

## Preserving biodiversity: the critical role of herbaria in plant conservation

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**Abstract:** Plant species are disproportionately suffering from the world's unprecedented loss of biodiversity. Herbaria, repositories of preserved plant specimens, play a vital role in plant conservation by providing a permanent record of plant diversity, facilitating taxonomic research and species discovery, informing conservation status assessment and monitoring, supporting ex situ conservation and restoration, and contributing to climate change research and policy development. This review underscores the crucial role of herbaria in plant conservation, highlighting their crucial role in maintaining plant biodiversity and guiding conservation efforts. It posits that herbaria serve as crucial infrastructure for plant conservation, warranting priority in biodiversity research and policy initiatives.

**Keywords:** Plant conservation, biodiversity, taxonomy, botanical collections, species discovery

### Introduction

Plant species are disproportionately affected by the extraordinary global loss of biodiversity (Corlett, 2016). Plants constitute the foundation of ecosystems, supplying sustenance, refuge, and habitat for

numerous species and humans (Fernando, 2012). They serve a vital role in climate regulation, oxygen production, and the enhancement of human well-being. Herbaria, collections of preserved plant specimens, are essential for plant conservation (Bebber et al., 2010). These collections offer a lasting documentation of plant diversity, enabling researchers to examine and comprehend the evolution, distribution, and ecology of plant species (Eckert et al., 2024). Herbaria function as a resource for conservation initiatives (Nualart et al., 2017), offering critical information regarding the distribution, abundance, and habitat necessities of plant species (Figure 1). Herbarium specimens (Figures 4-6), beyond being mere dried plants, encapsulate extensive information regarding plant diversity (James et al., 2018). Each specimen serves as a tangible record of a plant's morphology, anatomy, and reproductive traits, offering a glimpse into the plant's evolutionary history (Eckert et al., 2024). Herbarium specimens provide crucial information regarding a plant's habitat, distribution, and ecology, rendering them an indispensable resource for conservation initiatives (Bebber et al., 2010). Notwithstanding the significance of plant conservation, numerous plant species are encountering unparalleled threats. Habitat destruction, climate change, and overexploitation are among the primary reasons contributing to plant extinctions (Shivanna, 2022). The decline in plant diversity has extensive repercussions, encompassing ecosystem disruption, the diminishment of ecosystem services, and the degradation of human well-being (Mooney, 2010). Therefore, require efficient conservation techniques to address the magnitude and immediacy of the plant extinction catastrophe. Herbaria can significantly contribute to conservation initiatives by supplying essential data on plant variety, distribution, and ecology (James et al., 2018). Utilising the extensive data housed in herbaria, researchers and conservationists may formulate more efficient conservation strategies aimed at the most susceptible plant species (Eckert et al., 2024). This review seeks to emphasise the essential function of herbaria in the conservation of plants (Lang et al., 2019). We will examine the significance of herbarium specimens, the obstacles confronting plant conservation, and the necessity for efficient conservation techniques.



