Biodiversity science is improved when silent herbaria speak

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Herbaria represent a global biodiversity heritage essential for botanical research and conservation assessments. Despite their importance, herbaria in many parts of the world—especially in under-resourced regions such as much of Africa—are "silent". These silent collections are poorly integrated into global research networks and hence underused and especially vulnerable to neglect. Here, we illustrate these problems through a detailed case-study of Nigerian herbaria and demonstrate that biodiversity assessments can be dramatically improved when silent herbaria are empowered to speak. Nearly 80% of Nigerian herbaria are unrecognized in key international registries, making them nearly invisible and inaccessible to the global research community. More than 90% of these collections remain undigitized and thus are inaccessible online. Because these collections capture critical temporal and spatial gaps not represented in herbaria outside of Nigeria, their absence from global databases reduces the accuracy of large-scale biodiversity models. Despite these many challenges, the number of silent herbaria in Nigeria has increased at a rate faster than the global average owing to commitments by Nigerian biodiversity scholars to prioritize herbaria for research and education. However, severely limited funding and inadequate infrastructure to effectively house these collections threaten their continued use, growth, sustainability, and online mobilization. Integration into global networks, increased investment, and digitization efforts are crucial for giving voice to silent herbaria in Africa. Large benefits to biodiversity science will accrue rapidly from such investment and integration.

Silent herbaria and global isolation

Herbaria are foundational to plant science and biodiversity conservation, and serve as critical repositories of taxonomic, ecological, multiomic, and historical data (Davis, 2023; Davis & Knapp, 2024; Davis, 2024). Yet, many herbaria around the world have limited visibility, connectivity, and are therefore unable to make contributions to global scientific discourse. We define silent collections as those that are relatively unknown, underused, and/or underappreciated by the global botanical community. The global isolation of such collections marginalizes the valuable botanical knowledge required to understand and mount responses to biodiversity loss and climate change, and simultaneously undermines efforts to build inclusive, collaborative networks of biodiversity scientists (Ondo *et al.*, 2024; Thiers, 2024). Herbaria also serve as invaluable educational resources, preserving local and Indigenous knowledge (Marsico *et al.*, 2020; Monfils *et al.*, 2020).

A key first step of being centrally integrated into the Global Metaherbarium (Davis, 2023) is to become a registered collection in *Index Herbariorum* (*IH*; http://sweetgum.nybg.org/ih; Thiers, 2025), which is the key international resource representing the world's herbaria. Registration in *IH* provides herbaria with global visibility and connectivity to a network of international scholars and institutions, fostering collaborations and facilitating the exchange of specimens and data. Registration in *IH* greatly enhances the likelihood of visits from both local and international researchers, increases loan activity, and facilitates collaborations among scientists, all of which collectively promote increased citation, recognition and the overall impact of herbaria as important repositories of biodiversity heritage (López & Sassone, 2019; Smith *et al.*, 2011). Here, we define 'silent herbaria' as all collections that are not included in *IH* and excluded from global species assessments. These collections are thus relatively unknown, underused, and underappreciated by the global botanical community. Although the phenomenon of silent herbaria remains understudied, there is reason to believe that they may be particularly prevalent in Africa. For example, since 2016, approximately 800 new herbaria have been formally registered in *IH* (**Table 1**). Of these newly registered herbaria, 40% (n = 326) are in the Global South, but only 6% (n = 47) are from institutions in Africa.

The disproportionately low number of recent registrations from Africa has three possible explanations: (1) The number of African herbaria is indeed lower compared to other regions; (2) African herbaria are already largely registered and accounted for in *IH*, or (3) a significant number of African herbaria remain unregistered and, as such, are effectively silent. To explore this further, we present a focused case study of Nigeria's herbaria, where we identify that 80% of the country's 51 herbaria remain unregistered in *IH* (**Fig. 1A**; Thiers, 2025). These silent herbaria steward approximately 70% of the 560,000 specimens housed in Nigeria (**Fig. 1B**). By giving voice to these herbaria, we highlight the importance of silent herbaria worldwide for biodiversity research and education.

Table 1. New registrations of herbaria in the Global South in *Index Herbariorum* (IH) since 2016. In 2017, *IH* moved to a self-registration model, allowing any herbarium in the world to include itself in the index. The only requirements for registration are that the herbarium has at least one specimen in the collection and examination of specimens by those with a legitimate reason to do so is permitted. Since 2016, 801 new herbaria have self-registered. Of these, 326 (or 41%) of new registrants are from countries in the Global South. The majority of these new registrations from the Global South are from Southeast Asia and South America, while Africa accounts for only 6% of the new entries.

