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Research Article

# The state of herbarium specimen backlogs: Perspectives from bryophyte collections

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## Abstract

An herbarium must have its specimens processed, identified and accessioned so that members of the botanical community can readily consult these materials. However, many herbaria struggle to keep up with the influx of specimens and accumulate a backlog of unaccessioned specimens. In this study, we surveyed herbarium staff about their institution's specimen backlog, focusing on the number and taxonomic lineage of backlogged specimens as well as the challenges associated with specimen curation. Based on responses from staff members at 65 herbaria, we calculated an average of 30,372 unaccessioned specimens per herbarium across all plant and fungal taxa. According to Index Herbariorum, there were 3,426 active herbaria in 2020 and, thus, we estimate at least 104 million specimens are present in herbarium backlogs worldwide. We also asked specific questions about unaccessioned bryophyte specimens in order to explore these collections in depth. While bryophytes represent only 9.0% of the accessioned specimens reported in our survey, they are overrepresented in the specimen backlog (16.0%). More than half of the bryophyte backlog is stored in field packets without labels and approximately three-quarters of these unaccessioned bryophytes lack species level identifications. Obstacles to backlog accessioning include labour shortages, insufficient bryological expertise and challenges integrating partially curated materials. Drawing on our survey responses, we offer strategies for reducing backlogs, such as accessioning straightforward specimens first and organising backlogs according to tasks leading to accessioning.

**Key words:** Curation practices, herbaria, identification level, natural history, specimen storage, survey research, unaccessioned specimens



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## Introduction

In order for natural history collections to be used for scientific studies, specimens must be identified, processed and catalogued. Many institutions struggle to keep up with the influx of specimens collected by their own researchers, as well as the donations they receive from across the world (Mitrow and Catling 2014). In natural history collections, people catalogue, research, exhibit and interpret the living world, including, but not limited to, plants, animals, fungi, geological material,

metals, minerals and more. Some collections contain many types of specimens and are organised into departments (i.e. botany, mammalogy, mineralogy etc.), while others specialise in a single type of specimen (i.e. arboretum, aquarium, herbarium etc.). Regardless of the specimens, these collections have a shared focus on discovering, researching and describing nature (Pearce 1992; Andreone et al. 2024). Additionally, natural history specimens are processed and prepared (i.e. labelled, stored and digitised) according to best practices in the field (Pearce 1992; British Columbia Ministry of Forests 1996; Vollmar et al. 2010; Ricco 2023). By looking at the past and present, natural history collections are able to seek out "unforeseen challenges facing humanity" (Davis 2024, p.1035).

Herbaria are natural history collections that house dried plant specimens. These collections enable us to understand where, when and the co-occurrence of plant species, which is the foundation of biodiversity tracking (Nic Lughadha et al. 2018; Marín-Rodulfo et al. 2024). Accessioned or catalogued specimens, especially when digitised, become available to the general public and experts alike, allowing them to be used in a variety of ways for both teaching and research purposes (Flannery 2024b). Like other collections of artefacts, herbaria may encounter challenges with 'backlogs' of unaccessioned specimens that are not yet incorporated or catalogued as part of the collection (Roberts 2004; Bebber et al. 2010). As herbaria are critical for fostering a better understanding of plants (Heberling and Issac 2017; Davis 2024) and addressing broader changes in global biodiversity and extinction rates (Heberling and Hardy 2025), it is essential to also understand their backlogs. Since these backlogged specimens are often not accessible to researchers, we know little about the content of backlogs (Vollmar et al. 2010; Flannery 2024a).

Active collecting results in a challenge where herbaria must balance processing the residual backlog from collectors of the past with the ongoing influx of new specimens from contemporary researchers (Bebber et al. 2010). Backlogged specimens can be found stacked on top of cabinets, in corners, warehouses and left in boxes (Flannery 2024a). The plants themselves can be found in field packets, newspaper wrappings, archival packets and even random household containers such as cheese cans (Nave and Spicer 1867; Gradstein et al. 2001; National Park Service 2009; Institute of Conservation 2013; Tocci 2019; Lewis and Budke 2022). Little et al. (2020) posit that these unaccessioned specimens store valuable scientific information (Noltie 2017; Andreone et al. 2024; Flannery 2024a), potentially including now extinct plant species from global biodiversity hotspots (Carbone et al. 2023; Sevigny 2023; McQuilkin and Chakrabarti 2024). While herbarium backlogs may be small in comparison to the size of the accessioned collections, these specimens may represent important knowledge that is not represented in the accessioned specimens (Prather et al. 2004; De Lutio et al. 2022; Flannery 2024a).

Both time and funding are needed for herbarium staff to process unaccessioned specimens (Mitrow and Catling 2014). Specimens must be moved to archival paper/packaging and field notes converted to formal labels (Glime and Wagner 2013; Harvey 2023). While collectors are encouraged to identify their specimens prior to sending them to a herbarium, if they have not, additional time and expertise is needed to identify these specimens so that they can be filed with the accessioned specimens of the same taxon (Massey 1974). If herbarium staff do not have the expertise and/or time to identify backlogged

specimens, then scientists from outside the institution may be recruited and potentially hired to help with specimen identification (Funk 2017). However, this process may generate additional costs for institutions that may already have limited resources (Glime and Wagner 2013). Estimating the number of specimens present in the unaccessioned backlog at institutions across the world remains an open question and with estimates that there are one million backlogged herbarium specimens (Joppa et al. 2011; Little et al. 2020). Some institutions know they have substantial backlogs requiring a large effort (Mitrow and Catling 2014; Flannery 2024a), while others simply acknowledge that they exist (Bebber et al. 2010; Flannery 2024a). Having a better estimate of specimens allows for better cost, time and people needed for accessioning.

