



The Nature of Trees
Arnoldia



Hope in the Herbarium: A Record of What is Lost and Found

By Molly Hardy and Mason Heberling

The specter of extinction has breathed new life into the herbarium, lending a fresh relevance to the age-old practice of collecting dried and pressed plants. An estimated 400 million specimens found in over 3,500 active collections worldwide document the world's botanical diversity across space and time (Thiers, 2024). The organization of these samples into plant collections known as herbaria dates back to at least the sixteenth century. Later systematized and organized into cabinets, this centuries-long practice of plant collecting is steeped in science and culture, as once-living organisms, turned into scientific and historical objects, now serve as evidence of species that have gone extinct.

Fears and questions around plant extinction bring these uses into relief. An estimated 51 species have gone extinct in the continental U.S. and Canada since European settlement (Knapp et al., 2021). Worldwide, it is estimated that nearly 600 plant species have gone extinct in recent centuries (Humphreys et al., 2019). However, identifying plant extinction is challenging and the exact number is disputed (Knapp et al., 2020). As Gary Krupnick explains elsewhere in this issue, extinction comes in many forms and is not as straightforward as you might think (see "Gradations of Extinction," page 38). Evidence for absence can rarely be complete, leaving us with lingering possibilities that a species might still be waiting for re-discovery in the wild. Any comprehensive tally of extinction since European colonization of North America is further complicated by the reality that many species likely went extinct before being documented by Western science, a phenomenon which has been called "dark extinction." In the face of these challenges, it becomes especially clear that the physical record of herbarium specimens is necessary to our understanding and prevention of plant extinction (Corlett, 2023).

Just as the herbarium developed into a widespread practice in the early modern period (Flannery, 2023), the herbarium today is having a renaissance of its own—in the scientific sense, as it registers plant extinction and climate change, and in the cultural sense, as its role as a repository of cultural heritage continues to emerge. As seen in this issue, artists manipulate it to create and recreate commentaries on permanence, loss, and human/natural interaction (see "In Search of Thoreau's Flowers," page 54), and humanists ask questions about its

Opposite: Authors Mason Heberling and Molly Hardy examining plant specimens in the Smith College Herbarium in Northampton, Massachusetts. *Photograph by Nicholas Anderson*

historical trajectories, its logics, and its stories, both present and erased.

And yet, amid renewed interest in the herbarium, the collections themselves seem to be under threat. The most recent, and perhaps most public, of plans to deaccession an herbarium comes from Duke University, which houses the second largest private university herbarium in the U.S. Due to its size (roughly 825,000 specimens), the Duke Herbarium will likely be given away in parts, scattered across many institutions. “This will not only disrupt the storied historical context of the collection, it undoubtedly will lead to confusion about where particular Duke Herbarium specimens have gone,” writes the American Institute of Biological Sciences in a recent letter to the University (2024). And Duke is just the most recent in a surge of such losses: dozens of herbaria have closed in the last twenty years, most without garnering wide public attention. At the same time herbaria are closing, there is some hope. More than 600 herbaria have been newly registered since 2016, yet 92 herbaria have closed and nearly 800 additional herbaria have been unresponsive to inquiries, suggesting inactivity or possible closure (Thiers 2024). Relatedly, the Royal Botanic Gardens, Kew, one of the premier collections in the world given the institution’s long history of supporting botanizing expeditions around the globe, announced that the Kew herbarium will be moving to Reading, where we are told it will remain accessible to researchers, though distant from the institution’s primary access point. A petition, which has almost 20,000 signatures at the time of writing, notes that “by isolating the herbarium at the new site over an hour distant, dividing it from the living collections in the gardens, from the library, from the Jodrell laboratories, [from] the MSc and PhD students and other scientists,” Kew is effectively “removing” its own “beating heart” (“Keep Kew at Kew” 2024). With iconic images of tall ceilings and spiral staircases leading to historic cabinets, the concern for Kew’s relocation highlights the importance of the herbarium, not as merely as storage, but as a convening space for inspiration, conversation, and innovation.

Scientists who protest the loss and relocation of these two premiere collections have noted the perverse irony: just as herbaria are being recognized for their value in understanding, and in some cases even mitigating, plant extinction, their own existence is threatened. Each specimen has scientific and cultural stories to tell, not only about what once was, but the future of plant life. This separation, this

disruption, this scattering, this confusion, invites a return to the history of collecting in the United States. How did this hybrid natural-cultural collecting practice become institutionalized in the first place? And what changes in academic science, horticulture, and the institutions that keep collections are fraying these ties in our time?

