

¹ BarnebyLives: an R package to create herbarium specimen labels
² and clean spreadsheets

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⁴ **Abstract**

⁵ **Premise:** Accessioning herbarium specimens is labor-intensive, yet remains vital for research in ecology,
⁶ evolution, and conservation. As institutional support for herbaria declines, efficient tools are needed
⁷ to streamline this process. BarnebyLives was developed to assist collectors by supplementing collection
⁸ notes, verifying taxonomic data, conducting quality checks, generating labels, and submitting digital
⁹ records.

¹⁰ **Methods and Results:** It integrates geospatial data from U.S. government sources to provide juris-
¹¹ dictional and site information, and checks taxonomic names using in-house spell checkers, IPNI author
¹² standards, and Kew's Plants of the World Online. Optional features include generating Google Maps
¹³ driving directions. The tool outputs data in tabular and spatial formats for review before producing
¹⁴ LaTeX-based labels and shipping manifests.

¹⁵ **Conclusions:** BarnebyLives improves data accuracy, ensures up-to-date taxonomy, and significantly
¹⁶ reduces the time and effort required to accession herbarium specimens.

¹⁷ **INTRODUCTION**

¹⁸ Nearly 400 million specimens are housed worldwide in herbaria (Thiers, 2021). However, The rate of ac-
¹⁹ cessioning new collections to herbaria diminished in the 20th century as priorities in biology shifted away
²⁰ from describing and documenting Earth's biodiversity and towards understanding cellular and molecular
²¹ processes underpinning life (Prather et al., 2004; Pyke and Ehrlich, 2010; Daru et al., 2018). This shift,

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22 among other factors, led to a decline in the funding allocated to collection-based research, the number of
23 staff maintaining and accessing new collections, and educating students in these practices (Funk, 2014).
24 Historically, specimens have been used to describe the taxonomic diversity of plants and document global
25 floristic diversity (Greve et al., 2016; James et al., 2018; Brewer et al., 2019; Rønsted et al., 2020). However,
26 renewed interest in herbarium collections utilizing ‘big data approaches,’ such as museomics, has brought
27 herbaria back to the forefront of the natural sciences and greatly expanded their roles in science (Rønsted
28 et al., 2020; Marsico et al., 2020).

29 Innovations in specimen digitization, data sharing, computing, DNA sequencing, and statistics have perhaps
30 brought about greater use of herbarium specimens than ever before (Greve et al., 2016; James et al., 2018;
31 Brewer et al., 2019; Rønsted et al., 2020). The current use of specimens and their ancillary data extends
32 well beyond their traditional roles in systematics and floristics, and studies utilizing collections are regularly
33 carried out to better understand the ecological niches, phenological processes, and interactions of plants
34 (Rønsted et al., 2020; Davis, 2023). We suspect that collections are yet to realize their full potential, and as
35 currently novel approaches, such as electronic and remote sensing and meta-barcoding, become more accessible
36 the use of collections will increase (Tosa et al., 2021). While image-based or purely observational (rather
37 than collection-based) citizen science approaches (e.g., iNaturalist, BudBurst) have recently dovetailed with
38 herbarium specimens to meet many current research needs, specimens contain rich data that are not accessible
39 via images. Of the two, specimens alone can provide samples of DNA, secondary metabolites, or
40 proteins, material for measuring (micro-)morphological attributes (Borges et al., 2020), and seeds or pollen.
41 These factors will ensure that the specimens remain the premier botanical data source into perpetuity.

42 However, despite renewed recognition of the utility of collections, efforts to grow them appear slow (Prather
43 et al., 2004). We conjecture that this is partly because collecting and depositing specimens is a fundamentally
44 slower process, especially for novice collectors, relative to taking photographs via commercially developed
45 apps on smartphones (Daru et al., 2018; Mishler et al., 2020; Manzano and Julier, 2021). While many
46 novice botanists are capable of using dichotomous keys and other resources to reliably identify and collect
47 satisfactory material, we observe that they face difficulties navigating several aspects of data acquisition,
48 processing, and preparation of labels for submission to herbaria. Some of the apparent problems include
49 the lack of dedicated time at the end of a field season to process specimens, a general lack of education
50 on cartography and orienteering, natural history (e.g., geology, geomorphology), nomenclature, familiarity
51 with various computer programs (for example, Microsoft Office suite), and foundational knowledge of plant
52 systematics and phylogenetics (Woodland, 2007; Barrows et al., 2016; Nanglu et al., 2023).