Region	Total new registrations (% of 801 total)
Africa	47 (6%)
Central and South America, Caribbean	132 (17%)
Southeast Asia (including Pacifica)	147 (18%)
Total	**326 (41%)**

The critical role of Nigerian herbaria in global biodiversity science

Nigeria harbors remarkable biodiversity (Keay, 1949), spanning three distinct climatic zones and is recognized as a global biodiversity hotspot (Myers *et al.*, 2000; Akindele *et al.*, 2021; Bello *et al.*, 2024; Olaoti-Laaro *et al.*, 2024). However, as in all tropical regions, Nigeria's biodiversity is threatened by deforestation, urbanization, and climate change (Okon *et al.*, 2021; Ibimilua & Ayiti, 2024). Herbaria serve as essential repositories of baseline data for documenting biodiversity (Igbari *et al.*, 2023), setting priorities for species conservation (Rondinel-Mendoza *et al.*, 2024; Bezeng *et al.*, 2025) and, in some cases, house the last remaining records of species and populations that have become extinct in the wild (Edwin-Wosu & Okafor, 2016; Muller *et al.*, 2021; Davis, 2023; Molano-Flores *et al.*, 2023; Davis & Knapp, 2024). We identified that only ≈20% of herbarium specimens in Nigerian herbaria have been digitized, and an even smaller fraction (≈7%) are digitally accessible via key biodiversity aggregators such as the Global Biodiversity Information Facility (GBIF; **Fig. 1B**). The underrepresentation of Nigerian data in global biodiversity aggregators mirrors findings of low digitization levels in other formerly colonized nations (e.g., Mongolia; Boldgiv *et al.*, 2025). We further reveal that local herbaria steward unique biodiversity data that is not represented in foreign herbaria. Here, we

identified that 97% of the digitized specimens collected in Nigeria since 2000 are stewarded by local herbaria ("in-country") and provide unique recent temporal sampling not represented by specimens from Nigeria that are housed in other countries ("out-of-country"; **Fig. 1C**). The expanded temporal sampling contributed by Nigerian herbaria provides invaluable information about how plants are responding to recent intensifying anthropogenic pressures and climate change (e.g., Meineke *et al.*, 2019; Del Toro *et al.*, 2024).

In-country specimens also provide more consistent temporal sampling throughout the year compared to out-of-country specimens. For example, within the Guinean Forests of Nigeria—a global biodiversity hotspot—out-of-country collections are extremely variable throughout the year with almost no collections during certain months (**Fig. 1D**). We hypothesize that this is a signature of "parachute science" (*sensu* Smit *et al.*, 2025), whereby the large expense and difficult logistics of travelling to a foreign country to collect specimens have led scientists to prioritize collecting in certain seasons, either to maximize the number of species in bloom during their trip or commensurate with traditional academic calendars. Conversely, in-country collectors can more easily collect throughout the year. This expanded intra-annual temporal sampling is crucial for many scientific endeavors, including correctly identifying plant phenology in the tropics (Davis *et al.*, 2022) or identifying diversity that is only present and identifiable for short periods during the year.

In-country specimens also capture greater spatial diversity than out-of-country ones (**Fig. 1F, G**). To elucidate the importance of the increased spatial coverage provided by in-country specimens, we inferred Maxlike species distribution models (SDMs; Royle *et al.*, 2012) for the important medicinal plant species *Cnestis ferruginea* DC., one of the most frequently collected species in Nigeria using in-country (**Fig. 1F**) and contrasted this with our model inferred from out-of-country specimens (Fig. 1G). We revealed that the inferred distribution of *C. ferruginea* using only out-of-country data (i.e., the area with >50% likelihood of occurrence) encompasses only 20% of the predicted area when compared to the more expansive in-country data (**Fig. 1F, G**). Ultimately, including in-country sampling, especially in poorly studied or undercollected areas, is essential for improving SDM accuracy (e.g., Glon *et al.*, 2017), estimating extinction rates (e.g., Knapp *et al.*, 2020), and documenting patterns of species richness (e.g. Valdez *et al.*, 2023).

This point highlights the important fact that expanded temporal and spatial sampling provided by in-country herbaria reinforces findings about the importance of smaller regional collections, which have been shown to steward unique specimens not found in larger herbaria (Monfils *et al.*, 2020; Marsico *et al.*, 2020; Delves *et al.*, 2024). Our results further indicate that in-country collections similarly preserve specimens that capture important spatial and temporal dimensions of biodiversity not represented in out-of-

country herbaria. Thus, incorporating data from in-country collections is critical for comprehensive and accurate biodiversity assessments.