The Herbarium as Cultural Heritage Object

A figure known for any number of botanical “firsts,” it was none other than Carl Linnaeus who initially specified the form the botanical information system should take, in remarkably practical and detailed plans, in his *Philosophia Botanica* (1751). He codified the storage of the pressed plants that botanizers had been collecting for centuries into a cabinet that reflected the intellectual control he was also proposing for the plant kingdom. Linnaeus offered explicit instructions for botanists collecting plants, detailing both immediate care for the specimen itself, as well as preservation techniques in cabinets. With each unbound leaf representing one specimen, the information becomes accessible on shelves, where each leaf can be placed and replaced, moved and shifted, adjusted as new knowledge presents itself to the herbarium being assembled.

In the form of an illustrative plate with measurements for each class, *Philosophia Botanica* precisely detailed the physical manifestation of this purpose-built cabinet for information storage and retrieval, as well as expansion (see plate, opposite). This structure anticipated the abundance that would come with collecting; when it was adopted in the United States, abundance was very much on the minds of its users as they strove to catalog the vast flora they encountered during westward expansion.

Like so much of what was true in the early Republic, the more the newly formed nation tried to differentiate itself from its European counterparts in its efforts to name and classify the natural world, the more it ultimately adopted their practices (Lewis 2011). The inheritance of the information system to govern the growing abundance of botanical knowledge in the form of mounted specimens was no exception. In the early nineteenth century, herbarium collections were hardly prized, however, and their early histories are ones of loss and languish, rather than of preservation and access. “The early institutional herbaria were poor financially, often did not have regular or appointed curators, and

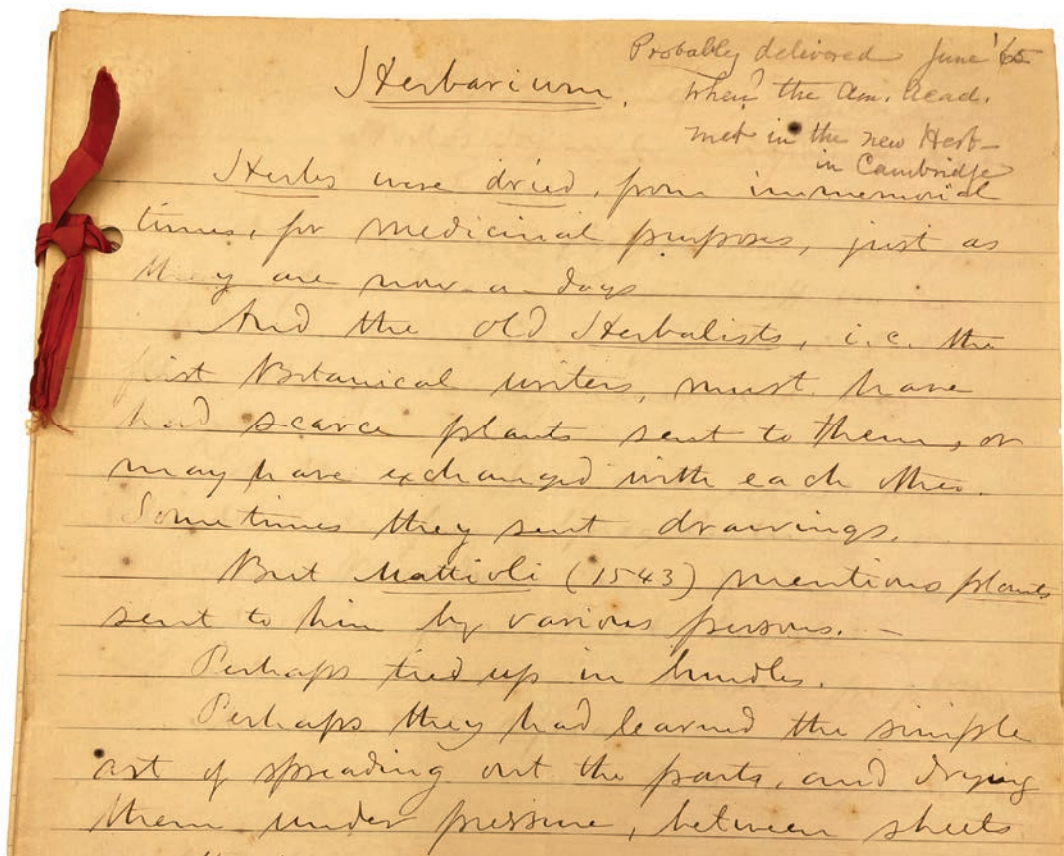
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Herbarium illustration from Carl Linnaeus, *Philosophia Botanica* (1751). Accessed through the Biodiversity Heritage Library. Copy from the North Carolina State University Library



