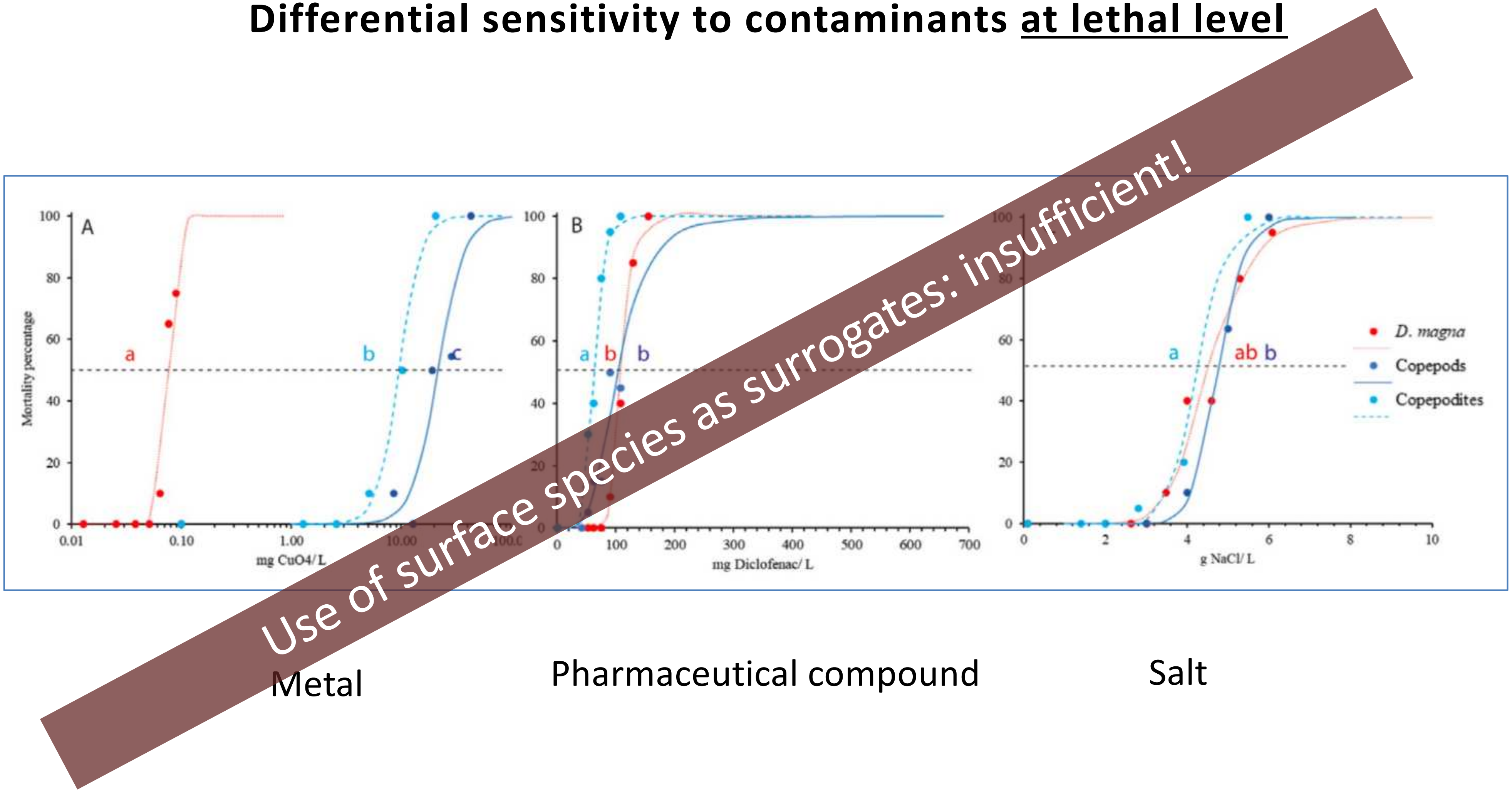
… bring the Lab to the CAVE!