A recent and dramatic surge in Nigerian herbaria

The number of herbaria in Nigeria has expanded substantially over the past two decades (**Fig. 1E**, **Table S1**). Although the first herbarium in Nigeria was founded in 1954, shortly before its independence from the British Commonwealth—over half of the country's herbaria were established within the past 25 years, including six in 2018 alone (**Table S1**). This rate of increase in Nigerian herbaria greatly exceeds the global rate of herbarium growth reported by *IH* in the last 25 years (**Fig. 1E**), suggesting that *IH* may greatly underestimate the number and size of herbaria in some parts of the world, especially in Africa. The tremendous growth in Nigerian herbaria has been driven by a combination of new research institutions, governmental initiatives, and growing interest in plant conservation, and underscores the potential of these collections to support global biodiversity initiatives when collections are supported (Federal Ministry of Environment, 2015; Anwadike, 2020). Indeed, an astonishing ≈90% of Nigerian herbaria report active and ongoing use of their collections for educational purposes (**Fig. 1B**), particularly in university courses on taxonomy, ecology, and conservation (**Table S1**)

Barriers to growth and sustainability

Despite their growth and importance to biodiversity science and education, small herbaria—like many of those in Nigeria—are often poorly funded, operate with limited staff, and are predominantly used for education within a limited geographical area (**Fig. 1B**, **Table S1**; Harris & Marsico, 2017). However, data about these collections are diffuse and seldom summarized or disseminated more broadly. Although the gross domestic product (GDP) of Nigeria is one of the highest in Africa (IMF, 2024), ≈90% of Nigerian herbaria reported that they experience severe financial limitations that impact their ability to sustain operations, specifically limiting digitization and pest management efforts (**Fig. 1B**). Our survey demonstrated that most Nigerian herbaria struggle to maintain essential infrastructure, including little to no climate-controlled storage or pest control measures placing specimens at enormous risk of damage from environmental factors, pests, and mold (**Fig. 1B**). Infrastructure and climate control are especially important in the tropics, where high humidity and pest densities pose constant threats to the preservation and longevity of herbarium collections (Drobnik, 2008; Mahtani-Williams & Jaramillo, 2023).

Unlocking the potential of silent herbaria: the way forward

The silence of Nigerian herbaria and possibly countless others in Africa and more broadly across the Global South greatly reduces the opportunity for them to be included in international scientific collaborative efforts and recognized for their contributions to biodiversity science (Hedrick *et al.*, 2020; Davis, 2023; Roma-Marzio *et al.*, 2023; De Smedt

et al., 2024). Giving voice to these herbaria requires overcoming resource constraints, building institutional capacity, and equipping all herbarium staff with agency and technical skills needed for implementing best practices in specimen curation and biodiversity informatics (Soltis, 2017; Rabeler *et al.*, 2019; Leliaert *et al.*, 2023; Davis, 2024; Davis & Knapp, 2025). These skills are shared readily within and among the global herbarium community. However, fundamental disconnections between silent herbaria and global networks hampers everyone's ability to improve, grow, use, and sustain collections. We advocate that all herbaria should prioritize efforts to integrate their collections into the global research community. An important first step is registering all new herbaria in global databases such as *IH*, which enhances their visibility to researchers and funding agencies worldwide, thereby creating opportunities for collaboration and support.

Digitization is equally critical, enabling wider accessibility and integration of herbarium data into GBIF and other global databases (Rønsted *et al.*, 2020; Hedricks *et al.*, 2020; Davis, 2023). Increased support for digitization in Nigeria and sub-Saharan Africa more broadly would allow researchers worldwide to access herbarium data, enabling comparative studies and enhancing biodiversity conservation efforts. These digitized data can also be leveraged to provide evidence for the impact and international usage of individual collections (for example, through programs like Bionomia, https://bionomia.net/). Our case study provides direct evidence of the importance of in-country collections to the global community. Similar investigations directly assessing the importance of these collections are essential for articulating their value in global biodiversity science and informing strategic investment in their future. Sustainable mechanisms such as targeted research grants, partnerships with biodiversity-reliant industries, and the establishment of National Biodiversity Initiatives can ensure that herbaria continue to serve as critical infrastructure for research, education, and conservation. Aligning such support with climate action plans further integrates herbaria into broader environmental strategies, emphasizing their relevance beyond national borders and reinforcing their role in addressing shared global challenges.

The integration of silent herbaria into the global research community is crucial for developing a holistic view of collections that will strengthen our global collection networks, democratize access to essential biodiversity knowledge, and enhance the Global Metaherbarium. By addressing infrastructural, financial, and technical challenges through targeted investments and collaborations, silent herbaria can fulfill their potential as critical resources for botanical research and conservation and become integral contributors to global biodiversity research and conservation.