Asa Gray's "Herbarium Talk," MC 42 (1865). Asa Gray papers, 1830–1953. Archives of the Gray Herbarium, Harvard University. Photograph by Molly Hardy

functioned largely as a storage place for the collections," writes Ronald Stuckey (1971). None other than President Thomas Jefferson deposited the journals of Lewis and Clarke at the American Philosophical Society upon their return in 1806, while "[a]ccident and loss" characterized the fate of their natural history collections (McCourt and Spamer 2004). As the century wore on, however, collecting became more ambitious and preservation followed suit, so that by the 1840s, the US Patent Office displayed bounty from the Wilkes expedition, before Congress transferred it to the newly formed Smithsonian a decade later.

At least at first, botanists in the early republic were less concerned about the archival work of nation-building than they were to name, know, and claim the flora of and for the new nation. Starting in the southeast with Mark Catesby's collecting on behalf of the Royal Society, and then in the northeast with John Bartram who sent plants to Europe and assisted Linnaeus's collector, Peter Kalm, American botanists started to establish their own collections.

Increasingly, these collections became institutionalized, as David Hosack and John Torrey's collections formed the cornerstones of Columbia University and then New York Botanical Garden's herbaria (Johnson 2018). By 1865, Asa Gray's collection would become the cornerstone of Harvard's botanical collections, a move made with much calculation on Gray's account. Like Linnaeus, he understood the herbarium as a mode of preservation, as much as of organization.

When he first came to Cambridge in 1842, Gray had a "a small but significant" herbarium that resulted from his collaboration with Torrey on the North American flora, which "brought him collections, both living and dried, from far and wide" (Wood 2010). Twenty-three years later, when he bequeathed that collection (then numbering some 200,000 specimens) to Harvard, he reflected on what his collection, and plant specimen collections more generally, meant. In a lecture at the American Academy of Arts and Sciences, Gray expounded on the herbarium's role; it is, he said, "the only certain



Main Room, Gray Herbarium. Robinson, Benjamin L. Gray Herbarium photograph, 1900. ID 11771. Botany Libraries photograph collection, circa 1770–2020. gra00083. Archives of the Gray Herbarium, Harvard University.

record of species, the only means of transmitting to posterity the knowledge—we have acquired the only means of making the full comparison which Botanists have to make between the plants of different parts of the world.” Gray saw Harvard as the site of secure transmission across time. Preservation could not come with the individual. Only the institution could secure that.

And Gray made clear that he had certain expectations for Harvard. He insisted that Harvard provide a fire-safe building to house the collection, which it was able to do thanks to a generous benefactor, as the President acknowledged in his annual report (Hill 1865). From the *American Journal of Science and Arts*, March 1865, we find a description of the Herbarium: with “the walls all hollow and ventilated, for greater security from dampness.” The space is maximized for storage; “(t)he principal room, for the herbarium, is about 30 1/2 by 35 feet, and 19 feet high to the vaulted ceiling.... The space between the floor and the gallery is completely filled by the herbarium-cabinets...”

The one exception to this is the wall with the furnace made of soapstone, which “supplies warm air by registers.” Chestnut wood forms the cabinets, casings, and woodwork, whereas hard pine “bedded in mortar” constitutes the floors. The building, we are told, has been constructed in “a thorough and durable manner,” to “form a safe and permanent place of deposit for the collections” (Silliman 1865). The message here is clear: this place is one of permanence, one that will protect against the ravages of time.

And so, by the end of the nineteenth century, august institutions held both the records of natural and human history. Brick and mortar institutions are supposed to fortify these collections against the ravages of time, and the crumbling of such commitments makes the precarious status of today’s herbaria so unsettling, and the need to communicate their importance so urgent.

In news coverage of the proposed closure at Duke and the division of collections at Kew, the focus has been on the scientific value of these collections. But

they also have a role to play as documents in the lives of the institutions that house them. Their records of collecting, their status as institutional histories, and their embeddedness in the moments in which they were and will be created, render herbaria relevant to more than a single discipline's purview. With growing attention to botany and horticulture in the humanities, we see disciplinary barriers breaking down; herbaria are key sites for new forms of scholarship and storytelling to emerge that critique imperial domination, highlight previously suppressed knowledge, and synthesize scientific and humanistic inquiry. The severance of collections inhibits such synthesis.