Validation of Lab protocols for groundwater crustaceans



Castaño-Sánchez et al. 2021. https://doi.org/ 10.3390/w13081132

Differential sensitivity to contaminants at lethal level



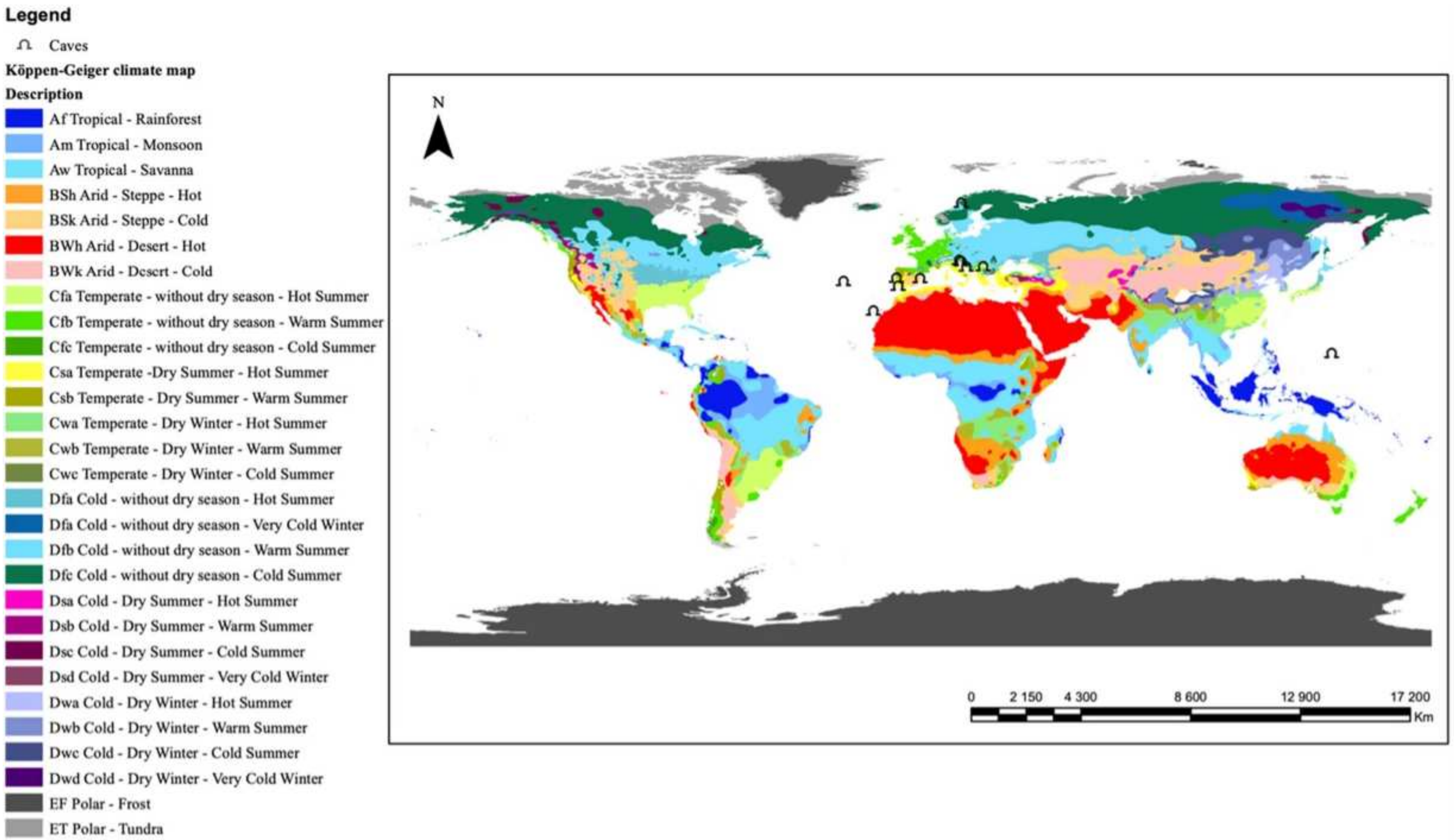
Metal

Pharmaceutical compound

Salt

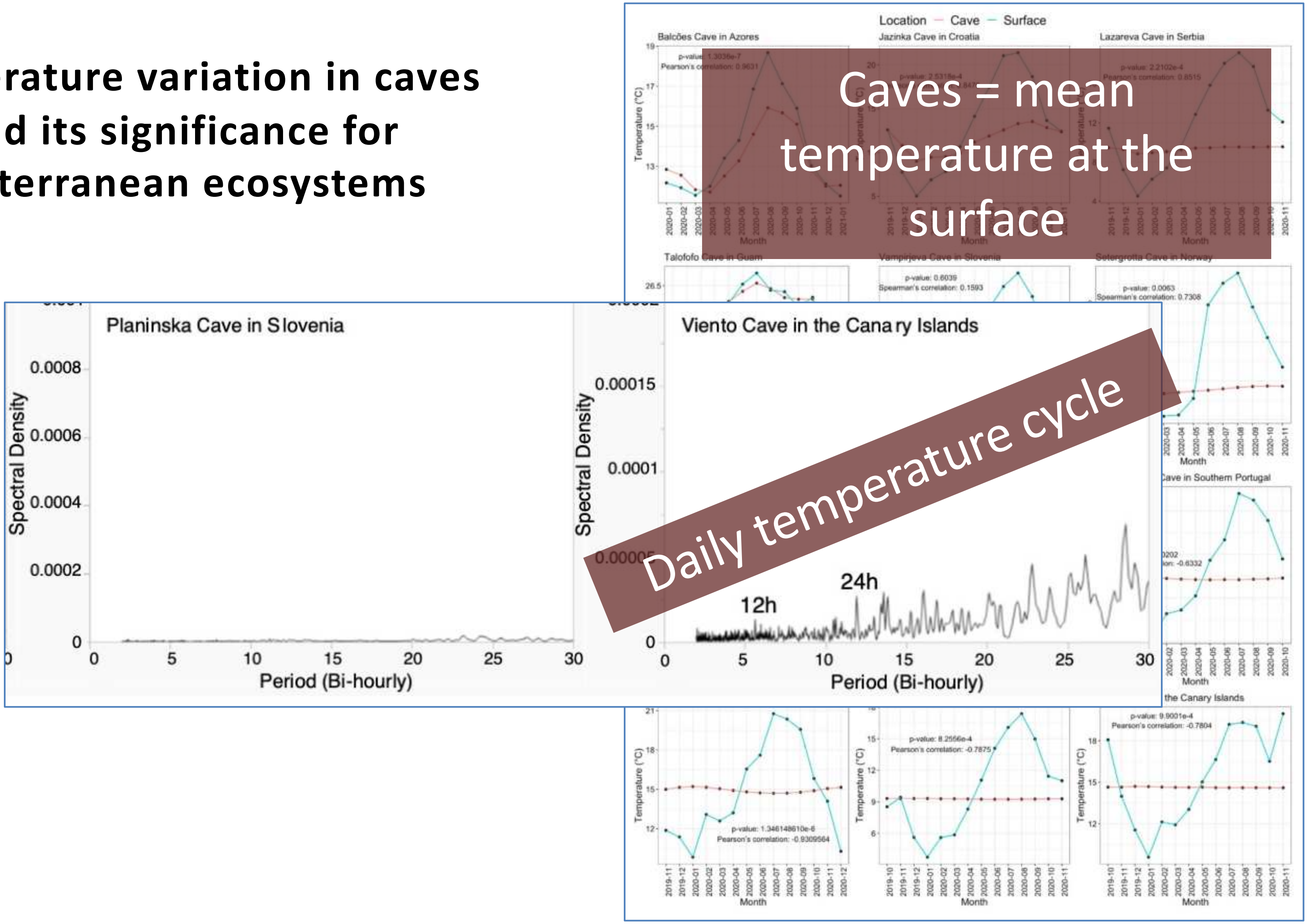
Castaño-Sánchez, Pereira, Gonçalves & Reboleira (2021) https://doi.org/10.1016/j.chemosphere.2021.129911