53 The generation of an herbarium specimen involves many steps that are easy to take for granted (Forman

54 and Bridson, 1989). For example, while acquiring appropriate political information for a collection site
55 appears simple, novice collectors rarely have adequate cartographic resources (printed topographic maps or
56 GIS software) at their disposal. In topographically complex areas, where administrative borders are often
57 associated with hydrological basins and the ridges defining them, collectors are liable to misinterpret their
58 true geographic position and report administrative details in error. Even finding appropriate site names can
59 rarely be resolved without a printed map, as many navigation-related software now consider most features
60 that would serve as site names extraneous. Similarly, the rate at which taxonomic innovations occur, the
61 volume of the literature, and the reluctance of some regional curators to embrace a phylogenetic approach
62 to plant classification have made it difficult to find more recently applied scientific names, even when these
63 names are unanimously accepted by taxonomic specialists in the group and other regional curators (Hitchcock
64 and Cronquist, 2018). Furthermore, formatting a label correctly (e.g., author abbreviations, italicization,
65 etc.) is a time-consuming process with many opportunities to introduce errors in formatting which reduce
66 the apparent credibility of a collector. Anecdotally, many mail merge templates offered by herbaria still
67 require collectors to modify many variables by hand, for example, applying italicization. Even if a collector
68 successfully navigates all these hurdles, the time allocated to each step is quite large, and may discourage
69 them from further collecting.

70 As a result of these concerns, we have developed an R package, BarnebyLives, that aims to increase both
71 the quality of data rendered to labels and recorded in databases and to speed up the generation of labels.
72 BarnebyLives rapidly provides political and administrative boundary information for a collection site using
73 data from the U.S. Census Bureau (Walker, 2024), the Public Land Survey System (PLSS), and ownership
74 details of public lands via the Protected-Areas Database (PAD-US) (Gap Analysis Project (GAP), 2024).
75 Site names are suggested by finding the closest unambiguously named place feature in the Geographic
76 Name Information System (GNIS) and the precise calculation of distance and azimuth from this feature to
77 the collection site (Survey, 2023). Using the Global Mountain Biodiversity Assessment (GMBA) Mountain
78 Inventory V. 2, a standardized named mountain data set with global coverage allows for a relevant descriptor
79 of the general region with less ambiguity (Snethlage et al., 2022). Spell checks on all scientific names
80 (including associated species) are performed using a copy of the World Checklist of Vascular Plants, and
81 the resolved species may be searched via Kew's Plant of the World Online for relevant synonyms (Govaerts
82 et al., 2021; POWO, 2024). Author abbreviations are verified using the International Plant Names Index
83 (IPNI) Standard Author Abbreviation Checklist and also returned by Kew's Plants of the World Online to
84 ensure proper abbreviations of authorities (The Royal Botanic Gardens and Herbarium, 2024; POWO, 2024).
85 Checks to search for and flag common issues associated with spreadsheet software or data transcription, such

86 as the autofilling of coordinate and date columns. After a final review of the data, flagged or generated by
87 the package, it allows for the option to export spreadsheets that are suitable for mass uploading of data to
88 multiple common herbarium databases as well as the generation of herbarium labels.