New Uses for Old Collections

Not long ago, herbaria were almost exclusively for taxonomists. That is not to say herbaria were not used by other scholars, including artists (Flannery 2023), but these were outlier cases, not the bread and butter of herbarium-based work. In recent decades, as new voices, perspectives, and disciplines enter herbaria, the uses of herbaria have also diversified (Heberling et al. 2019). Botanist Vicki Funk wrote "100 Uses for an Herbarium (Well at Least 72)," which, as the title suggests, enumerates the many ways herbarium specimens have been used across disciplines (Funk 2003); today, it is safe to say that these uses now easily exceed one hundred. While the taxonomic-centered uses remain, many unanticipated uses have emerged that were scarcely imagined by collectors and curators of generations past (Heberling & Isaac 2017).

Much of this increased attention and multidisciplinary use of specimens have emerged from access and awareness spurred by digitization. Herbarium specimens are receiving unprecedented attention due to recently developed methods, new perspectives, and perhaps most notably, their increased accessibility through widespread digitization. In the US, iDigBio, a program funded by the US National Science Foundation, is one such impactful initiative resulting in the digitization of millions of specimens at US institutions (Nelson and Ellis 2019). Global efforts, such as the Global Biodiversity Information Facility (GBIF.org), have created international networks that integrate a wide range of biological data from specimens to citizen science observations. These efforts have led to further interdisciplinary engagement with biological data (Heberling et al. 2021). The next generation of digitization and specimen use evokes the "extended specimen" (Lendemer et al., 2020), a concept that integrates disparate data

Herbaria provide important holistic insights into the broader context of long-term biodiversity change.

sources, including physical specimens themselves, digital data derived from the specimen, historical information, and a whole constellation of data streams enabling transdisciplinary research.

With these shifting trends in herbarium use in mind, and in the midst of the current ecological crisis, herbaria have gone from documenting existence to chronicling loss. Herbaria (and natural history museums more broadly) have transitioned from the core mission of documenting biodiversity to documenting biodiversity change. And much of this change takes the form of loss of a scale and kind it would have been difficult for early-modern collectors to contemplate outside of apocalyptic visions. The herbarium of the past was refined to tell of what species exist in the world. The herbarium of today tells us what is no longer there; an archive itself, it has come to document how the land has changed.

Herbaria document biodiversity loss across scales: from individual populations at a given site to

the community of interspecies coexistence to global distributions. Though conservation efforts and public conversation understandably draw most attention to the endpoint of species extinction, herbaria provide important holistic insights into the broader context of long-term biodiversity change. These specimens allow for a broader understanding of ecological gains and losses, and importantly, they provide a more nuanced definition of extinction in modern times. Human-caused climate change, non-native species introductions, pollution, direct exploitation, and habitat loss are now recognized as major drivers of global biodiversity change, as summarized in the recent report of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES, 2019). While shifts in biodiversity may culminate in individual species extinction, complete species loss is relatively rare.

And though each herbarium sheet is a single specimen, isolated from the entangled existence it once had, these singular specimens have much to tell us about plant communities. Contrasted with species extinction, shifts in ecological interactions compose a different, more complicated kind of loss. Community-level shifts often appear slowly or subtly, occurring over large spatial or temporal scales, which make quantification difficult. Such changes often happen over decades or more, making the consequences difficult to perceive in one human lifetime. Therefore, without knowledge of past conditions, without the archive of the herbarium, it is easy to accept the present as the norm for all future comparisons, a phenomenon known as “shifting baseline syndrome” (Soga and Gaston, 2018). While some species may have never been recorded before extinction (“dark extinction”), other species may be slowly marching towards extinction before our eyes (see Krupnick, this issue). Certainly, local extinctions and extinctions of interactions are frequent. Ecology is dynamic, and even in the absence of modern anthropogenic disturbance, change is normal. But without a baseline for comparison, biodiversity changes go unrecognized.

Herbarium specimens have a critical role in overcoming shifting baselines. These specimens archive the past and document the present, so we can forecast our futures. Joseph Grinnell, a zoologist at University of California, Berkeley, is perhaps best known for developing and using the concept of the “niche” in the scientific field of ecology. But he was also an early advocate for the role of collections in biological conservation. In a forward-thinking treatise on the roles

of museum-based research, he wrote: “At this point I wish to emphasize what I believe will ultimately prove to be the greatest value of our museum. *This value will not, however, be realized until the lapse of many years, possibly a century*, assuming that our material is safely preserved. And this is that the student of the future will have access to the original record of faunal conditions in California and the west, wherever we now work.” (Grinnell, 1910; emphasis added). And here we are, at the very moment Grinnell forecasted, left to wonder if “our material is safely preserved” for much longer. And further, whether we are adequately documenting for the future.