Using a data-driven approach, this study aims to expand on insights from the middle to late 20th century (i.e. Fosberg (1946); Shetler (1969); Waddell (1984); Bridson and Forman (1998)), along with those in more recent literature (i.e. Funk (2017); Nic Lughadha et al. (2018); Cowell et al. (2020); McQuilkin and Chakrabarti (2024)). In this study, we conducted a survey of herbarium staff focused on the state of herbarium backlogs. Our research addresses the following questions: A) How many unaccessioned specimens are present in herbaria around the world and which taxonomic groups are they from? B) Why might herbaria develop and retain a backlog of unaccessioned specimens? C) What might we do to address challenges associated with backlogs? We pay specific attention to bryophyte (moss, liverwort and hornwort) specimen backlogs, in order to provide insight into the unique challenges created and confronted by this group of plants. Our findings on the state of herbarium backlogs and perspectives from 79 curators and collections managers, representing 2.3% of active herbaria, can be used to enhance investment and interest in these scientific collections.

## Materials and methods

### Study population and participant recruitment

In 2020, Index Herbariorum (IH) listed 3,426 active herbaria in 172 different countries that together housed a reported 396,204,891 specimens with approximately 12,000 staff associated with these herbaria (Thiers 2021). We recruited herbarium staff to participate in our study from 20 September 2021 to 20 October 2021 via social media and two professional listservs: Herbaria (https://www.nacse.org/mailman/listinfo/herbaria; sponsored by the American Society of Plant Taxonomists and the Society of Herbarium Curators) and Bryonet-L (https://bryology.org/bryonet/; sponsored by the International Association of Bryologists).

### Data collection

We collected data via a 30-question survey containing a mixture of closed-ended (pre-defined response categories) and open-ended (free response) questions (see Suppl. material 1). Our survey instrument was divided into five subsections: a) respondent demographics (six questions), b) herbarium basics (seven

questions), c) institution-wide backlog overview (three questions), d) bryophyte gifts/donations (eight questions) and e) bryophyte collection backlog specifics (six questions). This survey and the broader study of which it is a part were reviewed and approved by the Institutional Review Board (IRB) at Hobart and William Smith Colleges (Application #20-28).

### Data analysis

In preparation for our analyses, we reviewed our dataset for duplicate responses (i.e. responses with the same IH code). In instances in which there was more than one response with the same IH code, we retained the response that answered the greatest number of total survey questions. We also retained incomplete responses as participants were permitted to skip question(s) as they completed our survey. As a result, sample sizes vary across the dataset.

Quantitative data were analysed using descriptive summary statistics and regression models. We utilised models to examine the influence of the main effects of total number of accessioned specimens (continuous), number of full-time staff (continuous) and number of part-time staff (continuous) on the response variable of total number of unaccessioned specimens. Focusing on the bryophyte backlog specifically, we examined the influence of the main effects of the number of accessioned bryophyte specimens (continuous), number of full-time staff (continuous), number of part-time staff (continuous), whether the herbarium has a staff member with bryological expertise (ordered categorical; 1 = yes, 2 = not presently, but did previously, 3 = no), the number of staff hours per month devoted to working with bryophyte specimens (continuous) and whether the herbarium accepts bryophyte specimen donations/gifts (ordered categorical; 1 = yes, 2 = not presently, but did previously, 3 = no) on the response variable of number of unaccessioned bryophyte specimens. Starting with a full model, which included all of the predictor variables outlined above, we then ran stepwise regression algorithms using R version 4.3.1 (R Core Team 2023) and RStudio version 2023.06.2+561 (RStudio Team 2023) to determine which variables, if any, had a significant effect on the response variables.

We utilised thematic analysis to analyse our qualitative survey data. This approach focuses on identifying themes across a dataset (Braun and Clarke 2006). We approached thematic analysis in an iterative fashion, starting with a close reading of survey responses during which we generated a list of common words/phrases in the answers which study participants provided. From this list of common words/phrases, we generated a list of qualitative codes (i.e. themes) to guide the remainder of our analyses. We then reread our qualitative data, assigning one or more code to each participant response. Once the data were fully coded, we grouped the themes into broader scale-based categories and calculated the frequency at which each individual theme appeared in the dataset.

## Results

Eighty-seven staff members responded to our survey. After duplicates were removed, 79 responses were retained for further analysis. Sixty-five of these responses included data on both their accessioned and unaccessioned specimens.

