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Citizen science as a promising approach for cave monitoring in protected areas

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Abstract: Caves hold significant tourist value due to their unique geology and biodiversity, making continuous monitoring essential for the preservation of their ecosystem services. This article aimed to assess the potential of citizen science in the environmental monitoring of caves within Protected Areas, with the goal of involving various stakeholders in the conservation of these environments. The research, qualitative and novel for this context, employed a methodology of literature review and questionnaires directed at experts from four State Parks in the Vale do Ribeira area (SP). Sixty international articles were analyzed, and responses from 20 researchers in the region were collected. Through Content Analysis, 17 best practices, 20 challenges, and 13 participatory monitoring indicators for public use in caves were identified. The results allowed for the identification of potential research gaps and the proposal of guidelines for future application of this approach in subterranean environments.

Keywords: Protected areas; participatory monitoring; underground environments; public use; parks.

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Introduction

Conservation Units (UCs) are protected areas essential for the preservation of the natural and cultural characteristics of Brazilian ecosystems, especially in the face of unregulated land occupation and unsustainable exploitation of natural resources (BENSUSAN, 2009). To ensure their effective protection, Law No. 9.985/2000 mandates that each UC must have a management plan, a guiding document for management, research, and monitoring actions (BRASIL, 2000). Monitoring is essential to address challenges such as threats to biodiversity, limited financial resources, and a shortage of qualified personnel.

Public use of UCs encompasses activities that allow society to access and benefit from these areas in a controlled and planned manner (BRASIL, 2000). Such use fosters public connection with nature, encourages conservation, and provides opportunities for learning and engagement. Activities range from recreational to scientific and educational (MMA, 2005). The growing number of visitors, especially in parks, demands guidelines that prioritize conservation (VALLEJO, 2013).

In the state of São Paulo, there are 60 UCs registered as parks (MMA/CNUC, 2020). This category plays a key role in conservation strategies and illustrates the management challenges stemming from the historical divide between society and nature (IRVING; MATOS, 2006). This is particularly relevant because parks aim to reconcile the full protection of flora, fauna, and scenic beauty with educational, tourism, and scientific use (BRASIL, 2000).

According to the database of the National Center for Research and Conservation of Caves (ICMBio, 2018), only eight state parks in São Paulo have registered caves: Intervales State Park, Alto do Ribeira Tourist State Park, Ilha do Cardoso State Park, Serra do Mar State Park, Caverna do Diabo State Park, Carlos Botelho State Park, and Rio Turvo State Park. Most caves are concentrated in the Vale do Ribeira region, home to one of the most important remnants of the Atlantic Forest, recognized as a UNESCO Natural World Heritage Site.

The lack of effective environmental monitoring in such environments has long been a concern. Trajano and Bichuette (2006) highlighted the urgency of defining more efficient monitoring strategies to meet conservation goals. According to these authors, caves are fragile ecosystems with unique characteristics that may play an essential role in water storage, aquifer recharge, and as archaeological and geological records. Their protection depends on conservation actions targeting both the surroundings and the internal environment of these cavities (TRAJANO & BICHUETTE, 2006).

The implementation of participatory environmental monitoring programs in protected areas has proven effective in engaging society in biodiversity conservation and promoting dialogue on the importance of protected areas (ORTEGA-ÁLVAREZ et al., 2017; DANIELSEN et al., 2009).

In Brazil, 275 citizen science initiatives have been registered on the Cívis platform, which compiles and categorizes projects involving public participation in scientific production (CÍVIS, 2025). These data reflect the growing adoption of this practice in the country, despite structural and governance challenges already discussed by Queiroz-Souza et al. (2023), such as project sustainability, integration with public policies, and social inclusion in participatory actions.

Citizen science should be understood broadly, encompassing a variety of partnerships between scientists and people interested in science, aiming at the shared production of knowledge based on scientific practice and the integration of diverse ways of knowing (RBCC, 2023). Nunes et al. (2023) describe this approach as an umbrella term in protected areas, covering practices from birdwatching, attracting visitors worldwide, to the observation of mammals, invertebrates, and landscapes (MAMEDE; BENITES; ALHO, 2017).

Beyond data collection, citizen science plays a key role in engaging the public in the conservation of threatened species, balancing education, environmental management, research, and social development (FREITAG, 2016; NUNES et al., 2023). Given its potential and the lack of studies addressing its application in subterranean environments, this article aims to explore the potential of cave environmental monitoring in protected areas, grounded in the principles of citizen science.

