

## VIEWPOINT

# A conservation roadmap for the subterranean biome

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### Abstract

The 15th UN Convention on Biological Diversity (CBD) (COP15) will be held in Kunming, China in October 2021. Historically, CBDs and other multilateral treaties have either alluded to or entirely overlooked the subterranean biome. A multilateral effort to robustly examine, monitor, and incorporate the

subterranean biome into future conservation targets will enable the CBD to further improve the ecological effectiveness of protected areas by including groundwater resources, subterranean ecosystem services, and the profoundly endemic subsurface biodiversity. To this end, we proffer a conservation roadmap that embodies five conceptual areas: (1) science gaps and data management needs; (2) anthropogenic stressors; (3) socioeconomic analysis and conflict resolution; (4) environmental education; and (5) national policies and multilateral agreements.

#### KEYWORDS

biodiversity, caves, convention on biological diversity, hypogean, indicator species

The 15th UN Convention on Biological Diversity (CBD) (COP15) (UNEP, 2021) will be held in Kunming, China in October 2021. Historically, CBDs and other multilateral treaties have either alluded to or entirely overlooked the subterranean biome (Sánchez-Fernández et al., 2021). Importantly, while the post-2020 global biodiversity framework (IUCN, 2020) briefly mentioned subterranean ecosystems, the need for an effective protected area network to safeguard biodiversity, freshwater, and ecosystem services had been strenuously and broadly emphasized. Globally, only ~7% of the modeled extent of the subterranean biome overlaps with protected areas (Sánchez-Fernández et al., 2021).

As the upcoming CBD meeting will be held in the South China Karst, a region supporting the highest diversity of subterranean-adapted fishes, beetles, and millipedes globally (and likely to emerge as a subterranean biodiversity hotspot), we provide this roadmap for conserving the world's subterranean resources. Through a multilateral effort to robustly examine, monitor, and incorporate the subterranean biome into future conservation targets, the CBD will further improve the ecological effectiveness of protected areas by including groundwater resources, subterranean ecosystem services, and the profoundly endemic subsurface biodiversity (Elshall et al., 2020; Mammola et al., 2019, 2020). To this end, this roadmap embodies five conceptual areas: (1) science gaps and data management needs; (2) anthropogenic stressors; (3) socioeconomic analysis and conflict resolution; (4) environmental education; and (5) national policies and multilateral agreements.