## Quantity and location of herbarium specimen backlogs

Study participants reported data on both their accessioned and unaccessioned specimens for 65 herbaria containing 46,5722,505 accessioned and 1,974,206 unaccessioned specimens across all taxonomic groups (i.e. algae, bryophytes, fungi/lichens, vascular plants). The number of unaccessioned specimens represents 4.1% of the total specimens contained in these herbaria. In our sample, the number of unaccessioned specimens per herbarium ranged from 50 to 417,000 with an average of 30,372 specimens per herbarium. However, the number of unaccessioned specimens differed across organismal groups. Notably, bryophytes and fungi/lichens only represent 9% and 10% of the accessioned specimens. Yet, these two groups are over-represented in the backlog comprising 16% and 13%, respectively, of all unaccessioned specimens (Fig. 1). When asked where herbaria store their backlog, 95.4% of the 65 staff responding to this question stated that they store their backlog specimens onsite (i.e. in the same building as the accessioned specimens). Herbarium staff also reported on the amount of time they have until their collection space is full. The 65 herbaria represented in our dataset reported remaining time estimates ranging from none/already being full ($n$ = 3) to 100 years until reaching capacity ($n$ = 1) with an average time until full of 14.8 years.

## Institutional background as predictors of backlog

We asked questions relating to institutional background so we could determine if these factors were predictors of the overall backlog size, as well as for the bryophyte backlog specifically. We asked staff to report the number of full- and part-time staff members, whether or not their institutions have a dedicated bryophyte curator, the hours of staff time dedicated to working with bryophyte specimens and whether they accept bryophyte gifts/donations. Across the 79 herbaria reporting their staffing numbers, there was an average of 3.3 full-time

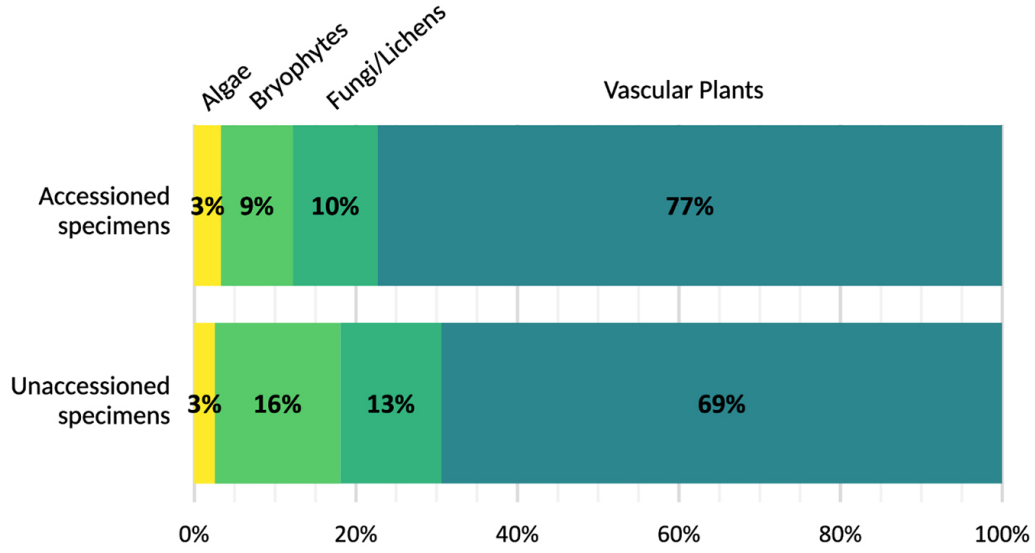


**Figure 1.** Accessioned and unaccessioned herbarium specimens. Specimens present in 65 herbaria as reported by the study participants in 2021. Percentage of accessioned (46,5722,505) and unaccessioned (1,974,206) specimens categorised by the type of organism.

and 3.1 part-time staff working at each herbarium. In terms of staff devoted to bryophyte curation, only 29.1% of respondents reported having a staff member with bryological expertise. Of the herbaria currently lacking staff with bryological expertise, approximately one-fifth had a bryophyte curator in the past. Seventy-two herbaria reported the number of hours per month dedicated to bryophyte specimens, which ranged from 0 ($n$ = 23) to 140 ($n$ = 1) hours per month, which is an average of 16.6 herbarium staff hours per month dedicated to working with these specimens. Regarding whether or not the herbarium accepts bryophyte donations/gifts, the vast majority of respondents answered yes (75.4%).

We then used a regression model to determine which of these potential predictors relate to the size of the herbarium backlog. In a reduced model, the total number of accessioned specimens ($F_{1, 60}$ = 9.42, $P$ = 0.0032) and the number of full-time staff were significant predictors ($F_{1, 60}$ = 4.49, $P$ = 0.038). Herbaria with a larger number of accessioned specimens and more full-time staff have a larger total number of unaccessioned specimens (backlog). Focusing on the size of the bryophyte backlog, two predictors explained the size of the backlog in a reduced model: the number of accessioned bryophyte specimens ($F_{1, 50}$ = 45.11, $P$ = 1.7e-08) and the number of staff hours per month devoted to working with bryophyte specimens ($F_{1, 50}$ = 16.66, $P$ = 1.6e-04). Herbaria with a larger number of accessioned bryophyte specimens and those that spent more time working with bryophyte specimens have a larger bryophyte backlog.

