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## Virtual Herbarium of Flora and Fungi: how to guarantee its sustainability

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## **Virtual Herbarium of Flora and Fungi: how to guarantee its sustainability**

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## **Abstract**

This viewpoint highlights the importance of, and the support required for the Brazilian National Institute of Science and Technology - Virtual Herbarium of Flora and Fungi (INCT-HVFF). It started in 2009 with 25 Brazilian herbaria and three from abroad. Now, it is a network of 170 Brazilian herbaria and 27 from other countries. The INCT-HVFF makes data and images of algae, fungi, and plants from these herbaria freely and openly available through the online repository *speciesLink*, as well as through GBIF and SiBBr. The *speciesLink* is a platform developed and maintained by CRIA (Reference Center for Environmental Information), a Civil Society Organization of Public Interest that provides tools for searching and analyzing biodiversity data and makes information about Brazil's biodiversity accessible to all interested. The focus of the INCT-HVFF, as well as of CRIA, is to provide biodiversity data, contributing directly to the conservation and sustainable use of Brazil's biological resources. Today, the INCT-HVFF shares more than 13.9 million records of algae, fungi, and plants from Brazil and neighboring countries. Adequate funding is essential to ensure that this network continues to be an important source of data, information, and knowledge, offering many benefits to its users.

**Keywords:** biological collections, Brazil, database, diversity, flora, funga, network, repository, sustainability, virtual Herbarium.

## Introduction

Herbaria play a crucial role in cataloging species and serving as a repository of algae, fungi, and plants. The specimens and data associated with them, as pointed by Funk (2018), “are the only direct evidence of species distributions through time” and form the basis for several studies, from taxonomy, biology, and biogeography to ecology and conservation (Schindel & Cook, 2018). In the face of the multiple crises of the Anthropocene, marked by accelerating biodiversity loss and global climate change, herbarium collections have emerged as strategic sources of information for understanding and addressing these challenges (Eckert *et al.*, 2026; Meineke *et al.*, 2019). By documenting plant diversity across space and time, these collections provide invaluable data for investigating questions in evolutionary biology, biodiversity conservation, and the impacts of climate change on species and ecosystems (Davis *et al.*, 2015; Hufft *et al.*, 2018). Furthermore, they provide elements that can be used to indicate species vulnerability and extinction (Vörös *et al.*, 2025).

With the advance of technology, virtual herbaria have emerged as an evolution of traditional methods, enabling better information exchange and scientific collaboration. As highlighted by De Smedt *et al.* (2024), “The digitization of herbarium specimens and their online dissemination is one of the most important recent developments in the curation of these collections.” Essential for botanical and mycological research, virtual herbaria provide access to a vast repertoire of data. This accessibility is crucial for studies on biodiversity, conservation, and restoration as well as to discuss genetic changes due to global change (Canhos *et al.*, 2015; Eckert *et al.*, 2026).

## INCT-HVFF

The National Institute of Science and Technology - Virtual Herbarium of Flora and Fungi (INCT-HVFF) originated from a long process that began with the National Botany Plan (PNB), launched in 1986 by the Botanical Society of Brazil (Barradas *et al.*, 2021). The PNB established short-, medium-, and long-term goals for training taxonomists, expanding collections, and improving herbarium conditions to preserve their specimens (Maia *et al.*, 2017). Around the same time, global discussions about biodiversity also

began, notably at the United Nations Conference on Environment and Development, held in Rio de Janeiro in 1992 (<https://www.un.org/en/conferences/environment/rio1992>). In the following decade, books such as "*Biological Collections: Support for the Inventory, Sustainable Use, and Conservation of Biodiversity*", organized by the Rio de Janeiro Botanical Garden Research Institute (Peixoto, 2003), and "*Guidelines and Strategies for the Modernization of Brazilian Biological Collections and the Consolidation of Integrated Biodiversity Information Systems*" coordinated by the Ministry of Science and Technology: Center for Management and Strategic Studies (Egler *et al.*, 2006) were fundamental in highlighting the importance of biological collections to research about Brazil's biodiversity and in fostering their funding.