Methodology

The methodology was structured in multiple stages, beginning with a literature review conducted on the SciVerse Scopus and Web of Science platforms, selected for their comprehensiveness and relevance in indexing peer-reviewed scientific articles. The review covered the period from 2009 to 2019 and initially employed keywords intersecting terms related to citizen science and cave environments. However, no articles addressing citizen science in the context of caves were identified, highlighting the scarcity of studies in this area and the unique contribution of this research. A second search was then performed, this time excluding cave-related terms ("cave*" OR "underground environments*"), and focusing the search equation on: ("citizen science" OR "community-based monitoring") AND ("protected area*" OR "natural heritage*").

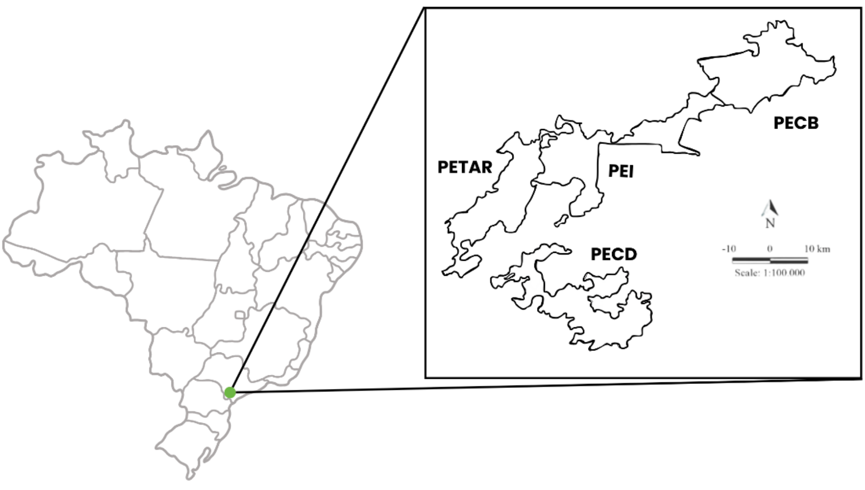
Eligibility criteria included: Language, limiting the review to articles written in Portuguese, English, or Spanish to ensure comprehension and proper analysis; Disciplinary focus, restricting the selection to articles from environmental and/or social sciences, due to the interdisciplinary nature of the topic; Access, including only open-access articles or those available through the CAPES journal portal, to ensure accessibility for analysis; and Relevance, selecting only documents that presented clear contributions regarding good practices and challenges in citizen science.

The selected documents were analyzed using Content Analysis, a technique that systematically examines texts to extract indicators that support inferences (Bardin, 2011). The process included a pre-analysis phase (organization), material exploration (coding and categorization), treatment of results, followed by inference and interpretation. Using this approach, the data were categorized into Good Practices and Challenges, with subcategories aligned to key dimensions of citizen science implementation in protected areas worldwide: Community, Governance, Research, Management, and Economy.

To understand the applicability of citizen science to cave monitoring in protected areas in Brazil, the Vale do Ribeira region was selected as a case study due to its ecological and cultural significance. Located in the state of São Paulo, the region is home to several *quilombola* and Indigenous communities that maintain ancestral traditions and ways of life. Additionally, it contains the largest remaining continuous stretch of preserved Atlantic Forest in Brazil, making it a critical refuge for both biodiversity and speleological studies.

Considering the ecological and cultural relevance of the region, a survey was conducted to review the public use indicators contained in the management plans of the four main state parks in the area that include caves open to visitation: Intervales State Park, Alto do Ribeira Tourist State Park, Caverna do Diabo State Park, and Carlos Botelho State Park (Figure 1). This survey aimed to identify which indicators could be monitored by ordinary citizens, thereby promoting active community participation in the conservation of these valuable natural environments.

Figure 1. Location of the selected parks in the Vale do Ribeira region, São Paulo: Alto do Ribeira Tourist State Park (PETAR), Intervales State Park (PEI), Carlos Botelho State Park (PECB), and Caverna do Diabo State Park.



Source: The authors, 2025.

The final stage of the methodology consolidated the data from the literature review and park management plans to support the development of an online questionnaire with semi-open questions. The questions were organized into sections on challenges, good practices, and recommendations, with the goal of assessing the applicability of the citizen science approach in cave environments within São Paulo's protected areas. This questionnaire was sent to 40 experts active in the Vale do Ribeira region (see Figure 1), identified through a search on the website of the Brazilian Speleological Society, using as a criterion the groups registered in the State of São Paulo. According to Gil (1999), the questionnaire is an effective research tool as it enables wide reach, cost reduction, response anonymity, and flexibility, without direct interviewer influence. This research method was approved by the Brazilian Ethics Committee via Plataforma Brasil (CAAE: 30608820.2.0000.5390).

