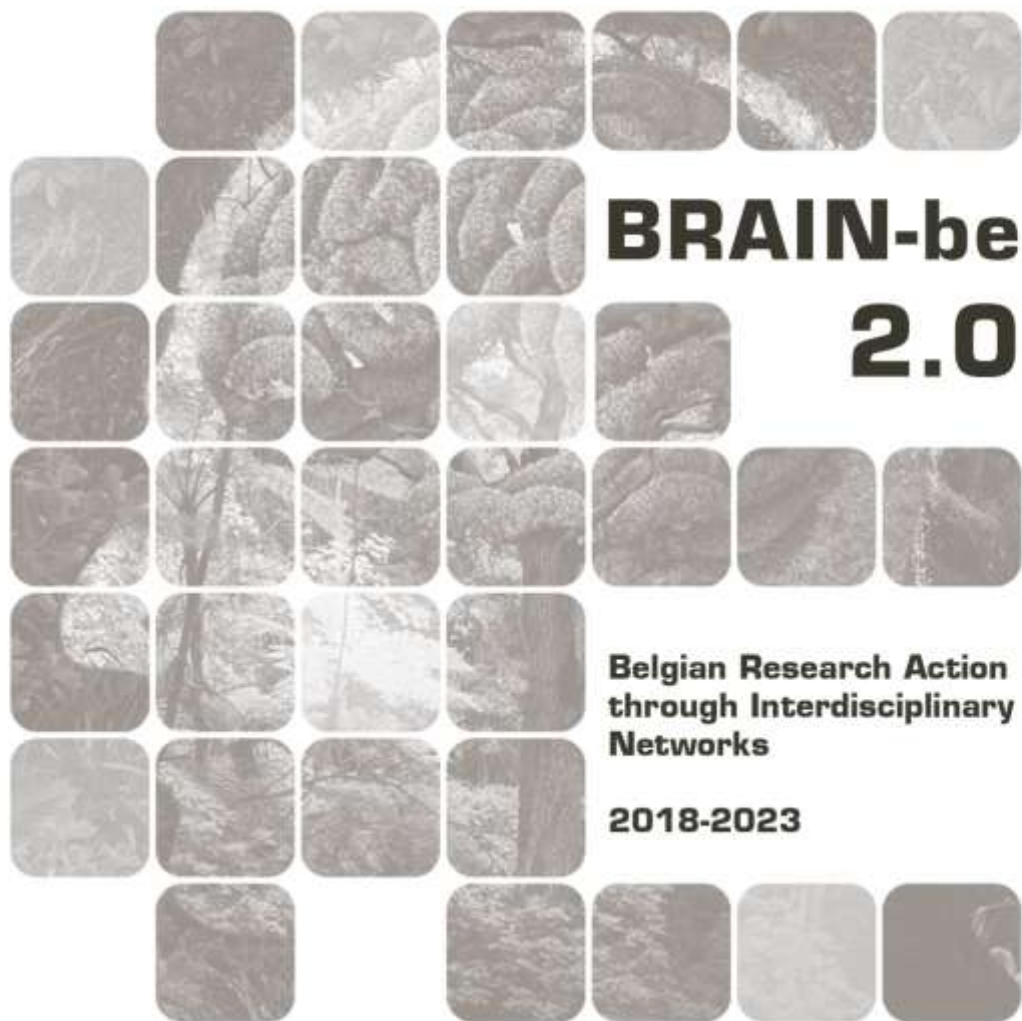




DarCo

The vertical dimension of conservation: A cost-effective plan to incorporate subterranean ecosystems in post-2020 biodiversity and climate change agendas

JEAN-FRANÇOIS FLOT (Université libre de Bruxelles)

Pillar 1: Challenges and knowledge of the living and non-living world

NETWORK PROJECT

DarCo

The vertical dimension of conservation: A cost-effective plan to incorporate subterranean ecosystems in post-2020 biodiversity and climate change agendas

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ABSTRACT

Context

Subterranean ecosystems (e.g., caves, aquifers, fissured systems) harbor a broad diversity of specialized organisms that contribute significantly to global taxonomic, phylogenetic, and functional diversity. This biodiversity is increasingly threatened by human activities. Currently, the network of surface-designed protected areas is inadequate to safeguard subterranean biodiversity, as only 6.9% of known subterranean ecosystems overlap with (surface) protected areas globally.

Objectives

The goal of DarCo was to improve our knowledge about life in subterranean ecosystems across Europe and to help protect it. Our long-term objective was to include these ecosystems in the European Union (EU) Biodiversity Strategy for 2030, a general plan by the EU to expand the percentage of protected areas up to 30% by 2030.

Conclusions

DarCo's main contribution to society was to transform how subterranean biodiversity is perceived by the public and target stakeholders. Score of scientific publications were also released.