The National Institutes of Science, Technology, and Innovation (INCTs) Program emerged in 2008 "to support large, long-term research projects in national or international scientific cooperation networks, involving researchers and fellows from a wide range of fields, for the development of high-impact scientific projects and human resource training" (<http://inct.cnpq.br/home/>). The INCT-Virtual Herbarium of Flora and Fungi (HVFF) was one of the 112 proposals selected in the first call for the program (Call MCT/CNPq/FNDCT/CAPES/ FAPEMIG/FAPERJ/FAPESP N<sup>o</sup> 015/2008). Its network initially had 25 herbaria in Brazil and three from abroad, sharing data made available online, freely and openly, through the *speciesLink* platform (Canhos *et al.*, 2022). At the end of the program's first phase in 2016, the Virtual Herbarium integrated and served data from 106 Brazilian herbaria and 21 from abroad, providing more than 5.5 million records and 1.5 million images of plants and fungi from Brazil (Maia *et al.*, 2017). During this period, *dataCleaning* and *Lacunas* tools, as well as *Biogeo*, *Exsiccatae*, and an *Annotation* system were developed, facilitating data analysis.

The *dataCleaning* tool (<https://splink.cria.org.br/dc/index?&setlang=en>) analyses data from online collections and produces, for each, individual online reports, highlighting potential geographic, nomenclatural, and taxonomic errors and inconsistencies. This facilitates the work of curators in identifying and correcting errors and users in assessing the quality of the data provided by each collection.

Through *Lacunas* ([lacunas.inct.florabrasil.net](http://lacunas.inct.florabrasil.net)), it is possible to cross-reference specimen occurrence data available *online* at INCT-HVFF with information available at *Flora and Funga of Brazil* and *CNCFlora* (National Center for Flora Conservation), revealing

taxonomic and geographic gaps for taxonomic groups and endangered species through the online interface. Identifying these gaps allows one to prioritize data entry from herbaria, identify understudied species, and prospect the addition of new collections to the network.

*BioGeo* - Biogeography of Flora and Fungi of Brazil uses environmental and species occurrence data to produce geographic distribution models and identify areas where these species potentially might occur. This tool has over 180 registered volunteers, and shares models for over 5,100 species (<https://biogeo.inct.florabrasil.net/>).

The *Exsiccatae Service* allows users to view images associated with records, facilitating taxonomic and floristic studies. Approximately 6.3 million images currently available online at INCT-HVFF are associated with more than 5.4 million plant and fungi records.

The *Annotation tool* was developed to facilitate the identification of *online* material, allowing expert users to associate comments with the records. All Annotations are published *online*, associated with the specimen data record, and sent to the herbarium curator by email. More than 36,000 annotations have been registered since 2012, 95% of which are related to scientific names and new identifications.

The ever-improving *search interface* allows for multiple accesses to herbarium data, including queries on taxonomic status, geographic coordinates, endangered species, annotated records, life forms, endemism, and origin. The interface also allows the use of geographic filters that include countries, regions, states, municipalities, biomes, hydrographic divisions, conservation units, indigenous lands, and Brazilian vegetation. Recently, through a partnership with MapBiomas (<https://brasil.mapbiomas.org/>), data on land use and cover were associated with each specimen record in *speciesLink* with consistent geographic coordinates. Search results can be viewed in a variety of formats, including records, inventories, maps, images, numbers, environmental profiles, and duplicates. Users can also download the results.

Currently, by using taxonomic lists, it is possible to determine the taxonomic status for each record submitted to the network. For plants, references used are *Flora and Fungi of Brazil*, *AlgaeBase*, and the *GBIF taxonomic backbone*; for fungi, *MycoBank* and *GBIF taxonomic backbone*. Thanks to the support received for the project's second phase, the scientific names of each data record receive a tag with its taxonomic status, which can be used in the search interface. Users can produce inventories of the taxonomic status when searching *speciesLink*. All features and tools offered by these

systems allow users to broadly explore the data provided by herbaria, contributing to making the work more agile and efficient. It was also during INCT-HVFF's first phase that data started to be shared with SiBBR (Brazilian Biodiversity Information System - Sistema de Informação sobre a Biodiversidade Brasileira), GBIF (Global Biodiversity Information Facility), and iDigBio (Integrated Digitized Biocollections) networks, and two important associated projects were approved: Sisbiota and Re flora.