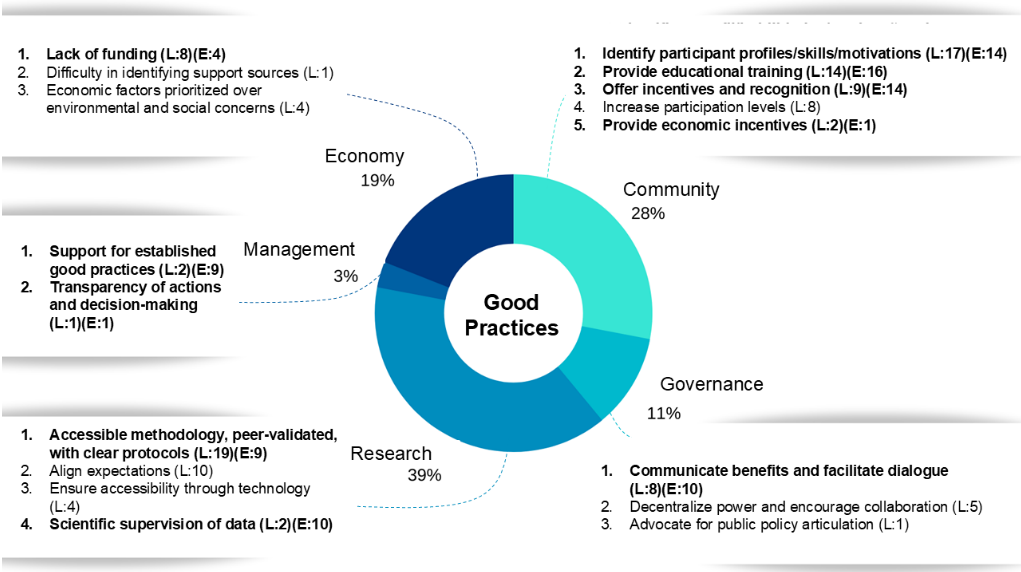
Results and Discussion

The results provide a comprehensive overview of the challenges and opportunities involved in applying citizen science to cave monitoring. The literature review initially identified 300 articles, of which 60 met the eligibility criteria and were analyzed in depth. The analysis of the management plans highlighted specific challenges and indicators for the Vale do Ribeira region. Additionally, questionnaires were sent to 40 researchers affiliated with Brazilian institutions, and 20 responses were received, representing a 50% response rate. Despite this moderate return, this pioneering qualitative research fills important knowledge gaps in the field.

Good Practices in Citizen Science for Cave Environments

To understand the most suitable methodological practices for the socio-environmental reality of the study area, this section presents findings from the literature alongside responses to the following semi-open questionnaire question: "Among the good practices identified in the literature, which do you consider important during the implementation of a citizen science-based monitoring program?" As a result, 17 recommendations were identified in the literature, of which 9 were reaffirmed by the specialists consulted (Figure 2).

Figure 2. Good practices identified through literature review and questionnaire responses. The number of times each practice was mentioned is shown in parentheses, with "L" indicating literature and "E" indicating experts. Bold lines highlight practices confirmed by both sources.



Source: The authors, 2025.

Scientific oversight of data in citizen science monitoring was one of the main concerns raised by respondents. One participant remarked: "If it occurs in an organized, collective way, and mostly with the participation of researchers, I see no reason why citizen science wouldn't be a good idea." This recommendation is especially relevant for sensitive environments such as caves, particularly in preliminary studies (TOOMEY ET AL., 2009; TRIMBOLI & TOOMEY, 2016).

Several respondents suggested that citizen science projects should be linked to institutions engaged in speleological research or education. The involvement of universities can bring significant benefits, such as ensuring scientific rigor and optimizing resources (STEGER et al., 2017). According to Volten et al. (2018), academic institutions can support these initiatives through professional expertise, existing infrastructure, interdisciplinary networks, and citizen science platforms.

Regarding data accessibility and transparency, citizen science is aligned with the broader open science movement, which includes open- access publications, open-source software, and standardized open data. One specialist stated: "Institutions and researchers leading citizen science projects should be encouraged to adopt open practices." Full transparency about research objectives, protocols, and analytical methods fosters public trust and ensures the quality and reproducibility of results (BROWN et al., 2018).