Temperature variation in caves



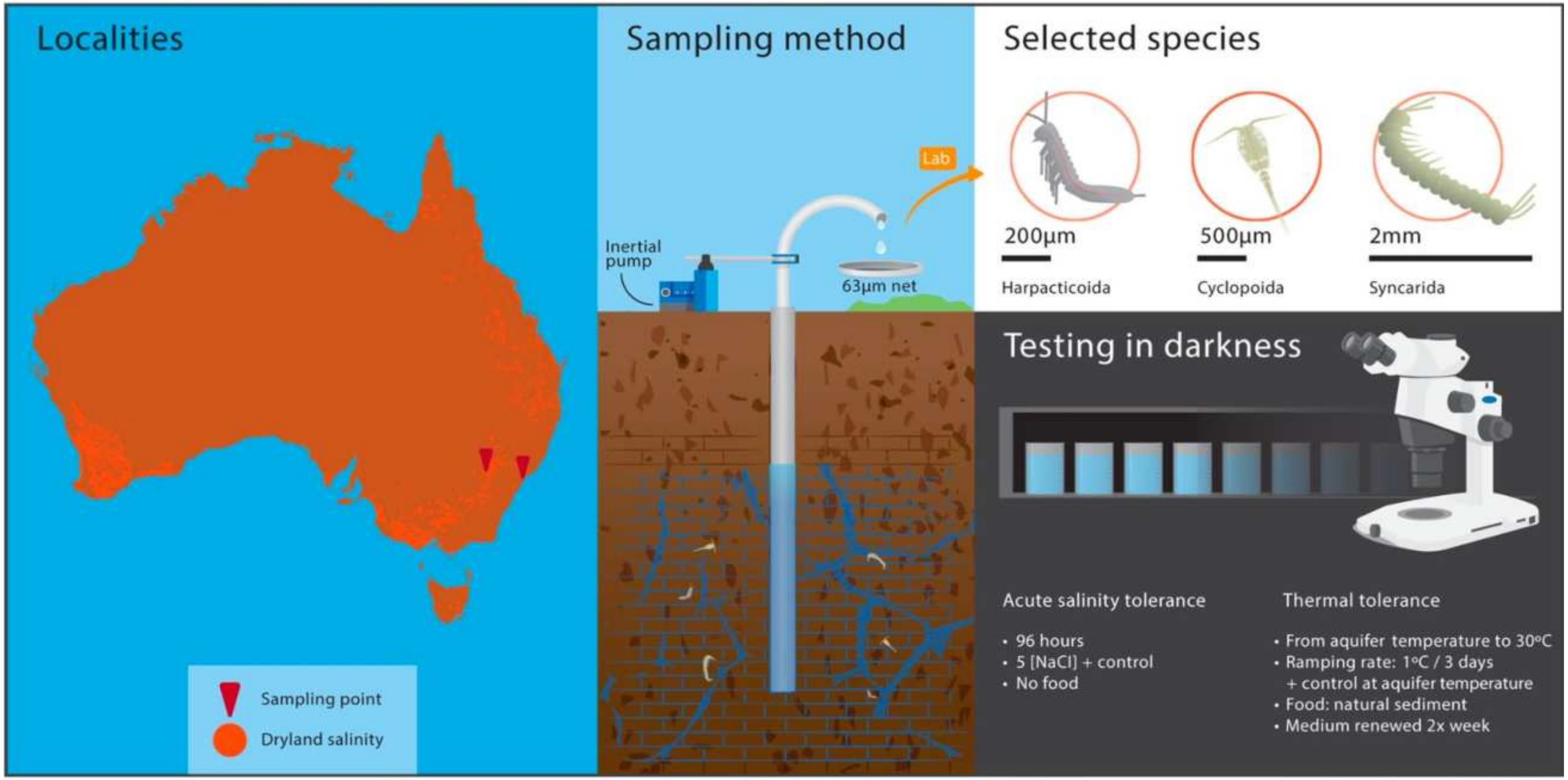
Medina et al. (2023) https://www.nature.com/articles/s41598-023-48014-7

Temperature variation in caves and its significance for subterranean ecosystems



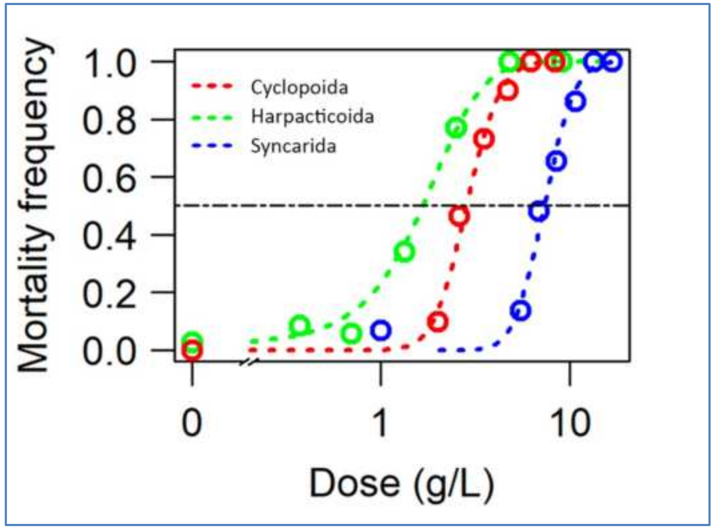
Medina et al. (2023) https://www.nature.com/articles/s41598-023-48014-7

Response to temperature and salinization at lethal level

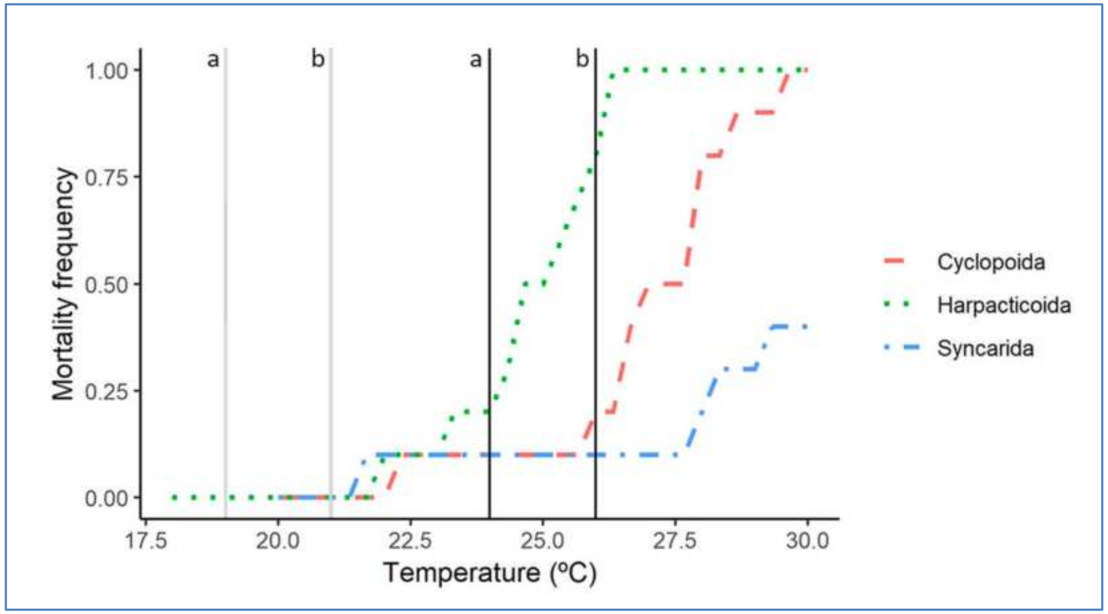


Castaño-Sánchez, Hose & Reboleira (2020) https://www.nature.com/articles/s41598-020-69050-7