Figure 1: A typical herbarium unit

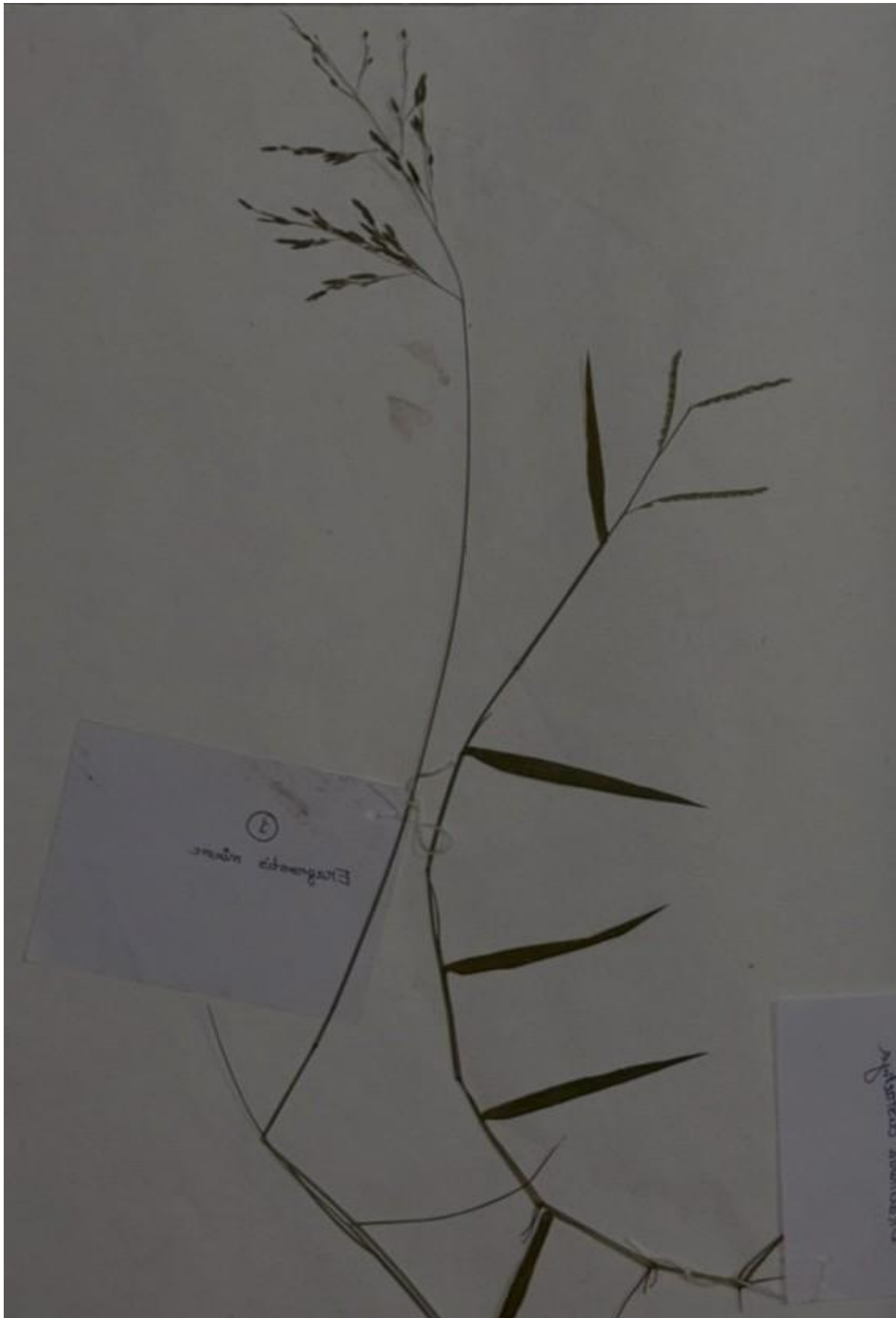


Figure 2: Dried plant specimen for herbarium

### The value of herbarium specimens

Herbarium specimens are a treasure trove of information on plant diversity, containing a wealth of data on plant morphology, anatomy, ecology, and evolution. These specimens are carefully collected, preserved, and documented to provide a permanent record of plant species, their distribution, and their characteristics (Bebber et al., 2010; James et al., 2018). Details are discussed in this section.

1. Morphological data: Details on plant shape, size, color, and texture, including characteristics of leaves, stems, flowers, and fruits.
2. Anatomical data: Information on plant internal structure, including details on cellular composition and tissue organization.
3. Ecological data: Notes on plant habitat, distribution, and environmental preferences.
4. Taxonomic data: Information on plant classification, including species identification, genus, family, and order.
5. Geographic data: Details on plant distribution, including latitude, longitude, and elevation (Marsico et al., 2020).

### Need of herbarium specimens

Herbarium specimens are a vital component of botanical research, conservation, and education, serving as a permanent record of plant diversity and distribution. The need for herbarium specimens arises from their role in facilitating accurate identification, classification, and taxonomy of plant species, which is essential for understanding ecosystem dynamics, monitoring biodiversity, and informing conservation efforts.