## Bryophyte backlog

Unaccessioned specimens can be stored at different curation and identification levels as they await further processing. In terms of curation, bryophyte specimens can be stored in either field packets or archival packets and with or without labels (Lewis and Budke 2022). Herbaria were asked to estimate the curation levels for their bryophyte backlogs. Forty-three respondents provided such estimates, indicating that 69.0% of their backlogged bryophyte specimens are in field packets without labels (Fig. 2). Meanwhile, bryophyte identification levels can range from division (Bryophyta, mosses; Marchantiophyta, liverworts; Anthocerotophyta, hornworts) to family to genus to species. Thirty-five staff estimated the percentage of their bryophyte specimen backlogs identified to each of these taxonomic levels. In this sample, the vast majority of unaccessioned bryophyte specimens were identified to only the genus level or above (Fig. 3).

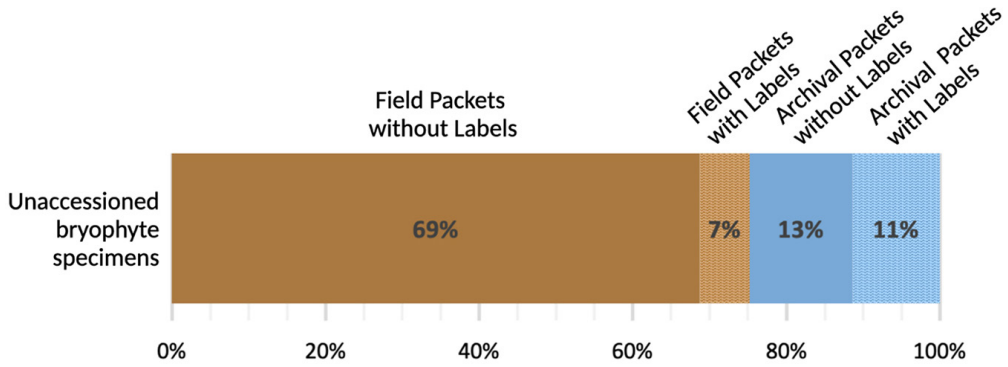


**Figure 2.** Curation level for unaccessioned bryophyte specimens. Percentage of specimens at each level, as reported by the study participants who responded to this question ($n$ = 43).

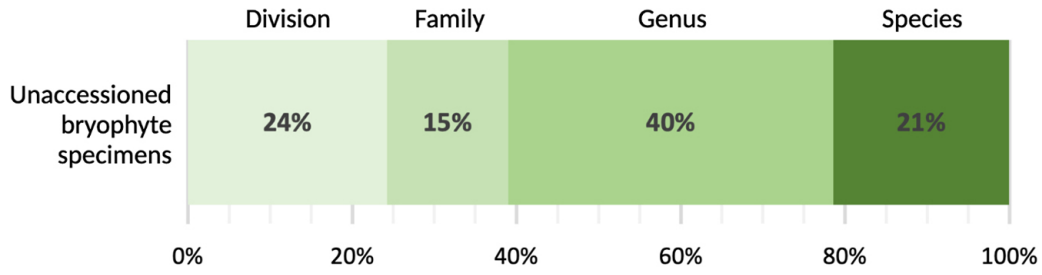


**Figure 3.** Taxonomic identification level for unaccessioned bryophyte specimens. Percentage of specimens at each level, as reported by the study participants who responded to this question (*n* = 35).

## Reasons for the presence of the backlog

Sixty-three staff members responded to our survey question regarding why their institutions have a bryophyte backlog. We identified 22 themes in these responses with 10 of these themes occurring at frequency of 10.0% or greater (Table 1). In an effort to better understand these ideas, we organised these themes into four categories reflecting the four scales at which study participants discussed why institutions have backlogs (i.e. institutional, backlog, specimen and individual levels). Institutional level factors are those that survey respondents describe as being institution-wide challenges, such as labour constraints and lack of expertise (Table 1). Backlog level factors, as described by our survey respondents, are more specifically related to the bryophyte backlog (in aggregate), such as total backlog volume and specimen source (Table 1). Meanwhile, survey participants also discuss specimen level factors (i.e. those related to an individual specimen, rather than the full backlog), such as its level of identification or whether a typed label is present (Table 1). Individual level factors, by comparison, are those related to persons working in the herbarium and, for example, their individual interests and priorities (Table 1).

## Institution level factors

The most frequent theme in backlog presence explanations was labour constraints (Table 1) with just over half of respondents citing an institutional deficit of "people", "staff", "curators" etc. as a major reason why their institutions have a backlog of bryophyte specimens. The need for people with specific skills and knowledge also became apparent. Almost a third of study participants discussed how bryophyte backlogs are the result of a lack of expertise at their institutions (Table 1). More specifically, several respondents identified how not having a "bryophyte" or "cryptogamic" "curator" and/or "researcher" has resulted in an accumulation of unaccessioned bryophyte specimens at their institution. Others drew attention to the fact that no-one is "specifically working in that field [bryology]" at their institutions and how that has resulted in the accumulation of backlogged bryophyte specimens. Retirements were also cited as an important contributor to the overall lack of bryophyte expertise at these institutions. For example, one respondent discussed how their last bryology expert "retired in the 1990s" and had not been replaced.