In terms of ensuring data quality and reliability, the literature highlights the importance of clearly defined protocols, data collection controls, and statistical robustness during project design (TORNEY et al., 2019). However, in sensitive environments, such as caves, methods must be validated by experts (BIRD et al., 2013). Involving large numbers of individuals may reduce measurement accuracy, such as in species identification or counts. Biases can also arise from species under-detection or non-random sampling efforts (NEWMAN et al., 2011).

Both the literature and experts emphasized the importance of including participants from diverse backgrounds. Bird et al. (2013) stress the need for collaboration between statisticians and volunteers to understand sampling limitations, which may involve trial and error. Given the variety of available modeling approaches, it is essential to identify data gaps, assess their impact, and choose appropriate methods to address them.

To minimize biases, one expert recommended: "It is vital to record data on environmental conditions or aspects of the research process likely to influence results." Bird et al. (2013) point out that while data collection protocols may be standardized, complete uniformity in sampling is unlikely. In cases where measurement subjectivity poses a risk, data collection methods should enable bias characterization, validation, or hierarchical modeling (Bird et al., 2013; Freiwald et al., 2018). Examples include resampling known areas, using training datasets, or conducting research with multiple observers.

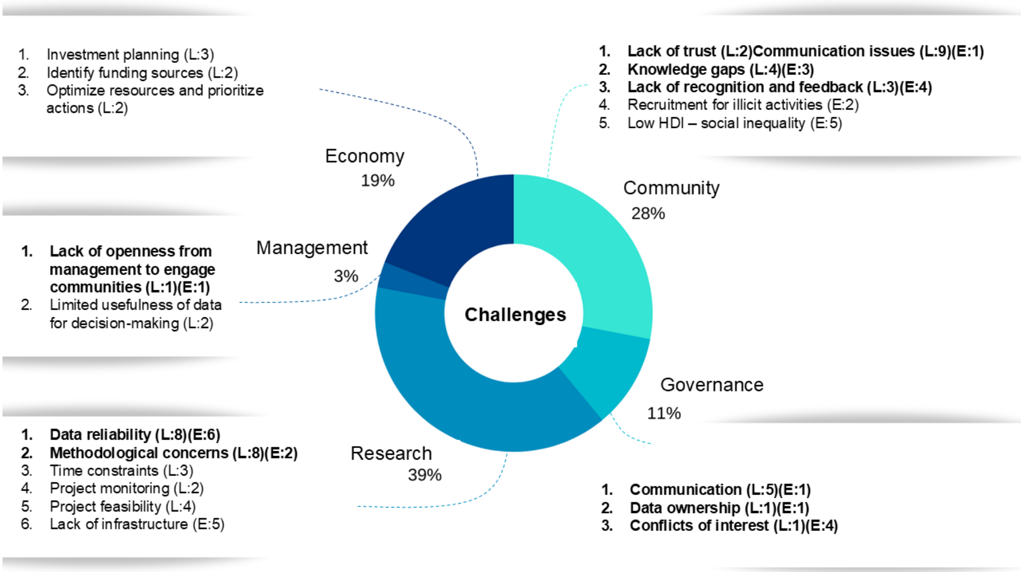
Another respondent emphasized the role of citizen science in promoting conservation awareness among residents: "I believe citizen science can contribute to cave conservation by building awareness among nearby communities. Many caves already have guardians, training these individuals is a way to help preserve speleological heritage. Tourism, when combined with local guide training, can be an excellent tool for sustainable use and cave preservation, while also generating income for local communities. This is the case in PETAR, where guides are trained and educated not only about cave conservation but also about the entire surrounding ecosystem, which is their main source of livelihood."

Lastly, the importance of "evaluating how citizen science programs are perceived by participants themselves" emerged strongly in the questionnaire responses, even though this aspect is often overlooked in planning. Feedback on both methodologies and participant experiences and expectations is critical to the continuity of monitoring efforts and can guide future improvements (KOSS et al., 2009).

Challenges to Adopting Citizen Science in Environmental Monitoring

In a semi-open question, researchers were asked: "What challenges related to local communities could, in your opinion, hinder the implementation of a citizen science project in State Parks?" The content analysis of both the literature review and questionnaire responses revealed 20 challenging scenarios, three of which represented new obstacles intrinsically linked to the local socio-economic context (Figure 3). These newly identified challenges included: (i) recruitment and influence by organized crime; (ii) low Human Development Index (HDI) in the region, with associated social and economic vulnerabilities; (iii) limited technological infrastructure for data collection and transmission.

Figure 3. Percentage of challenges identified in the literature review and questionnaire responses. The number of times each challenge was mentioned is shown in parentheses, with "L" indicating the literature and "E" indicating experts. Bold lines highlight challenges confirmed by both sources.



Source: The authors, 2025.