Keywords

Groundwater; subterranean environments; caves

1. INTRODUCTION

The goal of DarCo was to improve our knowledge about life in subterranean ecosystems across Europe and to help protect it. Our long-term objective was to include these ecosystems in the European Union (EU) Biodiversity Strategy for 2030, a general plan by the EU to expand the percentage of protected areas up to 30% by 2030. To achieve this, we focused on five main goals: 1) Assemble the hitherto most extensive data on distribution and traits for major animal groups inhabiting European subterranean ecosystems. 2) Map how well underground species and habitats are currently protected by Europe's network of protected areas (Natura 2000). 3) Understand how subterranean biodiversity is responding to different human impacts. 4) Develop a scientifically driven plan to expand the coverage of subterranean biodiversity within European protected areas. 5) Raise awareness about underground ecosystems and push for stronger legislation to safeguard them. Together, these objectives aligned closely with the scope of Biodiversa+ 2021–2022 BiodivProtect call to improve the protection, effective management, and equitable governance of biodiversity across Europe, ultimately delivering bold conservation outcomes. Because we were focused on subterranean biodiversity beyond political borders, DarCo was essentially transnational in its scientific scope, but also in terms of societal impacts and through the maintenance of Europe-wide ecosystem services associated with subterranean ecosystems and their biodiversity. To maximize societal impacts, we devised a work package fully dedicated to information dissemination and stakeholder engagement, with the hope to create a legacy beyond the project duration.

2. STATE OF THE ART AND OBJECTIVES

Subterranean ecosystems harbour a broad diversity of poorly understood specialized organisms that are of interest from both a conservation and evolutionary perspective. These species are often phylogenetically highly distinct, yet small-range endemics, and some represent ancient faunas that have disappeared from above surface habitats. Thus, they account for a unique fraction of the global taxonomic, phylogenetic, and functional diversity that is currently imperilled by human activities, including the destruction of their subterranean habitats, pollution, and climate change. Furthermore, subterranean ecosystems and landscapes deliver critical nature's contributions to people, including an array of cultural values such as recreation (caving), tourism, education, aesthetic and scientific values, and most notably, the provisioning of potable water. An estimated 95% of the world's available liquid freshwater supply is groundwater, and more than half of the world's population relies on this supply for consumption and agriculture. Globally, the human demand for groundwater is ~3.5 times the actual volume of aquifers. This situation will only deteriorate as the human population continues to grow, and the intensification of drought events will increase the demand on groundwater for agricultural irrigation. Provisioning of potable water is one of the most important ecological services associated with subterranean organisms, given that bacteria and invertebrates are essential in maintaining clean groundwaters by enhancing carbon turnover, attenuating and degrading harmful contaminants, and even eliminating pathogenic microorganisms from the aquifer. But the services provided by subterranean organisms extend beyond that. For example, cave-roosting bats form the largest congregations of mammals, and they play crucial ecological roles as insect pest controllers, seed dispersers, pollinators, and nutrient recyclers. This well illustrates the importance of subterranean ecosystems to human societies and the integrity of ecological systems but also reminds us about how little we still know about these secluded environments.

To emphasize the urgency of protecting subterranean biodiversity, the year 2021 was elected the International Year of Caves and Karst (later extended to 2022). Yet, the subterranean biome is still systematically overlooked in global biodiversity targets and climate change agendas. In a recent letter to *Nature Climate Change*, we showed that only 6.9% of known subterranean ecosystems overlap with protected areas globally. Importantly, most of these subterranean ecosystems are protected simply because they occur within protected areas established for surface species or habitats, and therefore not designed to account for their vertical dimension. To rectify this omission, we established a consortium with representatives from 23 nation-states and seven indigenous groups and proposed a roadmap to guide the conservation of the subterranean biome through 2030 and beyond. On paper, these calls for action emphasize a positive trend. Yet, if the warnings of scientists are not supported by quantitative evidence on what constitutes critical threats and conservation priorities, all our efforts are merely 'whistling in the wind'. Subterranean ecosystems are some of the most understudied ecosystems on Earth, and we are only now beginning to fully appreciate their potential as eco-evolutionary resources. Therefore, we must confront a prickly question: What prevents the establishment of effective protection of subterranean biota and their inclusion in global conservation goals?

Amidst a climate emergency and a biodiversity crisis, the proportion of which are unmatched in human history, DarCo aimed to develop a concrete plan to incorporate subterranean ecosystems in the European Union (EU) Biodiversity Strategy for 2030—a plan to create Protected Areas for 30%

of EU land and sea territories by 2030. Europe offers unique opportunities to advance solutions for the protection of the subterranean biome. First, temperate regions are the main global hotspots of subterranean biodiversity, and Europe has the longest tradition of speleobiological studies. Second, the EU has already demonstrated its willingness to account for subterranean ecosystems in future sustainable development goals, for example by embracing the SDG 6-target 6.6 in the 2030 Agenda for Sustainable Development, highlighting the importance of groundwaters from an ecological perspective. The need for protecting groundwater resources also aligns with the COP26 objectives, expressing a strong reference to the importance of water as an ecosystem and in mitigating climate change. Third, through Habitats Directive (92/43/EEC) and the financial investments of the LIFE program, the EU has become a global experimental arena for practical conservation, successfully supporting the recovery of several threatened species and habitats.