89 Currently, to our knowledge label generation functionality is provided explicitly by two programs, PLabel
90 and Symbiota, and by the Microsoft Word tool Mail Merge (Gries et al., 2014; Perkins, 2020). The office
91 suite costs money, and in our experience, can be difficult to set up; further, its functionality ends with label
92 creation. PLabel is a standalone program that has greatly enhanced functionality relative to a mail merge,
93 allowing users to specify the layout and formatting of label components using an intuitive and local graphical
94 user interface (GUI) functionality. However, beyond verifying the nations of collection it does not include
95 data cleaning functionalities. The increasingly popular Symbiota biodiversity data management software not
96 only provides label generation capabilities but also provides data cleaning functionality in an attractive GUI
97 web portal allowing for live management of collections and bypassing the need for a local installation, allow-
98 ing it to be accessed on all operating systems. Symbiota offers functionality similar to the first four of our five
99 stages of our ‘Taxonomic’ module and to our knowledge a check of the ‘Political Boundaries’ (see Figure 1).
100 However, not all herbaria use Symbiota and many have original database systems that they maintain (for ex-
101 ample, Harvard University Herbarium, https://kiki.huh.harvard.edu/databases/specimen_index.html; Mis-
102 souri Botanical Garden <https://tropicos.org/specimen/Search>; and The Consortium of Pacific Northwest
103 Herbaria <https://www.pnwhherbaria.org/>). However, and most importantly many collectors prefer to gener-
104 ate their own labels, especially as they are likely to send different sets of collections to different institutions.
105 Accordingly, the functionality of Symbiota should exist in an ecosystem with alternative systems. In sce-
106 narios where users want to keep rendering labels in either of the three existing alternatives, they can easily
107 export data in the appropriate formats after utilizing BLs data cleaning utilities.

108 BarnebyLives was named for plant taxonomist Rupert Charles Barneby (1911-2000), who published over
109 6,500 pages of text, described over 750 taxa, and is notable for balancing his studies at the William and
110 Lynda Steere Herbarium at the New York Botanical Garden with annual collection trips in Western North
111 America from 1937-1970 and sporadically until he passed in 2000 (Welsh, 2001). Select accolades of Rupert
112 include the 1989 Asa Gray Award from the American Society of Plant Taxonomists (ASPT), the 1991 Engler
113 Silver Medal from the International Association of Plant Taxonomists (IAPT), as well as being one of eight
114 recipients of the International Botanical Congress’s (IBC) Millennium Botany Award (1999) (Welsh, 2001).
115 Most germanely, Rupert was remembered as being generous with his time to assist younger botanists with
116 the more arcane aspects of field botany and taxonomy (Holmgren and Holmgren, 1988).

117 **METHODS AND RESULTS**

118 [Figure 1 about here.]

119 BarnebyLives was iteratively developed based on data submitted by approximately 20 seasonal field botany
120 teams over two years. Essentially, continual updates were made as the developers became aware of the
121 idiosyncrasies of collection notes and data entry. Several commands in BarnebyLives require output from
122 previous functions, and a workflow that satisfies these requirements is presented in Figure 1.

123 **Usage**

124 All steps of BarnebyLives, except for label generation are run within the freely available RStudio. Data
125 may be read from any common spreadsheet management system or database connection such as Excel, or
126 free alternatives such as LibreOffice, OpenOffice, or via the cloud on Google Sheets. The latter two options
127 are documented here and in package vignettes, detailed descriptions of the required and suggested input
128 columns are located on a Github Pages (<https://sagesteppe.github.io/BarnebyLives/>) and around 100 real-
129 world examples are on a Google Sheets accessible from the page. BarnebyLives is atypical for R packages in
130 that it requires a considerable amount of data to operate (Table 1). Virtually all on-disk memory associated
131 with the package are used to store spatial data. The amount of spatial data varies according to the domain
132 that the user decides to support (Figure 3). Functions that require on-disk data require a path to data as an
133 argument. Manually supplying the path argument allows users to determine an appropriate storage location
134 suitable for their needs.

135 We anticipate that for a typical user, BarnebyLives will require less than a couple gigabytes of memory
136 (ours covering all of the conterminous Western U.S. at 3-arc second (~90m) resolution is ~16 GiB), while the
137 processing requires relatively little RAM; hence, we believe installations can work on hardware as limited as
138 Chromebooks, while having the data stored entirely on thumb-drives. Given that the attributes which the
139 package collects data on are tailored to the Western U.S. region, we do not expect local installs to exceed
140 the size of ours. The final steps of BarnebyLives, generating the labels, requires working installations of
141 R Markdown, a LaTeX installation (e.g. pdfTeX, LuaTeX, XeTeX), and the open source command line
142 tools pdfjam and pdftk. While these steps are run through a shell scripting language such as bash, we have
143 wrapped them in R functions that bypass the need to enter the commands directly into a shell terminal
144 outside of RStudio. However, installation of the utilities on the three supported Operating systems (Debian
145 Linux, MacOS, and Windows 10 and 11) will require some minimal use of the command line to install

146 software which are required for the label-generating functionality as detailed on the README page.