Hidden Insights into Long-term Change

Perhaps more than ever, the time is now for herbaria to record and contextualize change in the Anthropocene. Yet the practice of plant collecting itself is on the decline (Prather et al., 2004), and many collections have far more specimens from a century ago than recent times. Research priorities have shifted away from natural history and basic taxonomy. Herbaria were once integral to botanical education with nearly every college, big or small, having a teaching collection, but now many universities no longer have a botany department or offer botany in the strict sense (Crisci et al 2020). Beyond the often-overlooked value of herbaria as physical spaces of education and inspiration for students, it is also worth noting that small herbaria have made big contributions to research, often documenting local diversity, which is not represented in larger, more internationally focused collections (Marsico et al. 2020). Though the recent announcement on the closure of Duke’s herbarium is concerning, many smaller collections have languished in recent decades, and this neglect in turn has removed educational opportunities for students. Beyond concerns for the data and specimens themselves, herbarium closures ricochet further to affect the culture of collecting as a routine scientific practice. These declines in collecting, especially at local scales, severely curtail our ability to detect biodiversity change.

A recently initiated long-term project led by collection manager Bonnie Isaac at the Carnegie Museum herbarium in Pittsburgh, Pennsylvania, seeks to grow the collection in an active and intentional way. Botanists are revisiting specific sites across western Pennsylvania where past museum botanists sampled specimens many decades ago.



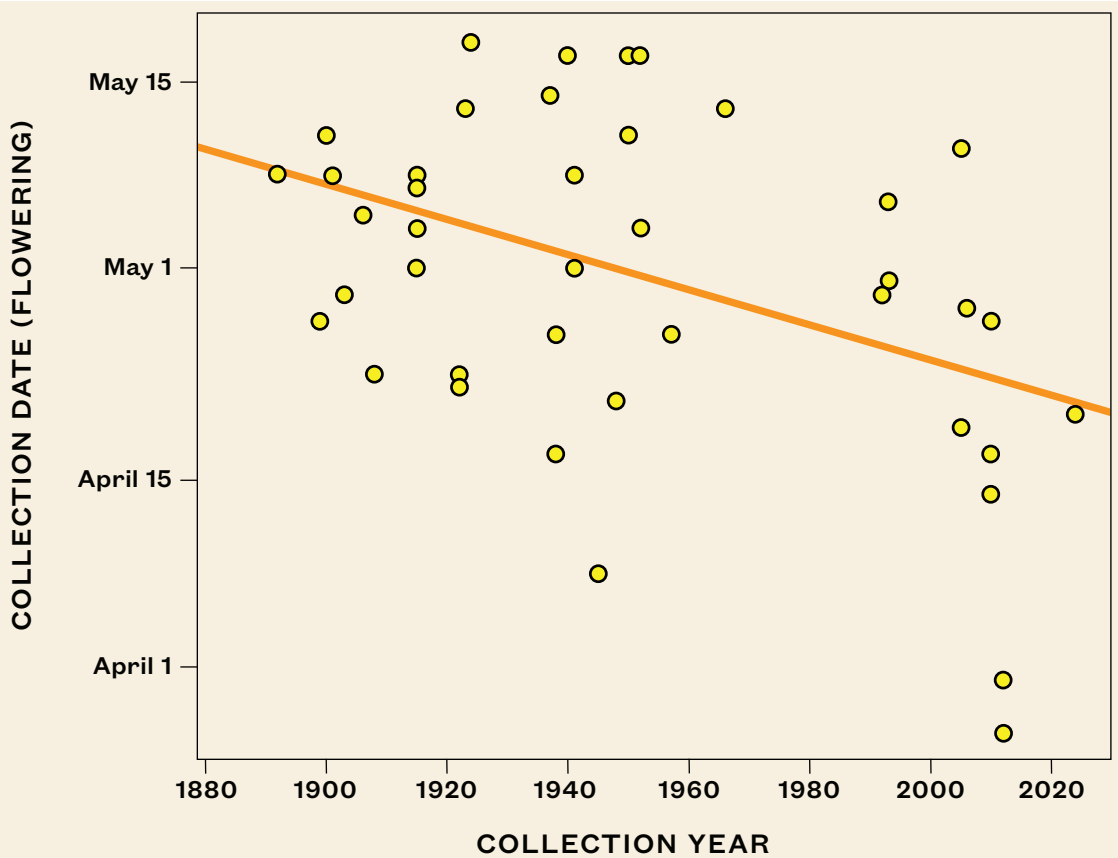
Two specimens collected in the same location near Pittsburgh, PA on the same date (May 4) but 102 years apart, the 1915 specimen (left) in full flower, the 2017 specimen (right) with leaves and developing fruits. Photographs courtesy Carnegie Museum of Natural History

About two dozen sites of varied habitats and geography are targeted across western Pennsylvania, with a collecting plan to comprehensively sample each site once per decade. A given site is sampled several times throughout a year in an effort to capture seasonal changes. As much as possible, sites are revisited on or near the same calendar date as historic collections to enable phenological comparisons, such as the timing of flowering. While research-specific and “non-targeted” general field collecting also continues, these re-collections give contemporary context to past collections, enabling focused comparison of biodiversity change, both now and in the future.