Figure 3: Preparation of herbarium specimen

Furthermore, herbarium specimens provide a tangible link to the past, allowing researchers to study the evolutionary history, biogeography, and ecological adaptations of plant species, while also serving as a reference point for future research and discovery. By preserving plant specimens, herbaria support a wide range of scientific disciplines, from botany and ecology to medicine, agriculture, and environmental science (Nic Lughadha et al., 2018; Eckert et al., 2024; Figure 2-3). By examining herbarium specimens, researchers can gain a deeper understanding of plant diversity, informing taxonomic research, species discovery, and conservation efforts (Bebber et al., 2010). The major needs are discussed below.

1. Taxonomic research: Herbarium specimens provide the foundation for plant classification, allowing researchers to study and describe new species.
2. Species discovery: Herbarium specimens can reveal new species, subspecies, or varieties, expanding our understanding of plant diversity.
3. Conservation: Herbarium specimens inform conservation efforts by providing data on plant distribution, abundance, and habitat requirements.
4. Understanding plant evolution: Herbarium specimens have provided valuable insights into plant evolution, including the study of fossil plants and the reconstruction of evolutionary relationships (James et al., 2018).
5. Informing conservation efforts: Herbarium specimens have informed conservation efforts, such as the development of species recovery plans and the identification of areas of high conservation value (Eckert et al., 2024).

### **Herbaria and conservation status assessment**

Herbaria play a crucial role in assessing the conservation status of plant species. By providing accurate species identification and distribution data, herbaria inform conservation efforts and help protect endangered plant species (Eckert et al., 2024). Important herbaria of world are Royal Botanic Gardens, New York Botanical Garden, Australian National Herbarium and Herbarium Unit of Botanical Survey of India. Herbaria contribute to conservation status assessment in several ways:

1. Species identification: Herbaria provide accurate species identification, which is essential for conservation efforts.
2. Distribution data: Herbaria offer detailed information on plant distribution, including geographic range, habitat, and population size (James et al., 2018).
3. Population monitoring: Herbaria can track changes in plant populations over time, helping conservationists identify trends and make informed decisions.
4. Red List categorization: Herbaria provide data used in Red List categorizations, which help assess the conservation status of plant species.
5. Targeted conservation efforts: Accurate data ensure conservation efforts focus on the correct species and habitats.
6. Habitat protection: Knowledge of the distribution and habitat requirements of plant species play role in habitat protection and restoration efforts.
7. Population management: Accurate data on population size and trends inform management decisions, such as seed banking and reintroduction programs (Lang et al., 2019).

### **Herbaria and *ex-situ* conservation**

Herbaria play a crucial role in *ex situ* conservation efforts, which involve preserving plant species outside of their natural habitats (Lopez et al., 2019). Herbaria contribute to *ex situ* conservation by providing plant material, expertise, and facilities for conservation efforts. Herbaria are involved in various *ex situ* conservation activities, including:

1. Seed banking: Herbaria collect, store, and conserve seeds from plant species, ensuring their long-term survival.
2. Tissue culture: Herbaria use tissue culture techniques to propagate plant species, creating genetically identical clones.
3. Living collections: Herbaria maintain living collections of plants, providing a safeguard against extinction.
4. Cryopreservation: Herbaria use cryopreservation techniques to conserve plant material at very low temperatures.

### **Herbaria and climate change research**

Herbaria play a vital role in climate change research by providing valuable information on plant responses to environmental changes (Lang et al., 2019). Herbarium specimens and associated data offer a unique window into the past, allowing researchers to study the impacts of climate change on plant diversity (Eckert et al., 2024). Herbaria contribute to climate change research in several ways:

1. Historical climate data: Herbarium specimens contain information on plant growth, flowering, and fruiting times, which can be used to reconstruct historical climate conditions (Marsico et al., 2020).
2. Plant migration and range shifts: Herbarium data can track changes in plant distribution and abundance over time, providing insights into plant responses to climate change (James et al., 2018).
3. Phenological studies: Herbarium specimens can be used to study changes in plant phenology, such as shifts in flowering times, in response to climate change.
4. Ancient DNA analysis: Herbarium specimens can provide ancient DNA samples, allowing researchers to study evolutionary responses to past climate change events.
5. Predicting ecosystem changes: Plant responses to climate change can have cascading effects on ecosystems, making it essential to understand these responses.
6. Developing effective conservation strategies: Knowledge of plant responses to climate change can inform conservation efforts, such as assisted migration and habitat restoration.
7. Improving climate models: Incorporating plant responses to climate change into climate models can improve their accuracy and predictive power (Lang et al., 2019).