According to UNDP data (2019), the Vale do Ribeira region has one of the lowest HDI scores in the state of São Paulo, averaging 0.711, compared to the state average of 0.783 and the national average of 0.769. Therefore, discouraging illicit activities must be accompanied by enforcement efforts and the provision of economic opportunities for local communities.

Respondents indicated that visitation in the parks plays a dual role in addressing irregularities: "The presence of environmental monitors, speleologists, and visitors in the protected area helps deter hunters and palm heart extractors, while also supporting enforcement teams and generating income." This potential aligns with local development strategies that seek to stimulate the region's economy by employing, directly or indirectly, a significant portion of the workforce currently involved in unsustainable practices (SÃO PAULO, 2010a).

Conflicts of interest and communication challenges affect how communities relate to decision-makers, whether managers or researchers. One respondent noted: "Low HDI levels in the region often lead to conflicts of interest between communities and Conservation Units, in addition to low levels of education and scientific literacy".

These challenges must be anticipated during the planning phase of monitoring initiatives. Open workshops and community dialogues can help address such issues and uncover underlying motivations, as discussed in the previous section.

Other concerns raised in the questionnaires related to scientific oversight and the reliability of collected data. One participant questioned: "How can the same individuals who benefit from cave tourism be expected to reliably collect data on the impacts of that tourism? Won't they be inclined to minimize negative impacts in their reports?" To reduce bias and ensure the credibility of monitoring, the rigorous maintenance of methodological standards and periodic oversight by experts are strongly recommended (BARNARD et al., 2017; KAYS et al., 2017; FLESCH et al., 2017).

The lack of infrastructure for data collection and transmission is widely recognized in the literature as a critical weakness requiring urgent attention (MILLER-RUSHING & PRIMACK, 2008; KOBORI et al., 2019; MCKINLEY et al., 2017). Providing adequate support for these activities is vital, especially considering the increasing importance of technology in natural resource conservation and inclusive management worldwide. However, in the context of Brazilian protected areas, this represents a major challenge, as these areas face one of the lowest investment levels globally (MEDEIROS, 2011).

Environmental Monitoring Indicators for Public Use Activities

This section presents a survey of visitation impact indicators contained in the management plans of the four state parks in the Vale do Ribeira region, alongside insights from specialists gathered through a semi-open question: "Which indicators do you believe could be monitored by ordinary citizens?" The responses were classified based on the principle that a good indicator must define specific conditions and be verifiable, replicable, objective, and reliable (MANNING, 1999), allowing for comparison between the indicators defined in the management plans and the suggestions from the experts.

The selected State Parks (PEI, PECD, PETAR e PECB) have monitoring programs outlined in their management plans that include specific indicators to assess visitation impacts. These programs define field verification methods, monitoring frequency, and action strategies. Indicators are generally categorized as Social/Anthropic, Biotic, Physical/Abiotic, and, in the case of Intervales State Park, also Climatic indicators.

The analysis yielded 6 social indicators, 4 biotic, 8 physical, and 4 climatic indicators considered feasible for citizen science-based monitoring (Chart 1). Responses that did not meet the criteria of a good indicator per Manning (1999) were grouped as "Unclassifiable," including items such as: "Cave surroundings and their use," "State of trail conditions," "Occurrence of fires near caves," "Reports of illegal practices," "Reports of vandalism," "Mining activity and particulate emissions from nearby industries," "General cave environment," "Obvious anthropogenic changes," "Terrain modifications," "Environmental degradation control," "Accessibility," and "Photomonitoring."

Chart 1. Questionnaire responses on potential indicators of public use impacts that can be monitored by non-scientists and their presence in management plan monitoring programs.

Indicators from Questionnaire	Responses	Indicators in Management Plans
Social	Litter	✓
	Infrastructure Damage	✓
Biotic	Changes in Fauna Composition	✓
	Changes in Bat Behavior	✓
	Vegetation Cover in Surroundings	
Physical	Water Quality	✓
	Particulate Matter Suspension	✓
	Stains on Walls	✓
	Damage to Speleothems	
	Water Level	✓
Climatic/Physical	Temperature	✓
	Relative Humidity	✓
	Climatic Variables	

Source: The authors, 2025.

Although photomonitoring appears in all management plans, it is more accurately classified as a method rather than an indicator per se, as it does not fulfill the definitional requirements of a public use impact indicator.

According to ICMBio's Methodological Guide for Managing Visitation Impacts (2014), social indicators measure the influence of visitation activities on the social context of the protected area, assessing economic, cultural, behavioral, and spatial dynamics.