This specimen re-collection project was featured in the exhibition *We Are Nature: Living in the Anthropocene* on display at Carnegie Museum of Natural History from 2017-18 (Oliveira et al., 2020). Historical specimens collected in the region near the museum a century or more ago were paired with

recent specimens. This juxtaposition not only elicited a sense of place and history from these specimens, but also tangibly, with decades of change perceptible in a single striking visual. The specimens themselves vividly illustrated the shifting of flowering times over multiple human generations. These locally collected specimens, juxtaposed side-by-side, evoke meaning and spur reflection in ways that are hard to produce from trendlines in data scatterplots alone.

Following the footsteps of past plant collectors can be eye-opening from both scientific and personal points of view. Some sites are now developed, and hence unable to be re-sampled. Some sites no longer harbor species that were collected a century, or even just decades, ago. Contrastingly, these same sites today regularly include new, introduced species that were absent entirely before but now thrive in abundance. The act of collecting makes you pay attention, often realizing more plant life is there than you might



In southwestern Pennsylvania, spring flowering dates for eastern redbud (*Cercis canadensis*) have advanced by an estimated 1.3 days per decade over the last century, as shown here with data from 47 herbarium specimens collected from 1892 to 2024. *Data from Carnegie Museum Herbarium*

think. Some new records of rare species are realized, often completely unexpectedly. If we look, there are many species (re)discoveries to be made, no matter where you are in the world.

Rethinking the Future of Herbaria

Albert Parr, director of Yale’s Peabody Museum of Natural History, wrote in 1939, “The natural history museum of today is rather on the defensive. It can no longer claim justification by mere existence of its collections” (Parr, 1939). Nearly a century later, this need for the justification of herbaria continues. Herbaria cost money to maintain, take up physical space, and require human effort. Crisci et al. (2020) in a somewhat hyperbolic essay on what appears to be the “end of botany,” points out the critical role of herbaria in curbing this doom. Curators will likely always need to justify their continued preservation and growth of collections, but the supporting evidence is clear.

In the modern era of biodiversity loss, the ethics of specimen collecting has come under question (Minteer et al. 2014). In addition to scrutinizing the need for more collecting, critics point to the financial costs of maintaining herbaria in light of alternatives such as non-lethal sampling of DNA and high-resolution photography. These and other recent technologies have not replaced the herbarium, however, but have augmented long-standing collection practices. For instance, the popular community science platform, iNaturalist.org, might at first seem to serve as a replacement for physical collecting. With your smartphone, you take a picture of an organism, and the observation is tagged with GPS coordinates and even identified with the help of artificial intelligence and a community of iNaturalist users. This method of biodiversity documentation clearly has power. But there are limitations to observations without physical specimens, which can be available for closer

inspection under a microscope, facilitate future measurements such as leaf size, or provide material for DNA analysis. On the other hand, details of the living plant, such as color or environmental context, can be lost in pressed specimens. Rather than view these approaches as conflictual, the complementary connection of iNaturalist with physical specimens enables new research (Heberling et al. 2018).

In addition to new technologies enabling new modes of botanical documentation, herbarium digitization has further changed the landscape of specimen use. Early in the digitization process, curators feared that administrators might see the scanned images as replacements for the physical specimens (Flannery 2012). Instead, digitized specimen images and derived data (label information, trait data, and more) have given the physical voucher new value. At the Carnegie Museum herbarium, requests for physical loans of specimens have actually increased, not decreased, upon digitization. Digitization enables access, and access enables new research, often across diverse disciplines of inquiry (Heberling et al. 2021).

Despite the heightened value placed on open data, the practice of collecting herbarium specimens has become less common. Every plant researcher should be collecting “voucher” specimens, or specimens specifically for the purpose of enabling verifiability of their research. Species names and our understanding of what a “species” is changes, but the specimens do not. These references are critical.