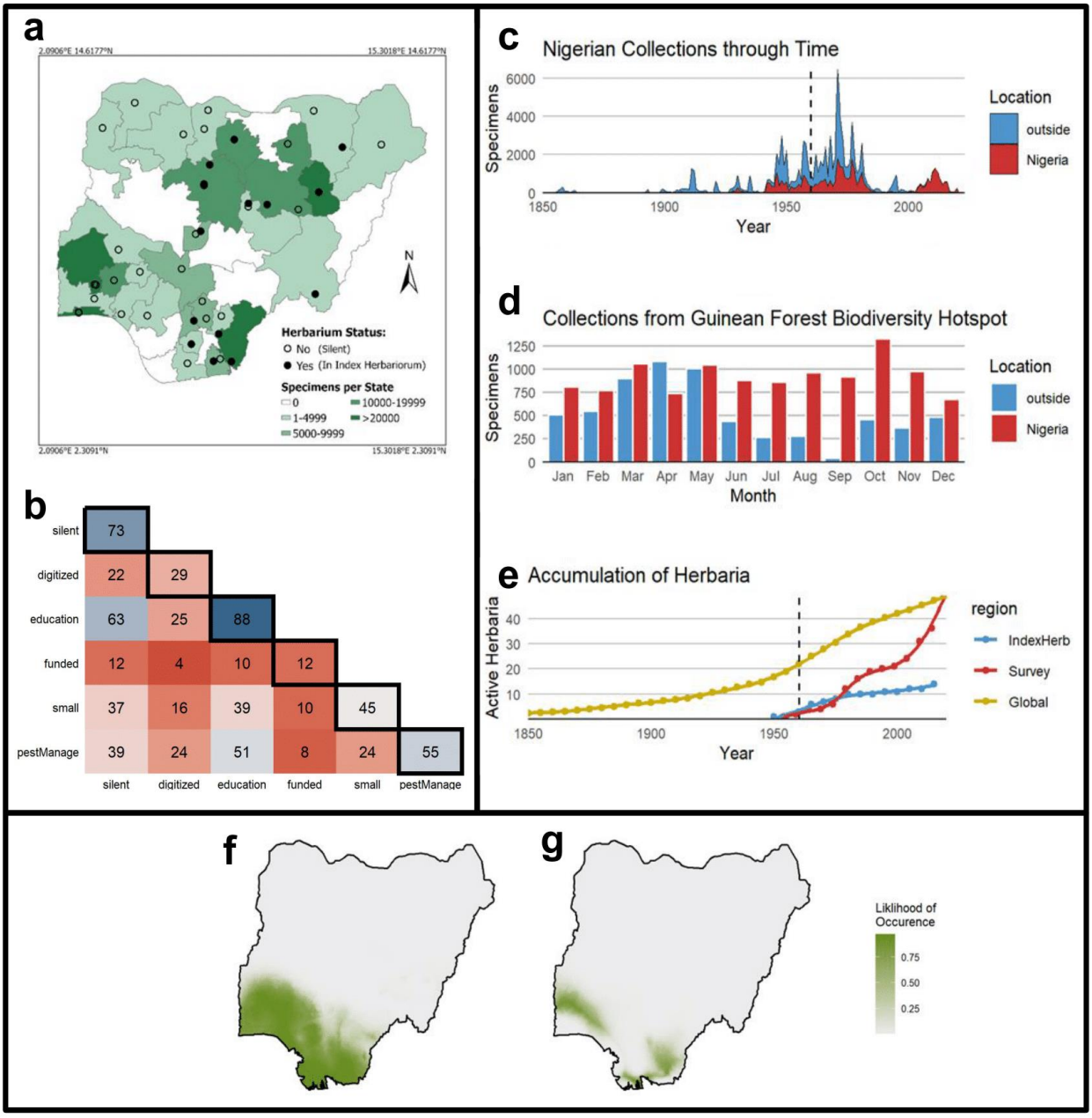

Figure 1. a) The map of Nigeria shows the location of silent herbaria (open circle) and herbaria included in *Index Herbariorum* (closed circle) with the number of herbarium specimens housed in each state indicated by the color. b) Selected results from our survey of Nigerian collections indicating—on the diagonal—the percentage of Nigerian herbaria that are small, have begun digitization, use their collections for education, are sufficiently funded, are small (<100,000 specimens), and have a pest management plan. The off-diagonal values show the interactions between these characteristics, indicating the percent of Nigeria that meet two of these criteria. The graphs show c) changes in the annual collection rate of Nigerian specimens and the shift towards more collections being housed in Nigeria (the dotted vertical line indicates when Nigeria regained its independence in

1954); d) monthly collections for states within the Guinean forest biodiversity hotspot (Abia, Akwa Ibom, Bayelsa, Cross River, Delta, Edo, Ekiti, Enugu, Imo, Lagos, Ogun, Ondo, Rivers) based on where the specimens are housed; and e) the accumulation of Nigerian herbaria through time according to Index Herbariorum (blue), our survey results (red), and global growth (yellow). The maps represent Maxlike species distribution models for *Censtis ferruginea* DC. using only specimens housed in Nigerian herbaria (e) and using only specimens housed outside of Nigeria (f).

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