Beyond monitoring litter and infrastructure damage, mentioned in both management plans and expert responses, some studies have analyzed tourist behavior and preferences using photos posted on social media platforms such as Instagram, Facebook, and Flickr (PICKERING et al., 2020). Image content and hashtags related to locations or activities have proven to be valuable sources of data, complementing traditional research methods and helping to identify harmful behaviors to the environment and other visitors.

Such approaches have also supported communication strategies targeting tourists, promoting adherence to safety guidelines (PICKERING et al., 2020). Despite their potential, the use of technologies within citizen science principles (ECSA, 2015) requires integrating non-scientists in data collection efforts, ensuring that volunteers understand how their hashtags, images, and posts contribute to monitoring and environmental education.

Among the many indicators studied globally, biotic and physical indicators are the most frequently assessed by non-scientists (EITZEL et al., 2015; KOBORI et al., 2018). Notable examples include monitoring changes in macrofauna composition through species presence/absence data collected by trained volunteers or photomonitoring (CONRAD & HICHEY, 2011; THIEL et al., 2014; LEONG & KYLE, 2014; BENJAMINS et al., 2018). These indicators are suitable for citizen monitoring when supported by clear data collection protocols.

Vegetation cover around caves, particularly along trails, was also identified as a viable indicator for citizen monitoring. Although not explicitly included in the management plans, this factor influences sediment input into caves, soil and water protection, and even visitor well-being, mitigating extreme climatic conditions (SILVERIO, 2014).

Sediment input occurs when soil or debris is carried into caves on the shoes of visitors, most commonly near cave entrances. The quantity transported depends on drainage conditions and trail soil type (TOOMEY, 2009). In some cases, sediment can be observed throughout the full extent of the visitor-accessible route (MARRA, 2001). This process may accelerate the dissolution of carbonate rocks due to decomposition-related acidification, or disrupt subterranean food webs, even though caves are typically stable in terms of organic matter content (MARRA, 2001; TOOMEY, 2009; ZANATTO et al., 2019). Since visitors are often the agents of this sediment transport, including them in monitoring could yield significant benefits.

As previously mentioned, physical indicators are well established for both conventional and citizen science-based cave monitoring. For example, water quality and water level, identified in the management plans and by speleology experts, are prominent. One illustrative case comes from Mexico, where researchers engaged students, teachers, divers, and residents to monitor groundwater quality in the Caribbean karst system. Their methods included photography, questionnaires, water sampling, and stakeholder workshops to foster sustainable water resource management (SCHILLER et al., 2019).

Although literature on citizen science for cave monitoring remains limited, some methodologies used in surface environments can be adapted to subterranean contexts (TOOMEY et al., 2009; TRIMBOLI et al., 2016). This includes indicators such as: (i) Suspended particulate matter; (ii) Changes in speleothems; (iii) Erosion. These three indicators are easy to observe and identify, and are suitable for citizen science monitoring through annotations, surveys, or photographs, especially when paired with educational efforts.

Suspended particulate matter, commonly found in dry cave areas, is linked to visitor movement, which stirs up soil particles that settle on speleothems and cave walls. Over time, this material builds up, altering the color and potentially the composition of these formations (MARRA, 2001; TOOMEY et al., 2009).

Darkening of speleothems and cave walls is often caused by direct contact with dirty hands and shoes. This typically results from a lack of infrastructure, prompting visitors to use formations for support while walking (MARRA, 2001). In the case of erosion, trampling leads to riverbank collapse, increasing water turbidity and potentially initiating sediment deposition in riverbeds. These effects can negatively impact aquatic fauna (SÃO PAULO, 2010a). As a mitigation measure, Marra (2001) recommends directing visitors away from river margins.

Climatic and physical indicators also play an important role. Analyzing cave environment parameters and their correlation with potential environmental damage is essential for planning and monitoring public use, particularly in determining the carrying capacity of caves (SÃO PAULO, 2010; MARRA, 2001).

Cave microclimates typically differ from external environments. Monitoring external climate conditions supports public use planning but is not directly associated with visitation impacts (SÃO PAULO, 2010a; SÃO PAULO, 2010b). However, certain events, such as flooding, pose risks in restricted cave areas, particularly those with perennial drainage (CIGNA, 2004). Flooding can also cause cyclical disturbances to troglobitic fauna, making flood risk monitoring advisable (MARRA, 2001; CIGNA, 2004).

Regarding water flow, negative impacts from public use in surrounding environments may reduce epikarst water volumes. In this context, some studies have utilized photographic or video-based monitoring to track hydrological volume changes, applying relevant keywords on digital platforms (KAYS et al., 2015; SWANSON et al., 2016; BENJAMINS et al., 2018).