The history of natural history collections, including herbaria, presents problems that must be confronted. Historic collecting practices and the very institutions themselves are rooted in colonial mindsets of resource extraction and imperialism, often at the expense of indigenous communities. Highlighting the legacy of colonialism in plant collecting, most plant diversity is archived in herbaria in Europe and United States, despite most of this diversity residing in the tropics (Park et al. 2023). This geographical asymmetry calls for a more collaborative, global science. Whether some specimens should be repatriated is a discussion that needs to be had. In many ways, the digitization of specimens have enabled a more global botanical science, making specimens available to local researchers and enabling a more diverse botanical community (Drew et al 2017).

New methods and perspectives have revolutionized herbaria as physical spaces of discovery, innovation, and collaboration. In the digital age, millions of specimens from thousands of herbaria across

the world are increasingly connected, alongside additional data and information, as a global “meta-herbarium” (Davis 2023). The burgeoning field of “Plant Humanities” has contextualized the interdisciplinarity of herbaria and the human connection. Improved methods of DNA extraction have made the herbarium an unanticipated DNA repository. Genetic analysis has even been done using fragment material from a single specimen of an extinct species (Zedane et al., 2016). Resurrecting extinct species from herbarium material may someday be a reality (Albani Rocchetti et al., 2022). Stopping plant extinctions is well within our reach, but doing so requires herbaria (Corlett, 2023).

Simply knowing there are millions of herbarium specimens preserved in herbaria across the world is not enough. They must be made accessible and used, placed in scientific and societal context. From across the arts, sciences, and humanities, together we are doing just that. Herbaria provide insight on plant diversity, biodiversity change, and society. These specimens are paradoxically both tombstones documenting what once was, but also objects of hope that provide insight into what can be. The future of herbaria, and indeed the future of plant conservation, is strong. But we must cultivate it. 🌿

MASON HEBERLING *is a plant ecologist and the associate curator of botany at Carnegie Museum of Natural History.*

MOLLY HARDY *is an historian who works in cultural heritage preservation and access.*