INCT-HVFF began its second phase in 2017 (INCT- MCTI/CNPq/ CAPES/FAPs nº 16/2014). The progress achieved is extraordinary. Supported by the experience acquired through a consolidated network and a clear strategy, at the end of the project, in 2025, the HVFF integrated and served data from 170 herbaria from Brazil and 27 from abroad, sharing more than 13.9 million records of algae, fungi, and plants from Brazil and neighboring countries (Fig. 1A).

The number of records retrieved by users exceeded all expectations. With social isolation due to the COVID-19 pandemic, the INCT-HVFF became broadly used in 2021 and continued to be widely consulted after that (Fig. 1B). Although available before the pandemic, the widespread use of digitized specimens during this period accelerated the incorporation of INCT-HVFF into routine scientific workflows and underscored its importance in expanding access to botanical collections and sustaining research under conditions of limited mobility. The use of images also grew during the pandemic and continues to grow. In 2024, over 40 million images were retrieved by users (Fig. 1C). New developments that reduced the search interface's response time and system accessibility also contributed to expanding access to data (Canhos *et al.*, 2022).

With INCT-HVFF's evolution, new integrative approaches were developed, combining land cover and use data (MapBiomias), environmental data (Bioclim/Worldclim), bioclimatic conditions (Laboratório de Física Atmosférica, University of São Paulo), and molecular data (GenBank). Species distribution analyses and the development of potential distribution models under different scenarios are also available online (Francisconi *et al.*, 2026). The integration of specimen and land cover data is extremely useful for public policies and restoration and recovery efforts in degraded areas (Güntsch *et al.*, 2025). Through the search interface, records can be filtered, for example, by administrative or ecological units (state, municipality, biome, protected area, or indigenous land), enabling comparisons of species occurrence between previous natural formations that are currently anthropogenic areas, obtaining a list of potentially affected

species (Verly *et al.*, 2025). This information contributes to understanding the impact, for example, of deforested areas on biodiversity loss. According to expert analysis, these species can also serve as a basis for the restoration process (Maracahipes *et al.*, 2026). It is also interesting to analyze the type of use and see that outputs of data through inventories, maps, numbers, and downloads are the tools most used for visualizing the data (Fig. 1D). Most users are educational and research institutions, government agencies, consulting and service companies, and NGOs (non-governmental organizations).

Based on feedback from registered users of the INCT-HVFF, 90% use the data predominantly in research, 55% in education, 15% in scientific dissemination, and 13% in collection curation. Equally relevant is its use in conservation (32%), environmental consulting (21%), ecological restoration (11%), public policy (7%), and bioeconomy (5%). Other reasons cited for using the system include environmental monitoring, analysis of deforestation projects, timber identification, urban forestry, art, data for artificial intelligence models, identification of plants with deep learning, and herbal medicines, among many others.

INCT-HVFF is a member of the World Flora Online Consortium, an international initiative to achieve Target 1 of the Global Strategy for Plant Conservation, a program associated with the Convention on Biological Diversity, and to provide a global overview of the diversity of plant species. It has also provided data and information for the Flora of Brazil project (BFG, 2020) and is contributing to the continuous updating of Flora and Funga of Brazil (<http://floradobrasil.jbrj.gov.br>). We emphasize here that the widespread use of data has driven scientific research in various fields of knowledge, supporting management, sustainable use, and conservation of species. The use of information on species occurrence contributes to understanding how climate change is affecting the country's flora and funga and enables the identification of endangered species (Verly *et al.*, 2025). Through official lists, HVFF has over 138,000 data records of threatened species.

To identify exsiccates and improve the quality of information about specimens, INCT-HVFF organized more than 170 visits of specialists to partner herbaria, with the participation of 83 taxonomists. These visits led to the discovery of new species among the samples deposited in the herbaria, as well as the recording of new occurrences, highlighting the importance of this activity. The description of the new species *Lippia*



*carrascoana* P.H.Cardoso & Salimena (Cardoso *et al.*, 2025), a plant endemic to the Caatinga, was only possible thanks to a visit of a taxonomist (P.H.Cardoso, pers. comm.) made to the EAC herbarium, sponsored by the INCT-HVFF.