Response to temperature and salinization at lethal level

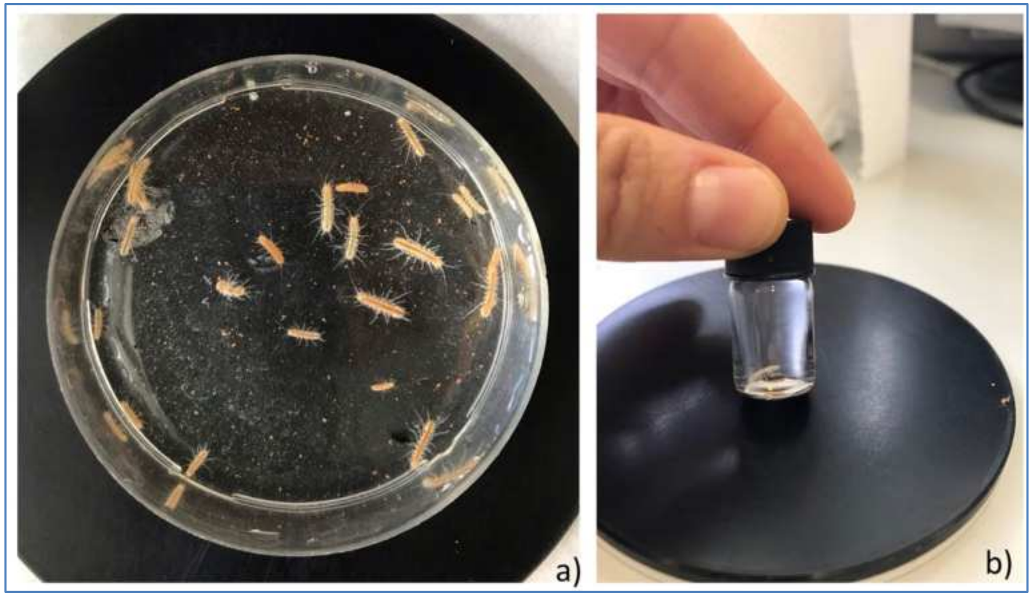


NaCl



Castaño-Sánchez, Hose & Reboleira (2020) https://www.nature.com/articles/s41598-020-69050-7

Thermal acclimation and metabolic scaling of groundwater species in the climate change scenario (sub-lethal level)



oxygen consumption
as proxy of metabolic rate

low thermal plasticity
in a fast-increasing thermal regime

Extinction

Oxygen consumption rates did not follow mass-dependent scaling

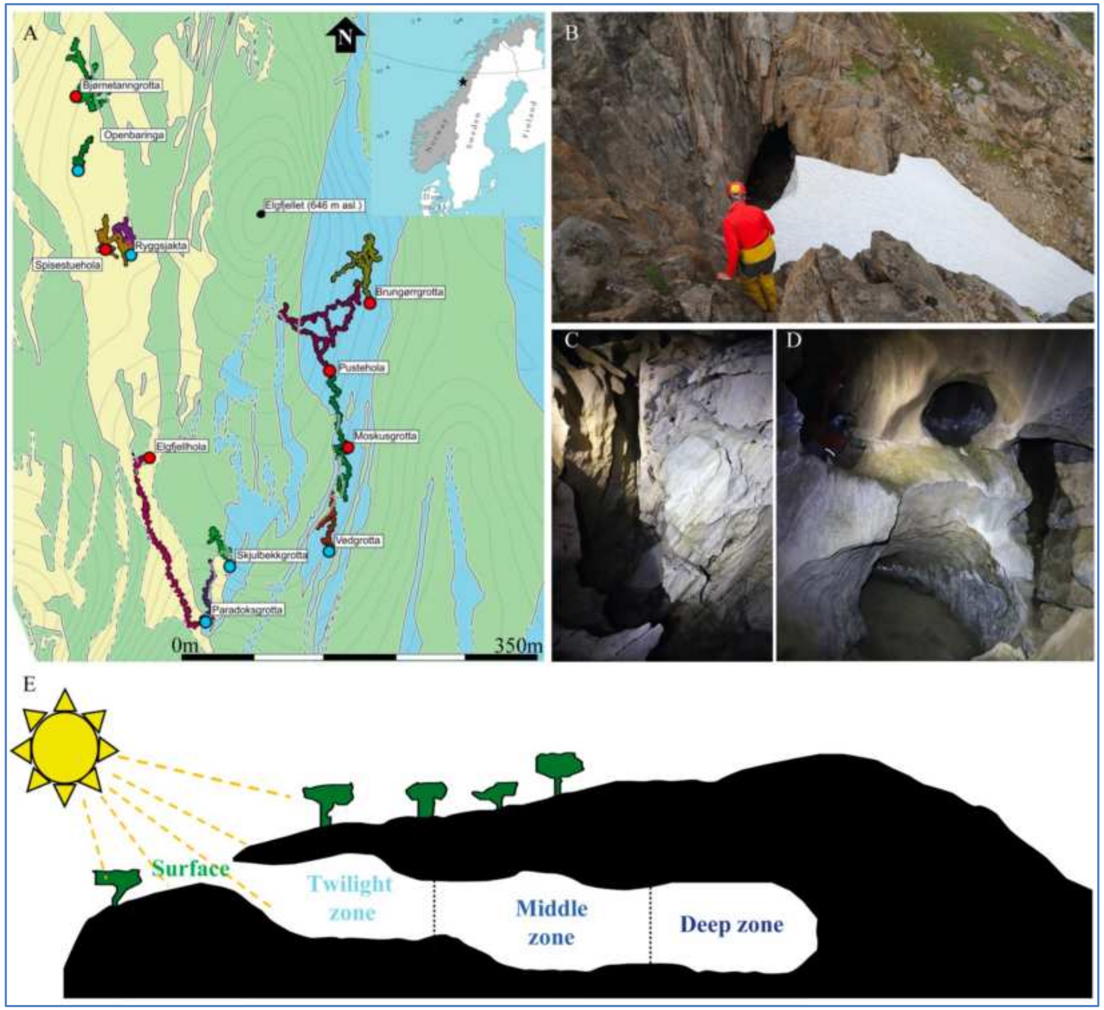
Di Lorenzo & Reboleira (2022) https://www.nature.com/articles/s41598-022-20891-4