Another institutional level theme evident in descriptions of why a backlog of bryophyte specimens exists at their herbarium was resource constraints, mentioned by 30.2% of respondents (Table 1). In this case, respondents often described how a lack of "funding" and/or "funds" for "support" and/or the lack of

**Table 1.** Themes for why institutions have a bryophyte backlog. Descriptions of the themes present in staff explanations of why their institutions have bryophyte backlog (*n* = 63) with a frequency of 10.0% or higher.

| Theme | Frequency | Description |
|---|---|---|
| Institutional level | | |
| Labour constraints | 52.4% | Lack of or limited staff, curators, faculty, collections managers, volunteers, students etc. |
| Lack of expertise | 31.7% | Lack of institutional knowledge in bryology |
| Resource constraints | 30.2% | Lack of institutional time and curation materials |
| Competing institutional priorities | 22.2% | Focus on digitisation, other backlog and research |
| Backlog level | | |
| Specimen source | 22.2% | Generated from research projects, surveys, expeditions, gifts/bequests etc. |
| Backlog volume | 19.0% | Backlog amount is either small and insignificant or large and overwhelming |
| Specimen age | 11.1% | Age of the specimens, new or old |
| Specimen level | | |
| Level of identification | 22.2% | Lack of completed specimen identification |
| Labelling | 9.5% | Lack of labelling information |
| Individual level | | |
| Interests/priorities | 14.3% | Focus on daily tasks over accessioning backlog |
| Time constraints | 11.1% | Lack of time that individuals have |

"[institutional] time" result(ed) in bryophyte backlogs. An additional 14 respondents mentioned competing institutional values as playing a role in the presence of a bryophyte backlog at their institution (Table 1). In such responses, herbarium staff described a lack of "reward" for backlog to be "part of their core job", as well as discussing an institution-wide prioritisation of backlog specimens of other groups, such as flowering plants. Additionally, several respondents argued their institutions prioritised "digitisation" or "a digital database" over other curatorial tasks.

## Backlog level factors

Around 20.0% of respondents mentioned specimen source as playing a role in the presence of a bryophyte backlog at their institution (Table 1). These respondents often characterised their backlogged specimens as resulting from "research [projects]", "gifts" and/or "bequest collections". Another backlog-related theme appeared in approximately 20.0% of survey responses was backlog volume (Table 1). "Specimens from all groups tend to pile up" was a common sentiment amongst our respondents with several mentioning that they were constantly "playing catchup" when there were "simply many more 'new' specimens" and/or "large quantities of materials" in their institution's bryophyte backlogs. The theme of specimen age appeared at a frequency of 11.1% in our data set (Table 1). Some respondents mentioned "old specimens" and "old boxes with specimens [that] tend to pile up", while others discussed specimen age in terms of "recent collections" or "preparing new accessions" with newer specimens being more likely to be put "on hold" or "halt[ed]".

## Specimen level factors

For specimen specific factors, a little over 20.0% of respondents cited the level of identification as playing a role in the accumulation of a bryophyte backlog at their institutions (Table 1). Some respondents argued that "unidentified

specimens" require more time and expertise. In other responses, "difficulty in securing determinations" and specimens that "require IDs" were referenced. Another theme mentioned at a frequency of approximately 10.0% was specimen labelling (Table 1). Respondents often discussed this theme in terms of "labels" needing to be "work[ed] on" or "created".

## Individual level factors

Amongst individual level reasons for the bryophyte backlog, the most frequent theme was individual interests and priorities, which occurred at a frequency of 14.3% (Table 1). In these instances, respondents described how people "liked to collect but didn't like to curate" or had "teaching duties". Others conveyed sentiments such as how people lack "particular interests in the br[y]ophytes, so it is a low priority to incorporate new accessions". Others drew attention to how "former curators were bryophyte experts who received many specimens as gifts". Mentioned at a frequency of 11.1%, individual time constraints were also a contributing factor to backlogs. Here, respondents discussed that their existing day-to-day job responsibilities "require a huge amount of time", leaving little time for working with backlogged specimens. As a result, some respondents discussed how backlog work was relegated to increasingly scarce "'free' time".

## Strategies to decrease backlog

Fifty-eight staff members responded to the question regarding the best strategies for decreasing their backlog. We identified 13 themes in these responses with eight themes occurring at a frequency of 10.0% or greater (Table 2).

The most frequent theme was more people being needed to decrease backlog numbers (Table 2), which was mentioned by 39 respondents. Responses varied in terms of the type of people needed. Twenty-two respondents described needing "more staff" in broad terms, while others indicated that they specifically needed more "students" (*n* = 9), "volunteers" (*n* = 8), "bryologists" (*n* = 5) and/or "curators" (*n* = 3).

Approximately one fifth of responses mentioned more curation and more funding (Table 2). Those respondents who referenced curation efforts did so by

**Table 2.** Themes of potential solutions for decreasing the size of bryophyte backlogs. Descriptions of the themes present in staff explanations of potential solutions to significantly decrease their backlog (*n* = 58) that occur with a frequency of 10.0% or higher.

| Theme | Frequency | Description |
|---|---|---|
| More people | 67.2% | Additional individuals needed, such as bryologists, curators, staff, students, volunteers etc. |
| More curation | 20.7% | Specimens in need of labels, accession numbers, value determination etc. |
| More funding | 20.7% | Additional financial resources needed |
| More expertise | 13.8% | Individuals with bryological skills are needed to identify specimens |
| More time | 12.1% | Additional or re-allocated time to focus on backlogged specimens |
| Fewer competing priorities | 12.1% | Balancing institutional projects focusing on databasing and digitising accessioned specimens |
| Improved workflow | 12.1% | Limited or lacking institutional processes and/or policies related to integrating backlogged specimens |
| Increased level of identification | 10.3% | Specimens either unidentified or only partially identified |

mentioning “proper methods”, “creating labels” or adding information. In comparison, those staff members who referenced needing more funding suggested “government” or “dedicated” funds and/or “money” for a variety of backlog activities.