147 **Functionality**

148 BarnebyLives can be thought of as consisting of five main modules (Figure 1): spatial, taxonomic, formatting,
149 manual review, and data exporting. Core functions are detailed below, while all functions are documented
150 on reference page <https://sagesteppe.github.io/BarnebyLives/reference/index.html>.

151 The spatial module has five required functions and two optional functions.

152 *autofill_checker* searches for patterns in the input latitude and longitude data associated with autofilling
153 from various spreadsheet programs and will emit a warning if they are encountered.

154 *coords2sf* creates a spatially explicit simple feature (sf) geometry dataset for the input data. *political_grabber*
155 determines many levels of administrative ownership, including land management and public land survey
156 system sections.

157 *physical_grabber* provides various geographic data, such as elevation, landform position, and aspect using
158 90m resolution spatial data.

159 *site_writer* write distance and azimuth to collection site from the nearest official named place from the GNIS
160 database.

161 *directions_grabber* is an optional function that writes driving directions from a reasonably sized town to the
162 closest drivable area to the site using the Google Maps API, which will require a valid Google account that
163 is free per month for most personal and smaller academic usages.

164 *dms2dd* is an optional function used to convert from coordinates denoted in the degrees minutes and second
165 format (for example, 42°08'39.9"N 87°47'08.3"W) to decimal degree format (for example 42.14439, -87.78569).

166 Please note that the function *physical_grabber* is the one portion of the package where a decoupling may
167 exist between the collection site, and the resolution of the spatial data. While we expect the mismatch
168 to be negligible for all effective purposes relating to: elevation, major geology type, and in general aspect,
169 estimates of slope at this resolution may be biased - generally to lower angles. For these reasons collectors
170 must always make notes on the truly local environment which taxa are found in, and consider that the notes
171 from BL reflect the greater landscape which a microfeature may be present in. While this mis-match will
172 seldom effect landscape ecologists, it may have implications for other data users.

173 The taxonomic module has four required functions and one optional function.

174 *spell_check* will perform a spell check on the entered scientific name based on a local copy of Kew Plants of
175 the World database filtered to the local continents or a user-specified backbone.

176 *spell_check_family* performs a spell check on the family entered for each scientific name.

177 *author_check* ensures that the authors are entered in a valid format, for example, the correct standard
178 abbreviations are used.

179 *associates_check* performs a spell check on all associated species using the local taxonomic database.

180 *powo_searcher* can be used in tandem with the functions *spell_check_family* and *author_check*, but we use
181 it in lieu of them to search the current Plants of the World Online to determine relevant synonyms and alter-
182 native higher taxonomy for the focal species. No API key or registration is required to use *powo_searcher*.

183 The formatting module has three functions. Two are optional; however, they are run locally and so quickly
184 that there is no reason to skip them. *date_parser* parses an input date into various formats for notating
185 collection and determination dates on labels.

186 *associate_dropper* silently removes the collected species from the list of associated species; however, it
187 searches for the species to be removed using the scientific name entered initially by the user rather than
188 returned via spell checks.

189 *field_lengths* will supply a warning messages for any fields that we suspect will create an ‘overflow’ on the
190 physical label and should be truncated for clarity.

191 The manual review process technically only has one optional function (after *coords2sf*), however given the
192 importance of ensuring that coordinates are appropriately located for many of the modules in the software,
193 we suggest all users perform it.

194 *geodata_writer* will write out a spatial copy of the data set to any geospatial format supported by the sf
195 package, but defaults to writing out ‘kmzs’ which are readily used with Google Earth, and can also be opened
196 in several other free geographic information system (GIS) softwares such as QGIS. Notably, many of the flags
197 that BarnebyLives generates will be placed into columns with obviously flagged names and can be manually
198 reviewed by the analyst, and many of these issues can be resolved by simply addressing the relevant issues
199 in the original data input spreadsheet.

200 The data exporting module contains three functions that interact with LaTeX templates and require slightly
201 more advanced R user interactivity, such as setting up mapping functions using the purrr package from the
202 tidyverse. *labels_skeleton* is an R ‘script’ which will require modifications to customize for institutions, these
203 R scripts will put data into a user specified template, and serve as the interface to LaTeX.