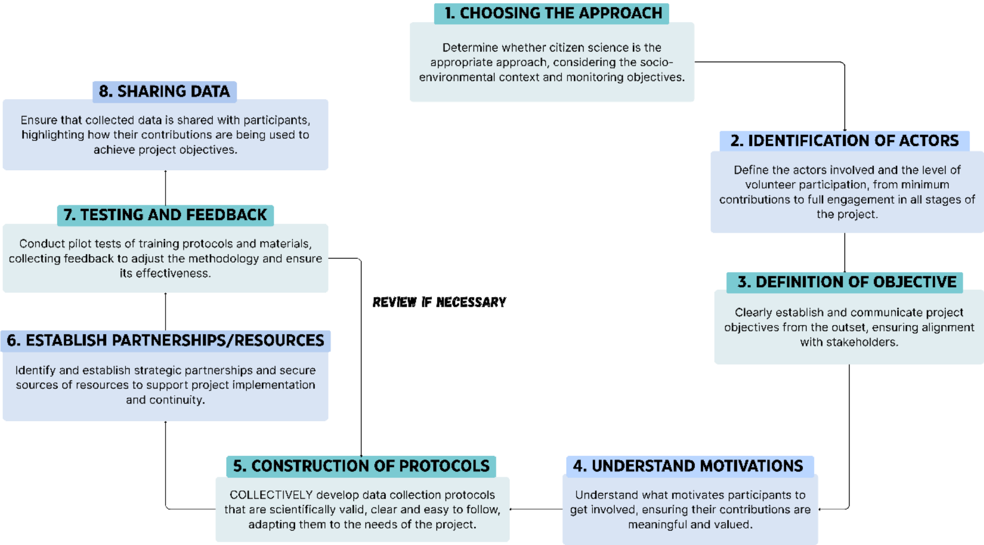
Another key point is the need to assess the conservation value of each cave. Some may only support adventure tourism or research activities. In cases involving endemic species, both the literature and consulted experts recommend prohibiting visitation and avoiding the application of citizen science approaches.

Finally, monitoring by citizen participants should be strictly limited to areas where public access is already permitted (ECSA, 2015). Thus, planners must design projects that match the type of data to be collected with the profiles of different participant groups, such as tourists, guides, or students.

Practical Recommendations

This section presents practical guidance derived from the content of the systematic literature review and responses gathered from the questionnaires. These recommendations are directed at planners and decision-makers to inform the necessary aspects for developing a citizen science project in cave environments within protected areas (Figure 4).

Figure 4. Recommendations based on questionnaire responses and literature review, outlining a suggested sequence of steps for citizen science projects.



Source: The authors, 2025.

Defining the citizen science approach before selecting specific methods is essential. This phase involves determining the level of volunteer participation in the project, considering the different models available (BONNEY et al., 2009; SHIRK et al., 2012; DANIELSEN et al., 2009). For example, in the final remarks of the questionnaire, some researchers recommended deeper volunteer involvement from the early stages of the project, provided that this engagement is strategically planned in the long term and includes efforts to build bridges between decision-makers and local communities in the Vale do Ribeira.

Likewise, the objectives of the project must be clearly defined and communicated from the outset (EITZEL, 2015; CONRAD & HICHEY, 2011). It is recommended that the core monitoring question be something that resonates with the public, since motivation to participate is often linked to a desire to contribute to a meaningful cause (LEONG & KYLE, 2014).

The methodology should include clear and scientifically valid protocols, with criteria that ensure data reliability (ROQUE et al., 2018). At the same time, these protocols must be simple and easy to implement, especially considering that many participants may lack prior scientific training (FLESCH et al., 2017).

When implementing a citizen science project within Conservation Units, it is essential to prioritize actions based on available resources and carefully define which stages will include participant involvement, in order to maximize the project's effectiveness and impact (TRIMBOLI & TOOMEY, 2016). Although citizen science is often seen as accessible, such projects are not cost-free and require investments in materials, training, and ongoing support (THIEL et al., 2014; LARSON et al., 2016; KOBORI et al., 2018).

The Brazilian Biodiversity Information System (SiBBr) offers national examples that can serve as references, especially for integrating data from large-scale projects. Partnerships with universities can help optimize resources and increase the scientific relevance of the data collected.

Although many citizen science projects focus on natural resource monitoring, attention should also be given to the cultural dimensions of cave environments. For instance, monitoring impacts on cave wall paintings is a relevant area of concern. The use of photographic documentation to monitor changes in cultural resources is a viable solution and has already been applied in other contexts (TRIMBOLI & TOOMEY, 2016). These photo records allow for direct comparison and the detection of changes over time.