An additional five themes appeared at a frequency of less than 20.0%. Nearly 14.0% of respondents considered access to more expertise as an important priority for handling bryophyte backlogs (Table 2). Eight staff members mentioned that their institutions did not have people with the “id skills” or “expertise” to “identify the specimens”. Meanwhile, three themes appeared in our dataset at a frequency of 12.1% (i.e. more time, fewer competing priorities and improved workflow; Table 2). Seven respondents referenced an “over-busy schedule” and struggling to “dedicate” or “devote” time. Others voiced concerns about how to deal with “future collecting” and/or needing “increased institutional support” before working on the backlogged specimens.

Approximately ten percent of study participants indicated that further identifying specimens as being key to reducing bryophyte backlogs (Table 2). Some of those surveyed explained that “identification of specimens” is necessary for the backlog to move into the accessioned collections ($n$ = 6). Other respondents mentioned “what family the specimen is classified in” was lacking or as having a “family identification”, but required more identification was still needed to be accessioned.

## Backlog accessioning priorities

A total of 52 staff members responded to the question regarding how they would prioritise backlogged bryophyte specimens, if provided with unlimited resources and expertise. We identified eighteen themes in these responses with seven of these themes occurring at a frequency of 10.0% or greater (Table 3).

The most frequent theme in participants’ backlog accessioning prioritisation responses was geographic significance with 36.5% of study participants mentioning this factor (Table 3). While some respondents discussed how they would prioritise bryophyte specimens with “location records”, others focused on the potential significance of backlogged specimens from particular geographical areas. Amongst the geographic reasons provided, ten participants highlighted a desire to first accession specimens “from other countries” with six participants prioritising “locally collected” specimens. Respondents also described prioritising the accessioning of backlogged specimens from “biodiversity hotspots”, “areas that are now significantly altered” and/or “areas in need of protection and conservation”.

**Table 3.** Themes for which specimens to prioritise from bryophyte backlogs. Descriptions of the themes present in staff explanations of how they would prioritise backlogged bryophyte specimens if they had unlimited resources and expertise ($n$ = 52) that occur in at least 10.0% of responses.

| Theme | Frequency | Description |
|---|---|---|
| Geographical significance | 36.5% | Specimens collected in geographical locations of significance to the herbarium and/or world |
| Specimen significance | 25.0% | Unique and/or understudied specimens such as types, unicates etc. |
| Project significance | 17.3% | Specimens collected as a part of specific and/or notable forays, research projects etc. |
| Convenience | 15.4% | Specimens that are easily accessible and therefore easier to accession |
| Collector significance | 15.4% | Specimens collected by specific and/or notable collectors |
| Specimen type | 11.5% | Taxonomic division in which specimens belong |
| *Historical significance* | 11.5% | Specimens having historical value to the herbarium and/or world |

Specimen significance was mentioned by a quarter of respondents (Table 3). The majority of these 13 individuals stated that they would first prioritise backlogged specimens that have "great value to researchers" or otherwise have the potential to "increase our knowledge of our bryophyte flora" (*n* = 9). Six responses described prioritising backlogged specimens that "may represent less common, possibly rare, species".

Prioritising specimens due to their project significance was mentioned at a frequency of 17.3% amongst the 52 respondents (Table 3). Seven respondents mentioned that specimens "that are part of a research study" are from "research projects" or general "project" should be accessioned first. Meanwhile, two staff members stated that they would prioritise specimens that were "vouchers for published papers".

Two themes occurred at a rate of approximately 15.0% in our survey responses – convenience and collector significance (Table 3). In the case of convenience, eight study participants highlighted that specimens that are "located at the top of the pile" and, therefore, could be integrated more easily than other backlogged specimens would be a priority. Respondents also referenced specimens related to projects that have "staff [who] are still present to answer questions" or that current "staff are focused on" would be prioritised. Eight respondents stated collector significance as a priority and mentioned focusing on described specimens from "professional collector[s]" and/or "important collectors from around the world".