WORKS CITED

- Albani Rocchetti, G., A. Carta, A. Mondoni, S. Godefroid, C. C. Davis, G. Caneva, M. A. Albrecht, et al. 2022. Selecting the best candidates for resurrecting extinct-in-the-wild plants from herbaria. *Nature Plants* 8: 1385–1393.
- AIBS. 2024. "AIBS Calls on Duke University to Reconsider Decision to Close Herbarium." *AIBS*. <https://www.aibs.org/news/2024/240221-duke-herbarium-closure.html> (March 13, 2024).
- Bebber, D. P., M. A. Carine, J. R. I. Wood, A. H. Wortley, D. J. Harris, G. T. Prance, G. Davidse, et al. 2010. Herbaria are a major frontier for species discovery. *Proceedings of the National Academy of Sciences* 107: 22169–22171.
- Corlett, R. T. 2023. Achieving zero extinction for land plants. *Trends in Plant Science*: S1360138523000997.
- Davis, C. C. 2022. The herbarium of the future. *Trends in Ecology & Evolution*: S0169534722002956.
- Flannery, M. C. 2012. Flatter than a pancake: Why scanning herbarium sheets shouldn't make them disappear. *Spontaneous Generations: A Journal for the History and Philosophy of Science* 6:225–232.
- Flannery, M. C. 2023. *In the Herbarium: the Hidden World of Collecting and Preserving Plants*. Yale University Press, New Haven.
- Funk, V. A. 2003. 100 Uses for an Herbarium (well at least 72). *American Society of Plant Taxonomists Newsletter*. 17 (2):17–19.
- Gray, Asa. "Herbarium Talk" in the Asa Gray Papers. Box 16. Botany Libraries, Gray Herbarium, Harvard University, Cambridge, MA.
- Grinnell, J. 1910. The methods and uses of a research museum. *Popular Science* 77: 163–169.
- Heberling, J. M. 2022. Herbaria as big data sources of plant traits. *International Journal of Plant Sciences* 183: 87–118.
- Heberling, J. M., and B. L. Isaac. 2017. Herbarium specimens as exaptations: New uses for old collections. *American Journal of Botany* 104: 963–965.
- Heberling, J. M., and B. L. Isaac. 2018. iNaturalist as a tool to expand the research value of museum specimens. *Applications in Plant Sciences* 6: e01193–e01193.
- Heberling, J. M., J. T. Miller, D. Noesgaard, S. B. Weingart, and D. Schigel. 2021. Data integration enables global biodiversity synthesis. *Proceedings of the National Academy of Sciences* 118: e2018093118–e2018093118.
- Heberling, J. M., L. A. Prather, and S. J. Tonsor. 2019. The changing uses of herbarium data in an era of global change. *BioScience* 69: 812–822.
- Hill, Thomas. 1865. "Harvard University. Annual Report of the President of Harvard University to the Overseers on the State of the University for the Academic Year 1863-1864." *Welch, Bigelow, and Company*: 7–11.
- Humphreys, A. M., R. Govaerts, S. Z. Ficinski, E. Nic Lughadha, and M. S. Vorontsova. 2019. Global dataset shows geography and life form predict modern plant extinction and rediscovery. *Nature Ecology & Evolution* 3: 1043–1047.
- IPBES. 2019. IPBES, 2019. Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science–Policy Platform on Biodiversity and Ecosystem Services. In et al. S. Díaz [ed.], *Global assessment report on biodiversity and ecosystem services of the Intergovernmental Science–Policy Platform on Biodiversity and Ecosystem Services*. Bonn, Germany.
- Johnson, Victoria. 2018. *American Eden: David Hosack, Botany, and Medicine in the Garden of the Early Republic*. New York: Liveright: 334.
- "Keep Kew at Kew." *Change.org*. <https://www.change.org/p/keep-the-kew-herbarium-at-kew> (March 13, 2024).
- Knapp, W. M., et al. 2020. Regional records improve data quality in determining plant extinction rates. *Nature Ecology & Evolution* 4: 512–514.
- Knapp, W. M., et al. 2021. Vascular plant extinction in the continental United States and Canada. *Conservation Biology* 35: 360–368.
- Lendemer, J., et al. 2020. The Extended Specimen Network: A strategy to enhance US biodiversity collections, promote research and education. *BioScience* 70: 23–30.
- Lewis, Andrew J. 2011. *A Democracy of Facts: Natural History in the Early Republic*. Philadelphia: U of Pennsylvania Press: 49.
- Linnaeus, Carl. 1751. Transl. by Stephen Freer (2005). *Philosophia Botanica*. Oxford: Oxford University Press.
- McCourt, Richard M., and Earle E. Spamer. 2004. "On the Paper Trail in the Lewis and Clark Herbarium." *Bartonia* (62): 2.
- Marsico, T. D., E. R. Krimmel, J. R. Carter, E. L. Gillespie, P. D. Lowe, R. McCauley, A. B., Morris, et al. 2020. Small herbaria contribute unique biogeographic records to county, locality, and temporal scales. *American Journal of Botany*. 107(11): 1577–1587
- Oliveira, G., et al. 2020. "The Anthropocene in Natural History Museums: A Productive Lens of Engagement." *Curator*, 63: 333–351. <https://doi.org/10.1111/cura.12374>
- Parr, A. E. 1939. On the functions of the natural history museum. *Transactions of the New York Academy of Sciences* 2: 44–58.
- Prather, L. A., O. A. Fuentes, M. H. Mayfield, and C. J. Ferguson. 2004. The decline of plant collecting in the United States: a threat to the infrastructure of biodiversity studies. *Systematic Botany* 29: 15–28.
- Silliman, B. 1865. Scientific Intelligence: Harvard University Herbarium. *American Journal of Science and Arts* ser.2:v.39 no. 11: 225–6.
- Soga, M., and K. J. Gaston. 2018. Shifting baseline syndrome: causes, consequences, and implications. *Frontiers in Ecology and the Environment* 16: 222–230.
- Stuckey, Ronald L. 1971. "The First Public Auction of an American Herbarium Including an Account of the Fate of the Baldwin, Collins, and Rafinesque Herbaria." *Taxon: The Journal of the International Association for Plant Taxonomy* 20(4): 444.
- Thiers, B.M. Strengthening partnerships to safeguard the future of herbaria. *Diversity* 2024, 16, 36. <https://doi.org/10.3390/d16010036>
- Vargas, C. A., M. Bottin, T. Sarkinen, J. E. Richardson, M. Celis, B. Villanueva, and A. Sanchez. 2023. How to fill the biodiversity data gap: Is it better to invest in fieldwork or curation? *Plant Diversity*: S2468265923000823.
- Wood, Emily W. 2010. "Gray's Herbarium to the Gray Herbarium to the Harvard University Herbaria." *Harvard Papers in Botany* 15(2): 321–42. doi:10.3100/025.015.0212.
- Zedane, L., C. Hong-Wa, J. Murielle, C. Jeziorski, B. G. Baldwin, and G. Besnard. 2016. Museomics illuminate the history of an extinct, paleoendemic plant lineage (Hesperelaea, Oleaceae) known from an 1875 collection from Guadalupe Island, Mexico: Biogeographic History of Hesperelaea. *Biological Journal of the Linnean Society* 117: 44–57.