Training human resources in biodiversity, particularly in the taxonomy of algae, fungi, and plants, and in herbarium curation, was also one of INCT-HVFF's main objectives. In this context, the project encouraged and promoted courses at various levels, serving more than 1,000 students, technicians, and researchers. More than 500 people received CNPq or CAPES scholarships via the INCT-HVFF and expanded their knowledge in biodiversity by attending courses and training sessions and in interacting with researchers, technicians, and herbarium curators within the network. In addition, there was an ongoing online support in biodiversity information technology provided by CRIA (Reference Center for Environmental Information), INCT-HVFF's partner responsible for online tools and information systems. The number of finished theses and dissertations, the quality of published articles, advances in collection curation, and the evolution of online systems reflect the impact of the activities promoted for the training and development of human resources.

Various platforms have been used to publicize the activities and initiatives implemented by INCT-HVFF. The project's online page (<https://inct-hvff.org.br/>) contains general information, such as a list of partner herbaria, courses and visits offered, news, and promotional videos created by participants

([https://www.youtube.com/channel/UCI5-TpNwT2BPU\\_VuIF95Fjw](https://www.youtube.com/channel/UCI5-TpNwT2BPU_VuIF95Fjw)). The project also uses social media platforms such as Instagram (@incthvff) and Facebook (Virtual Herbarium of Flora and Fungi) to broaden and reach more general audiences.

Furthermore, to enable direct interaction with the community, the Museum of Fungi and Plant Diversity (Fig. 2) was created at the Federal University of Pernambuco (UFPE), home of the INCT-HVFF. This provides the community with interactive access to information about the INCT-HVFF and the operation of both physical and virtual herbaria, including details on the production of exsiccates, and collections databases, among others. Meetings promoted through the project (Fig. 3) allowed the presentation and discussion of INCT-HVFF's accomplishments as well as planning for the future.

By providing rapid and comprehensive access to taxonomic data, INCT-HVFF allows species identification and classification, helping to improve botanical and mycological research. In this context, the INCT-HVFF plays a vital role in biodiversity studies

(Güntsch et al. 2025). It promotes collaboration between researchers of different regions and institutions and facilitates data exchange and joint studies, increasing research effectiveness. It is important to highlight that there is no equivalent network in Brazil that provides INCT-HVFF's analytical tools. However, there is still a lot to be done. The work is ongoing, considering that new specimens are daily deposited in the network's herbaria. Data from 14/May/2026 show that 8,213,684 (57%) records do not have any associated image, 1,476,713 (10,3%) are identified only to genus, 372,248 (2.6%) only to family, and 278,295 (2%) are not identified at all, highlighting the need for specialist visits to further qualify the collections. With the improvement of data collection technologies and the use of artificial intelligence, new opportunities arise for more robust and accessible research, including real-time monitoring.

## **The future**

Despite all the work and successful results, the discontinuity of the support by CNPq to the third phase of the INCT-Virtual Herbarium of Flora and Fungi (Edital CNPq/INCT 2024) was a surprise. Of greater concern is the fact that it will affect the continuity of a network skilfully built by many hands over 16 years, with public funding. This directly undermines national and international biological collection policies, including those outlined in the National Biodiversity Policy (Brasil, 2002), the National Strategy and Action Plan for Biodiversity (Brasil, 2025), Kunming-Montreal Global Biodiversity Framework (<https://www.cbd.int/gbf>), and the 2015 Paris Agreement on Climate Change (<https://unfccc.int/process-and-meetings/the-paris-agreement>).

One might therefore ask if this INCT-HVFF was so well established, why isn't it self-sustaining? The answer is simple. The network is made up of herbaria that, in general, do not have sufficient financial resources. They require financial support from the institutions to which they are linked to (mostly public universities and research centers) which, in turn, do not have sufficient funds to guarantee the sustainability of their scientific collections. The funding cut will affect not only the inclusion of new data and the development of new tools/services but also compromise the infrastructure of several of the herbaria involved, which were provided with computers, printers, and consumable materials by the project. Added to this there is the loss of technical support grants, which, throughout the sixteen-year period of the INCT-HVFF, efficiently ensured the inclusion of data on the digital platform and the basic curatorial activities. In

summary, the funding cut threatens to dismantle the achievements and progress made over 16 years, disrupt equipment maintenance, and risk causing irreversible damage and the loss of prior government investment.