## Study limitations

While our study makes significant strides to enhance our current understanding of herbarium backlogs, it has several limitations. First, specimen backlogs have not been studied comprehensively (Bebber et al. 2010; Andreone et al. 2024) and, therefore, remain a poorly understood part of herbaria (Bebber et al. 2010; Little et al. 2020; Flannery 2024a). As such, focusing on this topic is challenging, since it is difficult to study something people do not acknowledge and/or feel prepared to discuss. Second, we administered a fairly lengthy survey during the height of the Covid-19 pandemic. As a result, our response rate is lower than anticipated with a final sample representing approximately 2.0% of the herbaria listed in IH in 2020. Although response rates and sample sizes are often viewed as proxies for data quality, they are not the only important determinants of study value (Madans et al. 2023). Given that our dataset includes voices from a geographically diverse set of herbaria with a wide range of collection sizes (i.e. from small herbaria with 1,000 accessioned specimens to large herbaria with 6,000,000 accessioned specimens), we see value in the perspectives we were able to capture, particularly because our study is the first systematic attempt to shed light into the number of specimens in herbarium backlogs worldwide. Lastly, because a large portion of our survey focused on bryophyte backlogs and we allowed respondents to skip questions, item non-response bias may be evident in our dataset. Research suggests that non-response bias is fairly common in survey-based social science research and can impact the generalisability of the findings (Mignogna et al. 2023). While our findings provide critical evidence-based insights into the contents of and reasons for herbarium backlogs, we acknowledge that they are not comprehensive. We hope that our study and the insights it provides will prompt more sustained dialogue on this important, but often overlooked topic.

## Discussion

This study focused on surveying herbarium professionals to gain insight into the current state of herbarium backlogs with a specific focus on bryophyte specimens. We found that herbaria with a larger number of total accessioned specimens and more full-time staff have larger backlogs. With regard to bryophyte specimens, we found that herbaria with a larger number of accessioned bryophyte specimens and more staff hours devoted to working with bryophytes have larger bryophyte backlogs. Based on our own fieldwork-based observations at herbaria across North America and Europe (Lewis and Budke 2022), we interpret these findings as supporting anecdotal reports that collectors send their (bryophyte) specimens to larger institutions that are known to have full-time staff and, therefore, have more capacity to handle incoming (bryophyte) specimens.

### The untapped potential of herbarium backlogs

Our survey revealed that herbaria in our sample have an average of 30,372 backlogged specimens. Based on the total number of active herbaria worldwide listed in IH, we estimated that there are nearly 104 million unaccessioned specimens in herbarium backlogs around the world. If these backlogged specimens were accessioned, the total number of herbarium specimens worldwide would increase by approximately 27.0%. Accessioning these specimens may enhance our understanding of the botanical world (Noltie 2017; Nic Lughadha et al. 2018), leading to the identification of species new to science (Bebber et al. 2010). Accessioning backlogged specimens also results in more representative collections (Besnard et al. 2018), enabling scientists to know where plants were historically located and whether their distributions have changed over time (Besnard et al. 2018; de Vos 2019), thereby facilitating more accurate understandings of current threats to biodiversity (Prather et al. 2004; Nic Lughadha et al. 2018; Carbone et al. 2023; Sevigny 2023; McQuilkin and Chakrabarti 2024). As such, herbarium specimens play an important role in helping scientists identify which species are in need of conservation (de Vos 2019; Cowell et al. 2020; Davis 2022) and play vital roles in research, education and expanding our understanding of nature (Funk n.d.).

### Over-representation of bryophytes and lichens in herbarium backlogs

Based on our survey, when compared to other taxonomic groups, bryophytes and lichens are over-represented in herbarium backlogs (Fig. 1). There are several possible explanations for this finding. As noted by several of study participants, when bryologists/lichenologists retire, they are not necessarily replaced by individuals with the same specialised knowledge and skills. As a result, current staff may lack professional training and/or interest in these organisms. This situation results in herbaria not having sufficient bryological and/or lichenological expertise to identify backlogged specimens, an argument evident in staff explanations for why their institutions have a backlog (Table 1). The herbarium staff we surveyed often described feeling like they have to do more with less, while balancing competing institutional priorities (Table 1).

Even when expertise and interest in these organisms is present, bryophytes and lichens often require microscopic examination and dissection for accurate identification (Brodo et al. 2001; Flora of North American Editorial Committee 2007). Even when identifications are carried out by an efficient specialist, this extends the identification time relative to vascular plants. Multiplying the longer time needed for identification over a large number of specimens is an additional challenge for processing and accessioning bryophyte and lichen backlogs. These factors likely explain, in part, why these groups are over-represented in herbarium backlogs.

## Backlogged bryophyte specimens often lack archival packets and labels

Although Glime and Wagner (2013) assert that folded packets with complete labels are the gold standard for bryophyte storage and curation, we found that backlogged bryophyte specimens are often in field packets with many lacking labels. These are thought to be temporary storage methods, that include field packets, paper bags, boxes and recycled paper envelopes (Nave and Spicer 1867; Fish 1999; Gradstein et al. 2001; National Park Service 2009; Institute of Conservation 2013; Tocci 2019), which often become long term storage when the specimens are not moved into the accessioned collection (Gier 1952; Victor et al. 1994; Flowers et al. 1945; Smith and Chinnappa 2015). This suggests that most backlogged bryophyte specimens will require re-packaging, which necessitates additional resources and time (Buck and Thiers 1996; Glime and Wagner 2013; Seed and Ma 2024). This situation is further compounded by the fact that not all collectors include complete collection data on their field packets and they often do not generate archival labels prior to depositing them at an herbarium (Seed and Ma 2024).

Despite the relatively straightforward nature of re-packaging, survey participants consistently report having limited time and/or resources to dedicate to these curatorial tasks, particularly as they relate to working with backlogged (and incoming) bryophyte specimens (Table 1). A lack of people working on accessioning is mentioned by half of the respondents (Table 1), while more than half suggest more people working on the backlog to be a solution (Table 2). Research suggests that repetitive tasks, such as re-packaging and barcoding, can be carried out by students and/or volunteers after some initial training (McCarty 2014; Nature Museum 2022). It is important to note that volunteers are common at many herbaria (Thompson and Birch 2023; von Konrat et al. 2024), yet they require both training and supervision by staff.