Response to veterinary and human medicinal products (sub-lethal level)

Groundwater-adapted species *Proasellus lusitanicus* exposed to Acetaminophen (0 – 100 mg/L)

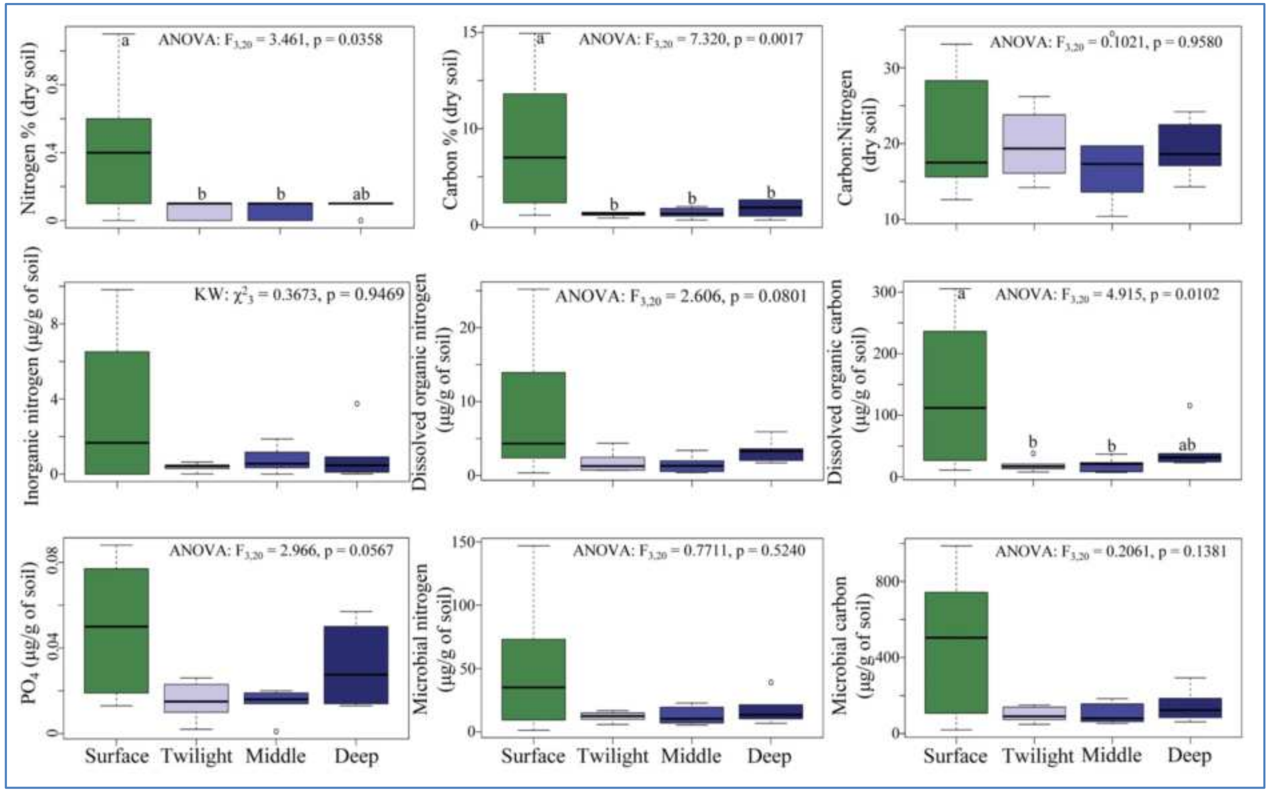
Duarte, Gravato, Di Lorenzo & Reboleira (2023) https://doi.org/10.1016/j.envpol.2023.121749