3. METHODOLOGY

We brought together a team of leading scientists from across Europe to study subterranean ecosystems and commonly develop strategies for their protection. Our work focused on understanding these unique environments and the animals and plants that live there, such as crustaceans, spiders, insects, worms, vertebrates, and mosses. To start with, we gathered data from existing studies and, working with an international network of experts, we collect information about the habitats of these animals, what their characteristics are, and what environmental conditions they depend on. Using this data, we developed computer models to predict how subterranean species might respond to human activities, like land development or climate change. These predictions helped us map underground life in Europe for the very first time. By comparing these maps with information about human impacts and protected areas, we developed a plan to better safeguard underground biodiversity. This plan aimed to fill gaps in the current system of protected areas in the European Union. We also wanted to spread awareness about the importance of subterranean ecosystems. This was achieved through target dissemination and engagement activities, including seminars, interviews, social media activities, and publications intended for the general public. We also worked with governments and organizations to ensure subterranean ecosystems are included in national and international policies. All data we collected were made publicly available through an online database called the Subterranean Biodiversity Platform. This platform serves as a central hub for researchers, policymakers, and conservationists, helping them work together to protect subterranean life. Making the data open will also allow future generations to build on our knowledge and track the success of today's conservation efforts.

4. SCIENTIFIC RESULTS AND RECOMMENDATIONS

DarCo's main contribution to society was to transform how subterranean biodiversity is perceived by the public and target stakeholders. These "out-of-sight, out-of-mind" ecosystems are largely overlooked in the global public discourse and legislation, despite the critical benefits they provide. As part of DarCo, we established key connections and collaborations with international policymakers and advisors, creating a concrete opportunity to advocate for legislative changes that better protect subterranean resources. Indeed, the project was highly successful in attracting international attention, including from influential EU policymakers and advisors. Notable achievements include a close collaboration with the European Environmental Bureau on revising the EU Water Directive and a formal invitation by the EU Common Implementation Strategy Working Group on Groundwater to provide consultation on groundwater ecological research and conservation. In parallel with these high-level goals, we have established important connections at national and regional levels with speleological groups, national park authorities, water managers, and other stakeholders involved in managing subterranean resources at more localized scales. These efforts are already contributing to improving the local management of subterranean resources, particularly groundwater. Furthermore, these collaborations are helping to collect and centralize data and knowledge on subterranean biodiversity available to local stakeholders but not usable more broadly. Indeed, a key outcome of DarCo will be the collation of diverse data sources on subterranean biodiversity—especially species-level information—into a central repository, the Subterranean Biodiversity Platform. Lead experts in the consortium started to merge databases of individual taxonomic groups from different European countries. By the end of the project, all data generated by DarCo were made open and reusable, ensuring that information on subterranean biodiversity is broadly available to society in the long term. This will empower future generations to build on the knowledge accumulated about subterranean biodiversity and monitor the long-term effectiveness of today's protection measures.

5. DISSEMINATION AND VALORISATION

The main results of DarCo was the generation of openly accessible data and scientific evidence to support the inclusion of subterranean systems in European conservation plans and biodiversity goals. Foremost, we assembled continental-scale distribution and trait data for various subterranean taxa in Europe, including spiders, beetles, bats, and diverse crustacean groups. Some of these databases are already published in an open-access format, such as those for Asellota isopods (<https://doi.org/10.1111/1755-0998.13882>), copepods (<http://doi.org/10.1111/geb.13953>), ostracods (<https://doi.org/10.1111/geb.70065>), and subterranean spiders (<https://doi.org/10.32942/X2MQ0F>), making them ready for analysis and re-use for other purposes. The remaining datasets are currently being finalized. Furthermore, to provide useful background information supporting subterranean conservation, we developed synthesis publications and analyses focused on the main threats to subterranean ecosystems and the effectiveness of protection measures in safeguarding subterranean biodiversity. These include a global assessment of the multifaceted effects of climate change on subterranean ecosystems (<https://doi.org/10.1016/j.oneear.2023.09.001>) and an expert-based assessment of subterranean ecosystem threats and conservation measures, based on an online survey targeting key academics and stakeholders working in subterranean conservation (<https://doi.org/10.1016/j.biocon.2023.110136>). Using spiders as a test case, we also developed key modeling pipelines to map species' responses to various anthropogenic threats and create prioritization plans for expanding the coverage of protected areas in Europe. These plans incorporate species-relevant threats into the calculations to better protect subterranean biodiversity. Once fully tested, these analyses will be extended to multiple taxa. Scientific results are complemented by initiatives aimed at expanding awareness of subterranean ecosystems and increasing legislative coverage for subterranean biodiversity. For instance, we established collaborations with representatives of the European Environmental Bureau to bring critical points about subterranean conservation to the attention of EU legislators. Additionally, we have consolidated policy-relevant actions central to DarCo in a series of position papers, including a recent letter in Science (<https://doi.org/10.1126/science.ads8140>), which highlights a key gap in groundwater-relevant legislation currently under discussion by the EU. Finally, at national and local scales, each DarCo partner has built specific connections with local stakeholders, speleological groups, national park authorities, and other natural resource managers, based on various targets and needs.

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