## Bryophyte specimens in backlogs are frequently not identified to species

Unaccessioned bryophyte specimens with incomplete identifications are a common occurrence in herbarium backlogs (Bebber et al. 2010). About a quarter of backlogged bryophyte specimens reported in our survey are only identified to division (i.e. mosses, liverworts, hornworts; Fig. 3). This makes determining an expert who might be willing to help with the identifications challenging, potentially making these collections likely to remain in the backlog until there is someone at the institution who has or develops bryological expertise. Specimens identified to family or genus could be accessioned in order to move them out of the backlog (Waddell 1984; Bebber et al. 2010). However, this does not resolve

the need for species level identifications. Physically placing partially identified specimens with other accessioned specimens would increase the likelihood that researchers examining specimens from those taxonomic groups would come across them and have the opportunity to identify them in the future.

### Strategies for reducing herbarium backlogs

Our recommendations for approaching herbarium backlogs have focused on both the tasks of backlog integration and maximising these activities given limited resources. When asked what the best strategy was for their institutional backlogs, respondents identified increasing the number of people to be vital (Table 2). Herbaria are often short-staffed with some institutions only having a few full-time staff, which makes decreasing the backlog a lower priority (Shetler 1969; Thiers 2021). A recurring suggestion among our participants was to lean on volunteers for tasks that require some training, but not as much expertise. The Chicago Academy of Science's Herbarium and similar institutions have had success with temporary staff members, as well as a volunteer force dedicated to processing the backlog (Nature Museum 2022).

Respondents also stated that increasing specimen curation was vital for decreasing their institutional backlog (Table 2). Changes to specimen donation policies, such as requiring full species identifications, could help to decrease the number of specimens placed into the backlog going forward. Encouraging financial donations along with gift specimens would assist with their accessioning and upkeep – mirroring current practices in art museums (Grant 2022). Fundraising initiatives specifically for accessioning specimens could also encourage backlogs to become an institutional priority (Bebber et al. 2010; Andreone et al. 2024).

Developing a backlog accessioning plan can assist in breaking down what can often feel like a monumental project into smaller more manageable tasks. Inventorying the contents of the backlog is the first step in this process, which includes identifying key attributes of the backlog, such as prominent collectors and significant collection periods, so that specimens can be prioritised. Specimen prioritisation could also be centred on the projects of botanical researchers at the institution or critical geographic regions, such as local areas or biodiversity hotspots, that align with the institution's mission (Table 3). Sorting the backlog, based on the level of identification (division, family, genus and species), would allow fully and partially identified specimens to be accessioned more quickly, while also enabling staff to better understand what expertise is required for identifying the remainder. Curating, which includes re-packaging and label generation follows. Prioritising specimens that have some level of identification, even if it is only family or genus, no matter the level of re-packaging that is required, will enable them to be filed where taxonomic experts can find them.

## Conclusions

Elucidating how and why backlogged specimens accumulate at herbaria across the world is critical to ensuring the utility of botanical collections. This study represents an important step that enhances the herbarium community's understanding of their collections by outlining the challenges and priorities institutions have in managing backlogs of unaccessioned specimens. Staff view

additional staffing, curation time and funding as solutions to decrease the overall backlog. Focusing on geographic and specimen significance when prioritising their bryophyte backlogs may also aid in this process. While incoming specimens remain an ongoing source of potential backlog, streamlining the donation process will help to increase the accessioning of these specimens. A decrease in these backlogs will lead to an increase in botanical specimens available for research and education. Hopefully, this broad overview of herbarium backlogs may inspire institutions to approach their backlogged specimens with more confidence and actively collaborate with peer institutions on how best to move forward in accessioning these scientific treasures.

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## Additional information

### Conflict of interest

The authors have declared that no competing interests exist.

### Ethical statement

No ethical statement was reported.

### Use of AI

No use of AI was reported.

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### Author contributions

HB, RAL: Conceptualisation. HB, JMB, RAL: Formal analysis. HB: Investigation. HB, JMB, RAL: Data Curation. HB: Writing - Original draft. HB, JMB, RAL: Writing - Review and Editing. JMB: Visualisation. RAL: Supervision. JMB, RAL: Funding Acquisition. HB, RAL: Conceptualisation. HB, JMB, RAL: Formal analysis. HB: Investigation. HB, JMB, RAL: Data Curation. HB: Writing - Original draft. HB, JMB, RAL: Writing - Review and Editing. JMB: Visualisation. RAL: Supervision. JMB, RAL: Funding Acquisition.

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## Data availability

All of the data that support the findings of this study are available in the main text or Supplementary Information.

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## Supplementary material 1

### Herbarium staff survey

Authors: Hannah Bendull, Jessica M. Budke, Robin A. Lewis

Data type: pdf

Explanation note: Consent form and 30 survey questions that participants received and responded to that was the primary mode of data collection for this study.



Link: https://doi.org/10.3897/nhcm.3.182936.suppl1