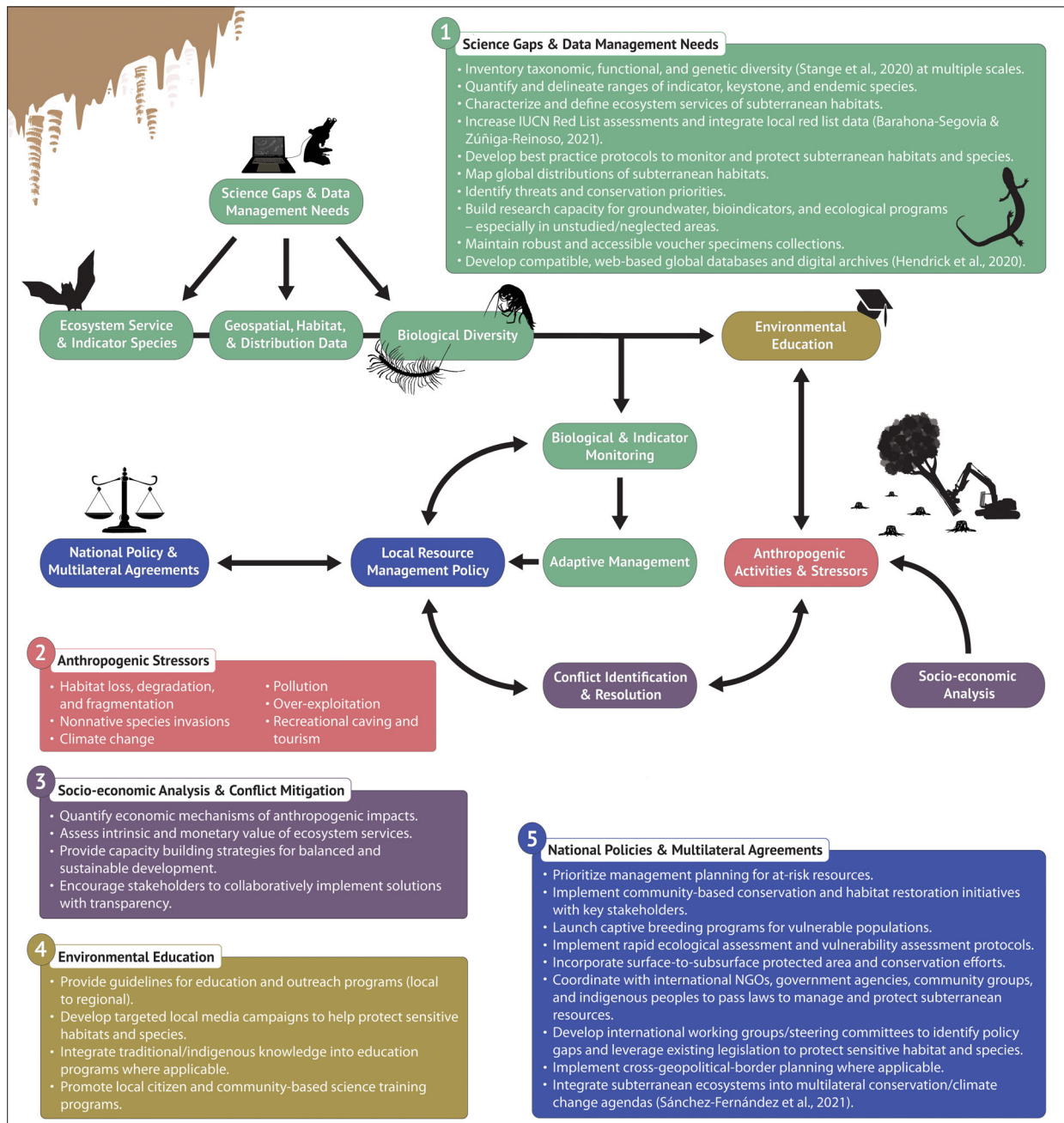
Perhaps even more than surface ecosystems, the terrestrial subterranean biome is riddled by extensive knowledge gaps (Box 1, Figure 1). For example, for most known subterranean-obligate species, we have little more than observational data from a few human-accessible localities (Mammola et al., 2019, 2020); this makes assessing species for protective management extremely challenging. While the importance of ecosystem services associated

with groundwater quality and cave-roosting bats is relatively well-documented (Elshall et al., 2020; Griebler et al., 2014; Mammola et al., 2019), a substantial effort will be required to quantify the scope, importance, and habitat requirements of subterranean bioindicator and ecosystem service species (Elshall et al., 2020).

Natural history information on the subterranean biome lags equally behind. Data deficiencies to be addressed should include developing a network of voucher specimen collections available both in brick-and-mortar locations and as digital archives. Additionally, the creation or adoption of an array of digital archives, tantamount to the World Karst Spring hydrograph database (Olarinoye et al., 2020), will provide conservationists and resource managers with the data to identify research needs and foster international and interdisciplinary collaborations. Such archives must house information on the geospatial extent of subterranean habitats, reference barcode/genetic and functional trait data on subterranean species, and synergistically contribute to or augment existing archives (Frick et al., 2020) (e.g., GBIF, iDigBio, and BoldSystems).