### **Challenges and future aspects**

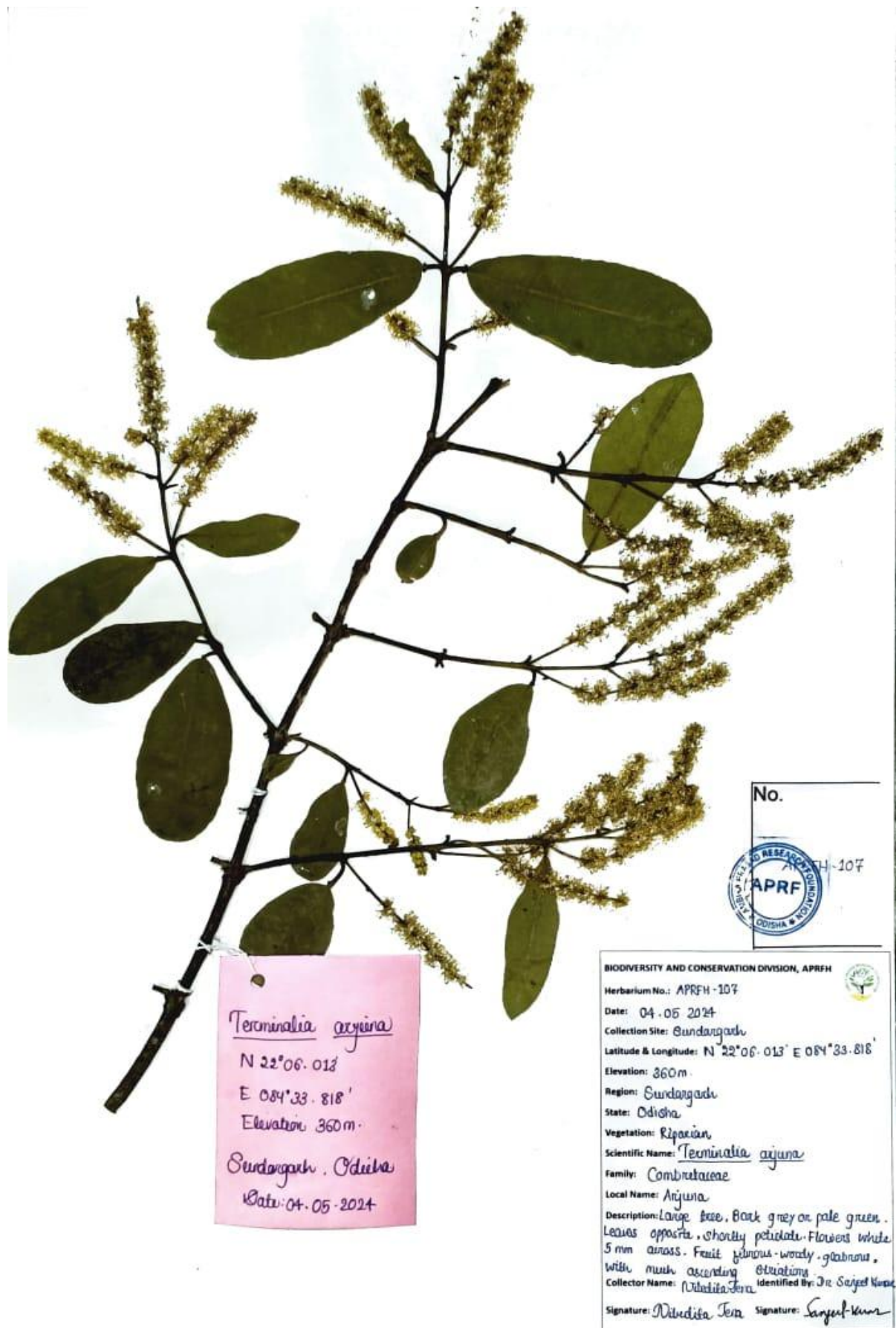
The development and maintenance of herbaria face several challenges, including limited funding, inadequate infrastructure, and insufficient trained personnel, which hinder the digitization, conservation, and accessibility of specimens (Papalini et al., 2023).