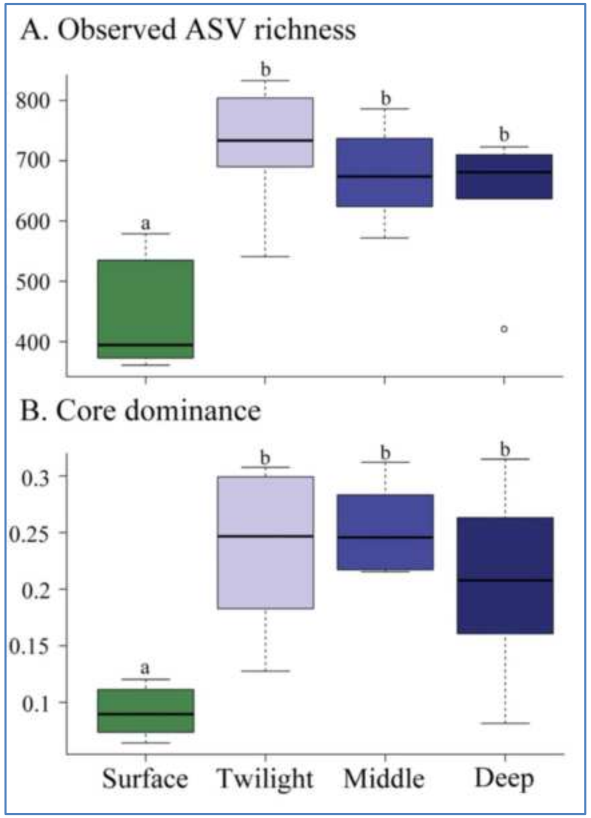
Biodiversity in subarctic caves



Reboleira et al. (2023) https://doi.org/10.1186/s40793-022-00435-z

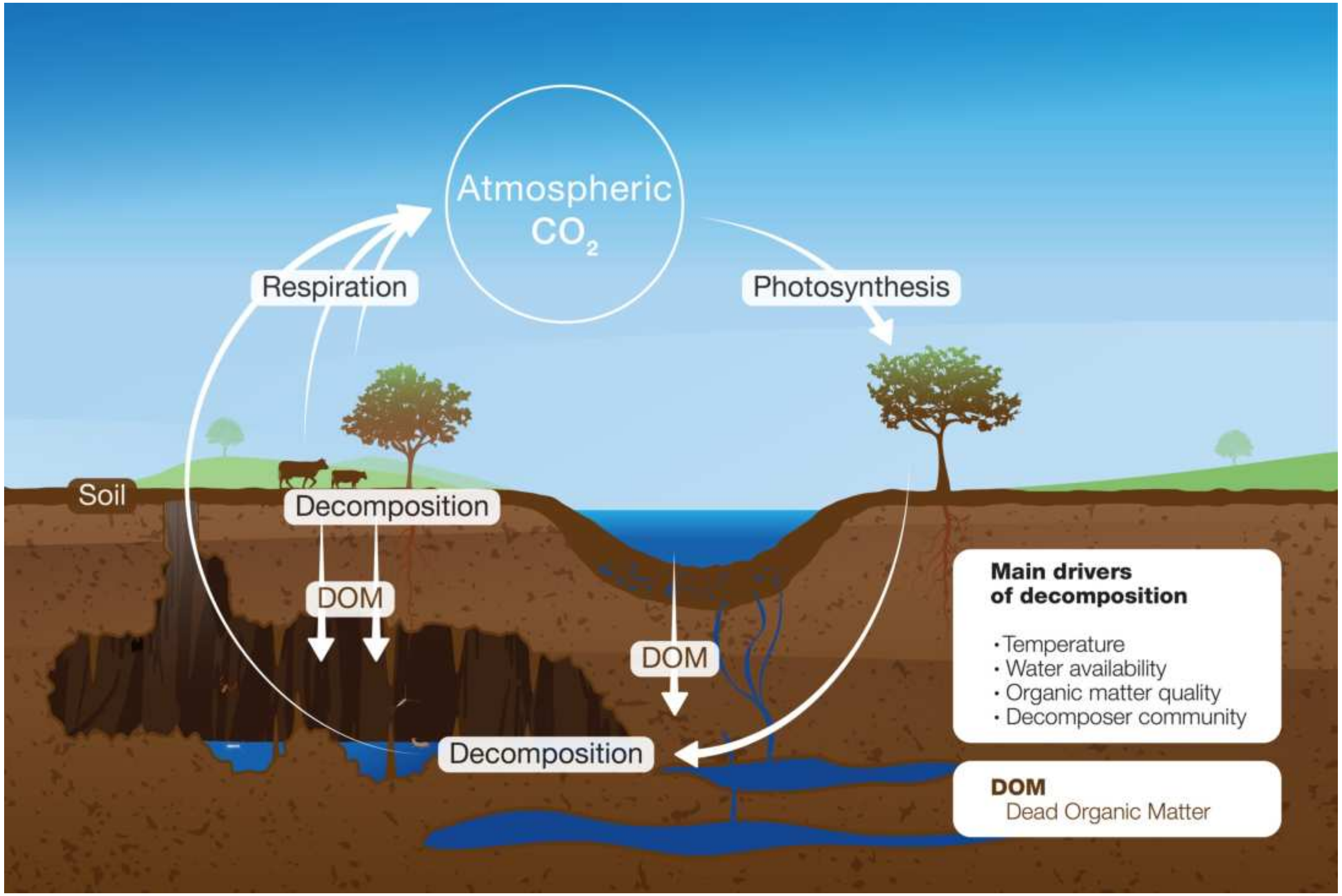
Nutrient-limited subarctic caves harbour more diverse and complex bacterial communities than their surface soil





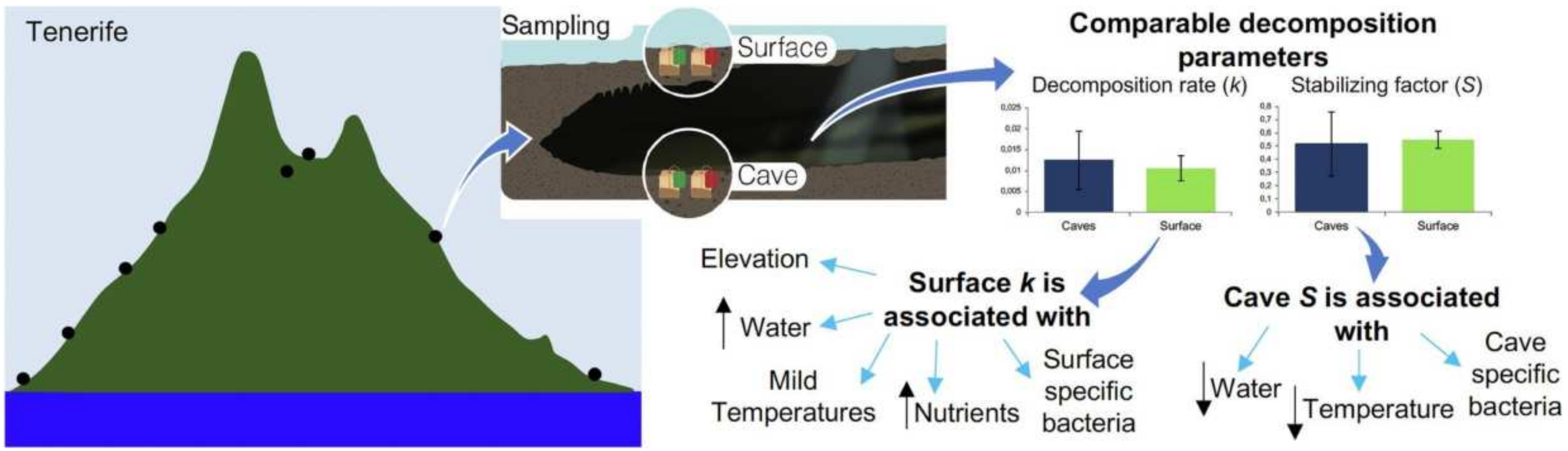
Reboleira et al. (2023) https://doi.org/10.1186/s40793-022-00435-z