Adequate funding is essential to ensure that this network continues being an important source of data, information and knowledge, offering many benefits to its users. We cannot allow that all efforts expended by curators, technicians, and researchers to make this magnificent collection available *online* are lost. Continued public support can ensure its sustainability.

In a country named after a plant and rich in biological and cultural diversity, the need to document, understand, and conserve biodiversity is both a scientific responsibility and a societal imperative. Despite this immense natural wealth, Brazil continues to face significant environmental degradation, including deforestation, habitat loss, and ecosystem disruption. These issues threaten biodiversity, undermine ecosystem stability, and contribute to the acceleration of global climate change. In this context, collaborative online initiatives like the INCT-Virtual Herbarium of Flora and Fungi play a strategic role by broadening access to scientific collections and the knowledge they encompass. This article emphasizes the importance of INCT-HVFF not only for the botanical and broader biological communities but also for society at large, illustrating that cooperative digital efforts to promote scientific knowledge and biodiversity conservation are essential and represent a critical turning point.

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## **Authors' Contributions**

All authors: Conceptualization; Writing – original draft; Writing – review & editing the final version of the manuscript.

## Conflict of Interest

The authors declare that there are no conflicts of interest related to the publication of this manuscript.

## Data Availability Statement

Not applicable.

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## Supplementary Material

Not applicable.

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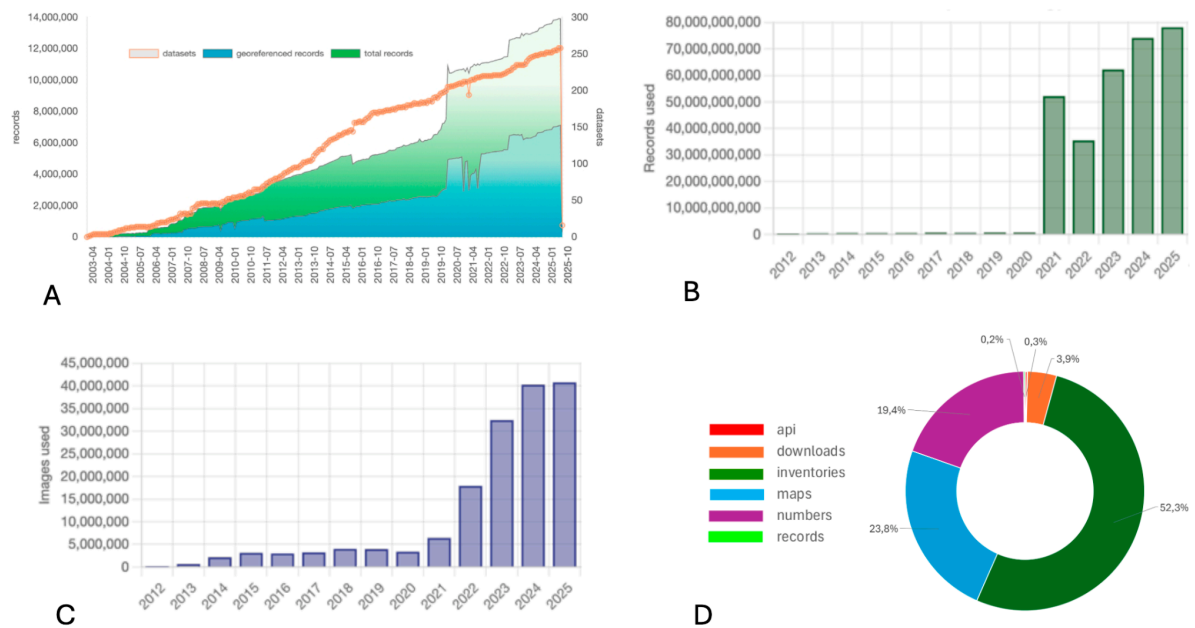
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## Figure Captions



**Figure 1.** Temporal evolution of the INCT-Virtual Herbarium of Flora and Fungi from 2003 to 2025. A. Cumulative number of digitized records available online. B. Number of records used/accessed. C. Number of images used/accessed. D. Distribution of record access/use by type of use.





**Figure 2.** General view of the Museum of Fungi and Plant Diversity at Universidade Federal de Pernambuco



**Figure 3.** Participants of the INCT-HVFF during the last general meeting (Recife, PE, 13/sept./2024)



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