Figure 4: Herbarium specimen of *Spondias pinnata*

Figure 5: Herbarium specimen of *Suregada multiflora*



Figure 6: Herbarium specimen of *Terminalia arjuna*

Additionally, the impact of climate change, habitat destruction, and species extinction threatens the very existence of plant diversity, underscoring the need for herbaria to adapt and evolve. Future aspects of herbaria include the integration of emerging technologies, such as artificial intelligence, DNA barcoding, and virtual reality, to enhance specimen digitization, identification, and visualization, as well as the development of collaborative networks and online platforms to facilitate global access, sharing, and conservation of herbarium resources. Herbaria face numerous challenges that impact their ability to fulfil their mission of preserving and providing access to plant specimens. The main challenges are discussed below.

1. Funding: Herbaria often struggle to secure sufficient funding to support their operations, including staffing, collections care, and digitization.
2. Staffing: Herbaria require specialized staff, including botanists, curators, and conservators, but often face difficulties in recruiting and retaining qualified personnel.
3. Digitization: Herbaria are working to digitize their collections, but this process is time-consuming and resource-intensive.
4. Space and infrastructure: Herbaria require suitable storage facilities and equipment to maintain their collections, but often face limitations in terms of space and infrastructure.
5. User engagement: Herbaria need to engage with users, including researchers, students, and the public, to demonstrate their relevance and importance (Mandrioli, 2023).

To address these challenges, herbaria are exploring new directions and strategies:

1. Increased collaboration: Herbaria are collaborating with other institutions, organizations, and stakeholders to share resources, expertise, and knowledge.
2. Digitization and online access: Herbaria are prioritizing digitization and online access to their collections, enabling global access, and facilitating research.
3. Outreach and engagement: Herbaria are developing outreach and engagement programs to connect with diverse audiences, promote plant conservation, and demonstrate their relevance.
4. Integration with emerging technologies: Herbaria are exploring the application of emerging technologies, such as artificial intelligence, machine learning, and genomics, to enhance their collections and services.
5. Development of new business models: Herbaria are investigating new business models, including subscription-based services and partnerships with industry, to ensure their long-term sustainability.

Despite their importance (Mandrioli, 2023), herbaria often lack recognition and support:

1. Raising awareness: Herbaria need to raise awareness about their importance and contributions to plant conservation, research, and education (James et al., 2018).
2. Advocacy and policy engagement: Herbaria should engage with policymakers and advocacy groups to promote their interests and secure support.
3. Building partnerships: Herbaria should foster partnerships with other organizations, institutions, and stakeholders to leverage resources, expertise, and influence.

4. Developing a global herbarium network: Herbaria should collaborate to establish a global network, facilitating the sharing of knowledge, resources, and best practices (Soltis, 2017).
5. Celebrating successes: Herbaria should celebrate their successes and achievements, demonstrating their value and impact to stakeholders and the broader community.

## Conclusion

Herbaria play a vital role in preserving plant biodiversity and informing conservation efforts. As repositories of plant specimens, herbaria provide a permanent record of plant diversity, facilitating research, education, and conservation. The critical role of herbaria in addressing the plant extinction crisis cannot be overstated. Herbaria contribute to plant conservation in various ways, including preserving plant specimens, supporting taxonomic research, informing ex situ conservation efforts, and providing insights into plant responses to climate change. By leveraging the wealth of information contained within herbaria, researchers and conservationists can develop effective conservation strategies and policies to mitigate the impacts of plant extinction. To address the plant extinction crisis, it is essential to recognize the value of herbaria, support their development, and foster collaboration among herbaria, research institutions, and conservation organizations. By working together to support herbaria and plant conservation efforts, we can help ensure the long-term survival of plant diversity and mitigate the impacts of the plant extinction crisis.

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