Decomposition of organic matter in caves



Ravn, Michelsen
& Reboleira (2020) http://doi.org/10.3389/fevo.2020.554651

Comparable early-stage decomposition but contrasting underlying drivers between surface and cave habitats along an elevational gradient



Bodawatta, Ravn, Oromí, Martin, Michelsen, Poulsen, Jønsson & Reboleira (2023). https://doi.org/10.1016/j.ecolind.2023.110607

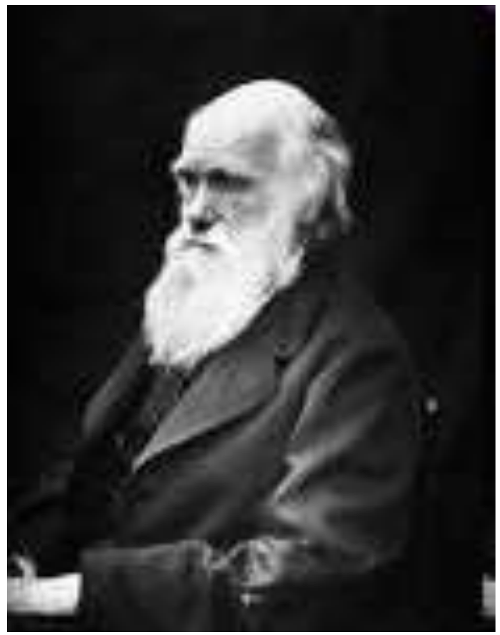
Conservation needs

- Establishment of thresholds for groundwater pollution – assessment needs to include biological aspects
- Whole Cycle – Water Dependent Ecosystems
- Holistic Approach – linkages with other policies/sectors, climate change
- Endemic/Local character requires local (but still integrated approach)

?

What is the contribution of the study subterranean ecosystems for science

Biogeographic history: living fossils



“wrecks of ancient life”

Models for Ecology and Evolution

Host (bat)

Jensen et al. (2019) https://doi.org/10.1016/j.jip.2019.107206

Medicine: new antibiotics

Subarctic caves, Norway, 2019

Reboleira *et al. Environmental Microbiome* (2022) 17:41
https://doi.org/10.1186/s40793-022-00435-z

Environmental Microbiome

RESEARCH Open Access

Nutrient-limited subarctic caves harbour more diverse and complex bacterial communities than their surface soil

Ana Sofia Reboleira[1,2*†], Kasun H. Bodawatta[1,2†], Nynne M. R. Ravn[2], Stein-Erik Lauritzen[3,4], Rannveig Øvrevik Skoglund[5], Michael Poulsen[6], Anders Michelsen[7] and Knud Andreas Jønsson[2]

Abstract

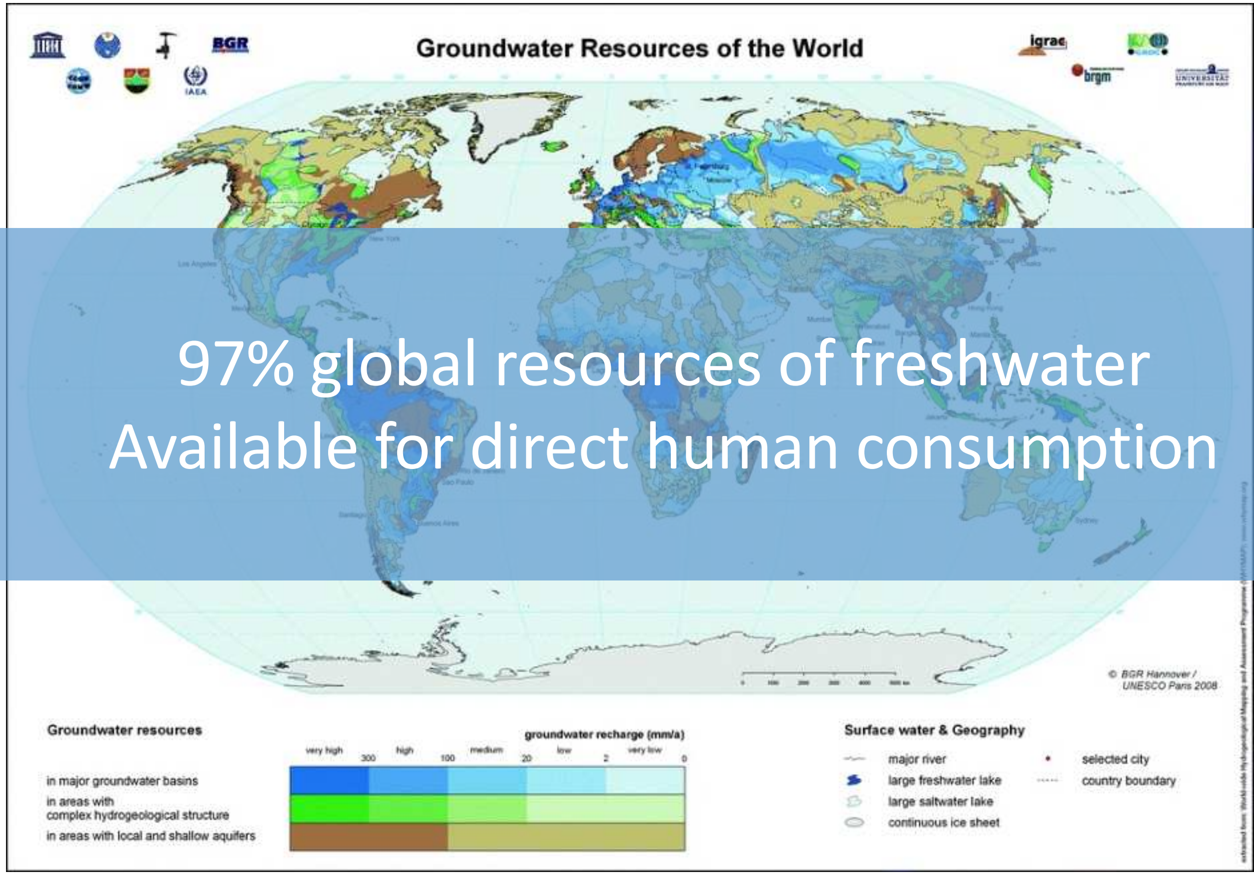
Background: Subarctic regions are particularly vulnerable to climate change, yet little is known about nutrient availability and biodiversity of their cave ecosystems. Such knowledge is crucial for predicting the vulnerability of these ecosystems to consequences of climate change. Thus, to improve our understanding of life in these habitats, we characterized environmental variables, as well as bacterial and invertebrate communities of six subarctic caves in Northern Norway.

