

EDITORIAL

A second Renaissance of herbarium-based research, almost five centuries after their invention

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The present issue of *Bauhinia* presents the Proceedings of the Bauhin2022 conference, that the authors organized at the University of Basel, Switzerland, from 15–16 September 2022 in honor of Caspar Bauhin (1560–1624), celebrating his pioneering *Flora of Basel* 400 years after its publication (Bauhin 1622). This meeting, with ca. 100 participants from 14 countries, with 25 invited and contributed talks, 31 posters, and a discussion workshop fueled our thinking on the increasingly pivotal role of herbaria in current day research.

Herbaria as scientific instruments arose in the 16th century in the context of the Renaissance in Italy, at the confluence of a renewed interest in classic botanical-medical texts, a rise in humanist thinking, an increasingly empirical rather than scholastic approach to plant species knowledge, and an influx of unknown exotic plants from colonial activities that also spurred an excitement to observe European plants in their native habitats (Reeds 1991; Ogilvie 2006). Besides the availability of paper, creating herbaria from living plants involved only desiccation while applying pressure as a preservation technique, and was thus in principle at everyone's disposal. An early term for herbarium was „hortus siccus“ (dry garden), emphasizing that they enabled scientific inquiry at all times of the year and everywhere. Assembling herbaria, which also spurred botanical expeditions to distant areas (Walter et al. 2022), is generally ascribed to Luca Ghini (1490–1556), who advised many influential students that went on to collect the plants for the earliest surviving herbaria (Baldini et al. 2022). The ability to study, exchange and compare plants year-round culminated in revolutionary scientific progress with lasting impacts over centuries (Arber 1912). One particularly profound example is the „*Pinax Theatrum Botanicum*“ (Bauhin 1623), the first approximately global catalogue of plants, which already included >90 % of the species of Linnaeus' „*Species Plantarum*“ (Linnaeus 1753). Bauhin based the „*Pinax*“ on his immense herbarium that he had assembled using a network of contacts from all over Europe since the 1570s. The precursor of the „*Pinax*“, the „*Phytopinax*“, even states in the title that plant descriptions were derived from herbarium specimens („*Phytopinax seu enumeratio plantarum ab herbariis nostro seculo descriptarum...*“ Bauhin 1596), reinforcing the centrality of herbarium specimens in the early development of botany as a scientific discipline.

From early herbaria to the present day

Since their invention, herbaria have never left scientific botany, even though not all botanical disciplines require a comparative

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approach. Currently, ca. 3500 herbaria hold almost 400 million plant specimens worldwide (Thiers 2023), of which about 0.004% were collected prior to 1600 (Baldini et al. 2022). Their enduring value is widely acknowledged (e.g. Besnard et al. 2018; Marsico et al. 2020, Burbano & Gutaker 2023), yet they remain under threat by closing facilities or moving collections off-site, away from the scientists that consult them (Miller et al. 2020), mainly for economic reasons. The monetary cost of maintaining herbaria are large: a simple back-of-the-envelope calculation for the Herbaria Basel (BAS/BASBG/RENZ; 700 000 specimens), Switzerland, gives a conservative, minimal estimate of the equivalent of 0,18 EUR or 0.19 USD per specimen per year (summing the yearly housing plus curatorial costs), on top of which come all other costs including processing new specimens, digitalization, and research. To ensure this support, herbaria need strong advocates and justification from their value for current research, not least because the highest-impact research may be conducted by researchers with a different primary affiliation than the collecting holding institution. Therefore, the significant, recurrent institutional investments that herbaria require should be broadly carried (Miller et al. 2020). Intriguingly, many herbaria are increasingly recognized as formally protected cultural goods (e.g., Swiss Inventory of Cultural Goods of National Importance), broadening the palette of arguments for the preservation of herbaria as accessible, pertinent research infrastructures.

Concerns for the future of herbaria are broadly shared, but we recognize a change in the wind. In our time of human induced climate change and radically altered land use, herbaria also represent long time-series that provide direct evidence of how the world changes. This enables addressing questions in ecology, physiology, and evolution using herbaria (e.g. Meineke et al. 2018; Albani Rocchetti et al. 2021), much expanding their original taxonomic, systematic, and biogeographic scope. Scientific revolutions frequently are preceded by technological innovation (for instance, how the polymerase chain reaction fueled genetic discoveries) and the future of herbaria is no different. To be mentioned first is the innovation of the digital specimen (Hedrick et al. 2020), allowing to consult and query specimens in ways and magnitudes unthinkable just a few years ago. Here, the trend is towards increased digital connectivity in the form of a „global metaherbarium“ (Davis 2023) and artificial intelligence applications extracting a multitude of information layers from specimens (Hussein et al. 2022). We note, however, considerable challenges in maintaining links between specimens and the (digital) data derived from them, that are necessary to preserve reproducibility (Manzano & Julier 2021). Secondly, it is now possible to obtain DNA sequences from even the oldest herbarium specimens for large portions of their highly degraded ancient genomes (Kistler et al. 2020) and target-enrichment methods (e.g. Johnson et al. 2019) unlock herbarium specimens for broad-scale phylogenomic research. Though much potential remains to be realized, progress for the broadening of specimen utility on both fronts is reassuringly rapid.

A second renaissance of herbarium-based research

As historic specimens become increasingly relevant, their remarkably challenging interpretation requires intensified collaboration between historians (of science) and natural scientists (e.g., Walter et al. 2022; Van Andel et al. 2022). Likewise, millions of natural history objects were collected or acquired during expeditions in the Global South that benefitted from collaborations with colonial powers, when not outright forcibly removed from foreign lands, leaving collection holding institutions today with the obligation to morally justify their inventory (Park et al. 2023). Discussions on how to identify and settle putative moral debts require multidisciplinary perspectives, but such debates are not yet very frequent.

Overall, researchers from very diverse scientific fields, administrators from collection-holding institutions, and funding agencies are all increasingly aware of the power of the existing 400 million herbarium specimens worldwide, yielding a novel potential for collection-holding institutions as sources of research. We believe that the combination of new technological possibilities, a renewed interest in the past from both ecological and historical perspectives, and the societal challenges posed by the worldwide biodiversity crisis are so profound that they may amount to a second renaissance of herbarium-based research (Burbano and Gutaker, 2023), almost five centuries after their invention. Capitalizing on these developments requires also strategically expanding collections for the future. Here, both promoting of local collecting, for instance in the context of citizen science, and a global, collaborative perspective on collecting priorities are needed. Given the multitude of current uses of specimens – many of which were unlikely to be envisioned by their collectors – it would be arrogant to assume that we foresee all future uses of herbarium specimens. What we can confidently hold, however, is that herbaria have proven their worth and potential repeatedly for over almost half a millennium. We see no reason to think that collections will ever become irrelevant.

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Artikel/Article: [second Renaissance of herbarium-based research, almost five centuries after their invention 3-6](#)