An important step in developing a citizen science project is the testing of research protocols, forms, and training materials, ensuring that the methodology is appropriate and understandable to all participants (CONRAD & HICHEY, 2011; SHUMBA et al., 2018). Conducting a pilot study allows for adjustments prior to full-scale implementation. Additionally, evaluation should be an ongoing process, addressing both data quality and participant experience. Involving all stakeholders in the evaluation process ensures diverse perspectives are considered and fosters improvements aligned with the monitoring objectives.

Finally, data sharing is equally critical. The recommendations highlight the importance of informing participants, whenever possible, about how their data are being used and what results the project has achieved. This practice reinforces the value of their contribution and underlines the significance of their engagement (BARNARD et al., 2017; HU et al., 2017).

Conclusions

This study encompassed an analysis of international best practices and the perspectives of researchers regarding the application of citizen science within the socio-economic and environmental context of caves in the state of São Paulo, Brazil. The questionnaire responses revealed novel aspects not previously addressed in the international literature, including specific recommendations for projects on this topic, challenges related to conflicts of interest and illicit activities within Conservation Units, and the identification of 13 environmental monitoring indicators deemed feasible for citizen science initiatives in caves open to public visitation.

This preliminary research provided an initial framework for the implementation of cave monitoring programs grounded in the principles of citizen science and aligned with the needs identified in the management plans of the State Parks located in the Vale do Ribeira (São Paulo). Nevertheless, the findings underscore the need for further studies to evaluate the effectiveness of citizen science methodologies in subterranean environments, as well as the development of strategies to overcome the challenges identified.

It is hoped that the results presented here will serve as a foundation for future research in this field, expanding both the understanding and application of citizen science in environmental conservation, fostering greater social engagement, and enhancing data collection in monitoring efforts.

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A Ciência Cidadã como Abordagem Promissora para o Monitoramento de Cavernas em Áreas Protegidas

Gabrielle Abreu Nunes
Victor Eduardo Lima Ranieri

São Paulo. Vol. 28, 2025
Artigo Original

Resumo: As cavernas possuem um elevado valor turístico devido à sua geologia e biodiversidade únicas, o que torna o monitoramento contínuo essencial para a preservação de seus serviços ecossistêmicos. Este artigo teve como objetivo avaliar o potencial da ciência cidadã no monitoramento ambiental de cavernas em Unidades de Conservação, buscando envolver diversos atores na conservação desses ambientes. A pesquisa, qualitativa e inédita para esse contexto, utilizou a metodologia de revisão bibliográfica e questionários direcionados a especialistas de quatro Parques Estaduais do Vale do Ribeira (SP). Foram analisados 60 artigos internacionais e coletadas as respostas de 20 pesquisadores da região. Através de uma Análise de Conteúdo, foram identificadas 17 boas práticas, 20 desafios e 13 indicadores de monitoramento participativo para o uso público em cavernas. Os resultados permitiram identificar possíveis lacunas de pesquisa e propor direcionamentos para futuras aplicações dessa abordagem em ambientes subterrâneos.

***Palavras-chave*:** Áreas protegidas; monitoramento participativo; ambientes subterrâneos; uso público; parques.

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La ciencia ciudadana como enfoque prometedor para el monitoreo de cuevas en áreas protegidas

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Artículo Original

Resumen: Las cuevas tienen un alto valor turístico debido a su geología y biodiversidad únicas, lo que hace que el monitoreo continuo sea esencial para la preservación de sus servicios ecosistémicos. Este artículo tuvo como objetivo evaluar el potencial de la ciencia ciudadana en el monitoreo ambiental de cuevas en Unidades de Conservación, buscando involucrar a diversos actores en la conservación de estos entornos. La investigación, cualitativa e inédita para este contexto, utilizó una metodología de revisión bibliográfica y cuestionarios dirigidos a especialistas de cuatro Parques Estatales en la región del Valle del Ribeira (SP). Se analizaron 60 artículos internacionales y se recopilaron las respuestas de 20 investigadores de la región. A través de un Análisis de Contenido, se identificaron 17 buenas prácticas, 20 desafíos y 13 indicadores de monitoreo participativo para el uso público en cuevas. Los resultados permitieron identificar posibles lagunas de investigación y proponer directrices para futuras aplicaciones de este enfoque en entornos subterráneos.

Palabras-clave: Áreas protegidas; monitoramento participativo; ambientes subterrâneos; uso público; parques.