Results: Only a minuscule diversity of surface-adapted invertebrates were found in these caves. However, the bacterial communities in caves were compositionally different, more diverse and more complex than the nutrient-richer surface soil. Cave soil microbiomes were less variable between caves than between surface communities in the same area, suggesting that the stable cave environments with tougher conditions drive the uniform microbial communities. We also observed only a small proportion of cave bacterial genera originating from the surface, indicating unique cave-adapted microbial communities. Increased diversity within caves may stem from higher niche specialization and levels of interdependencies for nutrient cycling among bacterial taxa in these oligotrophic environments.

Conclusions: Taken together this suggest that environmental changes, e.g., faster melting of snow as a result of global warming that could alter nutrient influx, can have a detrimental impact on interactions and dependencies of these complex communities. This comparative exploration of cave and surface microbiomes also lays the foundation to further investigate the long-term environmental variables that shape the biodiversity of these vulnerable ecosystems.

Keywords: Subterranean ecosystems, Subsurface, Subarctic ecosystems, Cave microbiomes, Microbial co-occurrence networks

Strategic resources for life on Earth



97% global resources of freshwater
Available for direct human consumption

From: https://doi.org/10.1007/978-90-481-3426-7_10

Thank you

Acknowledgements list:

www.sofiareboleira.weebly.com

fct Fundação para a Ciência e a Tecnologia

FUNDAÇÃO BELMIRO DE AZEVEDO

VILLUM FONDEN

Titanobochica magna Zaragoza & Reboleira, 2010
Photo: Robbie Shone

Boreviulisoma barrocalense Reboleira & Enghoff, 2013

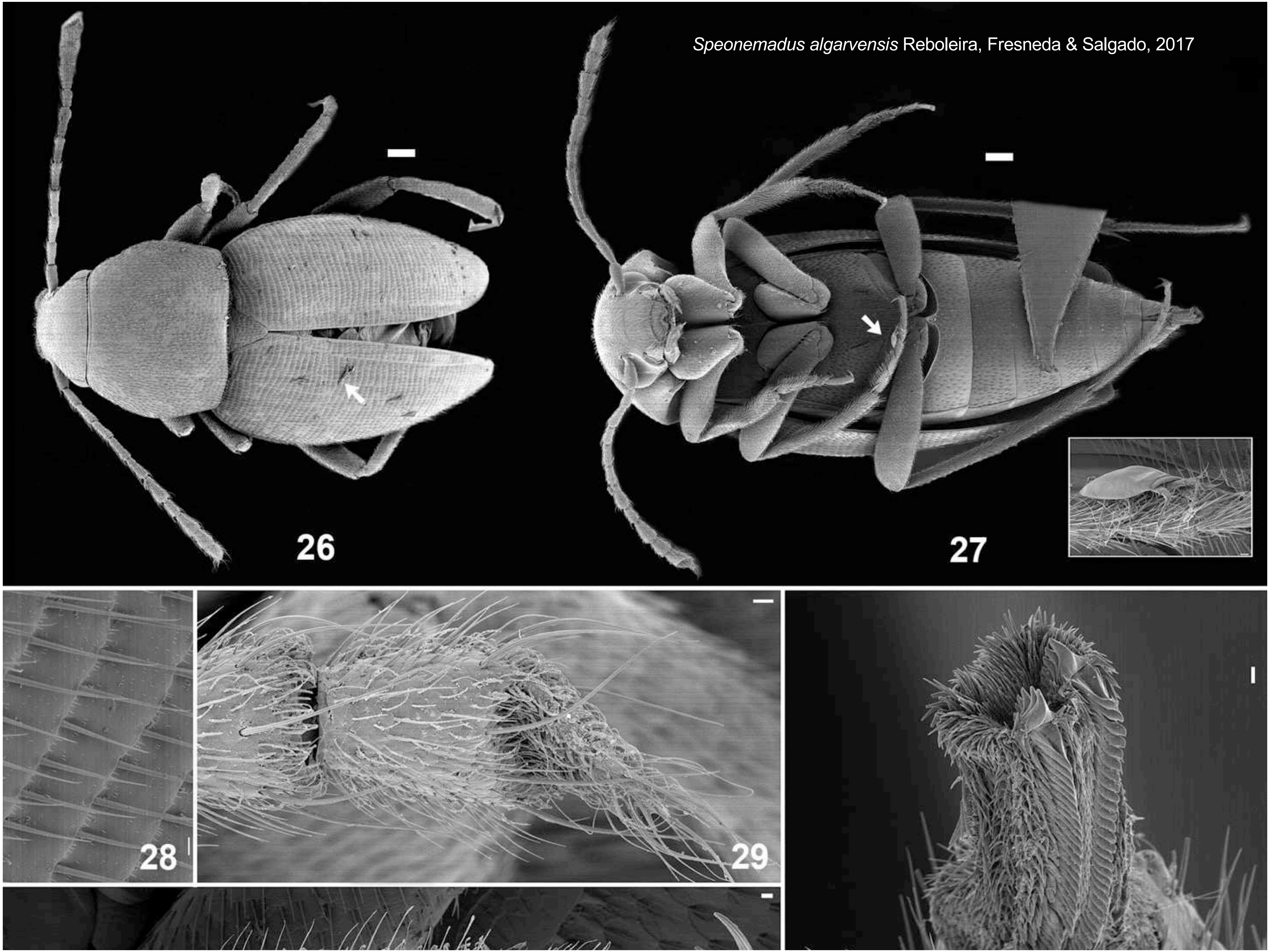
Trogleluma machadoi (Vandel, 1946)

Podocampa cf. *fragiloides* (Silvestri, 1914)

Squamatinia algharbica Mendes & Reboleira, 2012

Trechus tatai Reboleira & Ortuño, 2010

Trechus gamae Reboleira & Serrano, 2009


Speonemadus algarvensis Reboleira, Fresneda & Salgado, 2017
26
27
28
29

Domene lusitanica Reboleira & Oromí, 2011

Iberoporus pluto Ribera & Reboleira, 2019