Although researchers have qualitatively summarized most of the likely anthropogenic stressors threatening subterranean biodiversity and ecosystem function (Box 2) (Elshall et al., 2020; Griebler et al., 2014; Leclère et al., 2020; Mammola et al., 2020), their potential impacts have not been quantified (Mammola et al., 2020). Strategically focused, global studies to examine key impacts (in particular, surface habitat loss) (Hedrick et al., 2020) should be conducted across a range of subterranean habitats, a panoply of associated indicators, and ecosystem service and short-range endemic species. Through such a coordinated effort, researchers and policymakers can amass the information required to develop mitigation strategies to optimize decision-making.

Solutions (Box 3) will require scientists and legislators to work closely with local communities and municipalities to both ameliorate future land-use disputes and to find sustainable and economically viable pathways



**FIGURE 1** Conservation roadmap flows from addressing data gaps and data management needs (green ovals with callout box) to policy development and implementation (blue). Data acquisition and management moves in two directions: (1) toward a feedback loop of monitoring, adaptive management, and local resource policy development – with monitoring and management iteratively improved as scientific data dictates; and (2) to providing information necessary to create educational outreach programs (yellow), which are further sculpted by human activities (red). Socio-economic analyses (purple) aim to both characterize and lessen anthropogenic impacts and stressors. This information then feeds into local resource management formulation; national policy and multilateral agreements are both shaped and influenced by local decision-making

forward. Importantly, 50% of humans rely on groundwater for consumption, while 43% use it for agricultural purposes (Elshall et al., 2020). As we increasingly convert natural ecosystems to agriculture, pastureland, and human habitation, surface biodiversity, and ecosystem function (Gibson et al., 2011), as well as aquifers and other groundwater habi-

tats will become increasingly threatened and degraded. To maximize effectiveness and reduce conservation conflicts, improved dialog between social and natural scientists must occur so that social, political, and scientific contexts are well articulated, and stakeholders can negotiate with complete transparency (Gibson et al., 2011).

Successful environmental and conservation education programs (Box 4) should be crafted to: (i) address local problems/topics; (ii) establish partnerships and programs with local researchers and resource managers; (iii) emphasize action focused projects (e.g., ecological restoration, cave cleanups, and monitoring bioindicators and bat/bird roosts); and (iv) create targeted projects that quantify and report program outcomes (Redpath et al., 2013). Educational efforts must be established in partnership with local schools and universities, scientific organizations, indigenous and community groups, businesses, non-governmental organizations, and government agencies.

Conservation policies (Box 5) to protect significant subterranean habitats are lacking at most regional and national levels (Mammola et al., 2020). However, policies have been implemented to better manage local and regional groundwater resources (Elshall et al., 2020). Barring the European Union's Habitat Directive (which marginally considers subterranean habitats; EU, 2021), no multilateral agreements have been adopted to specifically include the subterranean biome (Sánchez-Fernández et al., 2021). Solidly integrating surface with subsurface conservation targets through equitable stakeholder participation represents a foundational next step toward optimally securing the groundwater supply (Elshall et al., 2020), safeguarding ecosystem services (Frick et al., 2020; Mammola et al., 2020), and protecting subterranean diversity.

While numerous lacunae exist concerning subterranean resources, sound directives can be enacted promptly with adaptive management. This roadmap represents a viable framework for near-term and longer duration conservation actions to protect the world's subterranean ecosystems. Formulating targets to further reduce threats to the subterranean biome is essential to this year's CBD meeting in Kunming. We must act now.

## AUTHOR CONTRIBUTIONS

J. Judson Wynne and Stefano Mammola conceived the project. Francis Howarth developed the initial roadmap. All other authors contributed to roadmap development and finalization.

## ETHICS STATEMENT

No data collection or scientific inquiries requiring ethics considerations were undertaken. Thus, this work complies with appropriate ethical standards.


## DATA ACCESSIBILITY STATEMENT

We did not collect any primary data to develop this manuscript. All references that aided in refining our positions are provided.

## CONFLICT OF INTEREST

We declare no conflict of interest with this work.

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