204 *label_writer* writes from a flatfile or spreadsheet to small 4x4 inch herbarium labels (users can modify these
205 dimensions as they see fit).

206 *format_database_import* will write out a spreadsheet of cleaned data in a variety of formats, currently:
207 Jepson, Symbiota, and Consortium of Pacific Northwest herbaria are supported.

208 **Herbarium Collections**

209 [Figure 2 about here.]

210 The testing of the package within this manuscript was performed using a subset of the first author's collections
211 from 2018-2022, while most development was performed on their 2023 and 2024 collections. Only collections
212 which had identifications to the level of species or lower, and transcribed collection dates and coordinates
213 were used for most functionality. In total 980 records were used for testing various functions, these records
214 were from 234 sites located across Western North America (Figure 2). In total this data set had 728 species
215 (with 558 distinct sets of authors), with 83 infraspecies (22 authorships) in 74 families.

216 BarnebyLives took roughly four minutes (227.481sec) to run all local steps, and roughly ten minutes
217 (595.294sec) to search Plants of the World Online for preferred synonyms, and a minute 64.869sec to search
218 Google Maps and write directions to sites.

219 Most of the local run time is attributable to the spatial (209.089sec), and taxonomic operations (17.932sec),
220 while formatting data for labels took 0.46sec. The spell check of the scientific name accounted for nearly
221 all of the time (17.688sec) spent performing local taxonomic operations. The generation of labels consumed
222 around nine minutes (523.5sec) for the rendering, and an additional 61.08sec to combine the 182 sheets
223 to a single Portable Document Format (PDF). The total label generation run time for processing these
224 728 collections was 15 minutes. In total the 728 collections, which underwent all processing steps, took 25
225 minutes to process.

226 **RESULTS**

227 Even on our test data set which had been manually cleaned and error-checked by a human several times
228 BarnebyLives was able to reduce transcription errors, identify typos, make nomenclature suggestions, and re-
229 format text elements for downstream use. While none of the 74 families were misspelled, BarnebyLives made
230 25 suggestions on family level nomenclature, identified 6 instances where the user entered an unequivocally
231 incorrect family (or taxonomic entity), identified 5 records where families were autofilled, and 1 instance
232 where an outdated circumscription was applied. At the level of family BarnebyLives flagged 6 records where
233 the author follows an alternative taxonomy, and flagged 7 records in error, it appears most of these errors
234 are due to issues in the backbone used by the earlier spell check function.

235 In the 326 genera analysed BarnebyLives identified 74 discrepancies at the level of genus between user
236 submitted and processed data. In 42 of these instances the user supplied an outdated name (21 unique

237 genera) flagged 4 records where the author follows an alternative taxonomy (2 genera total), and flagged 2
238 records in error.

239 Of 728 distinct species analysed BarnebyLives flagged 62 records, and detected 33 instances of misspelled
240 epithets (33 unique species). In 15 of these instances the user supplied an outdated name (15 unique species).
241 It also flagged 2 records where the author follows an alternative taxonomy (2 unique species), and flagged
242 8 records in error. The final record was an egregious error where the order of the specific epithet and the
243 genus name were swapped.

244 Five records were appropriately flagged for issues with autfills of the longitude value, and 3 records were
245 also flagged for autofilling increases in latitude values. All flags were correct, and in several instances more
246 errors were found in the rows following the flagged values.

247 [Figure 3 about here.]

248 DISCUSSION

249 While numerous tools have been developed for cleaning existing herbarium and museum records, few tools
250 help to ensure that the data entered are accurate (Patten et al., 2024). We argue that the original collectors
251 are the most qualified individuals to perform quality control checks and that BarnebyLives allows them to
252 assume this responsibility in a relatively fast and streamlined format. While BarnebyLives may be adopted
253 by herbarium curators, its original use was for natural resource management employees (for example, US
254 Forest Service, heritage programs, natural history surveys) and graduate students in ecology and conservation
255 (e.g., performing inventory and community ecology work), and we expect it to be most widely used in this
256 realm. Beyond always having the data collected by BarnebyLives terminating in a label for a physical
257 specimen, its utility may be extended to providing information for various biotic databases (e.g., heritage
258 program databases) or modelling applications (e.g., modelling in community ecology) as a user sees fit.
259 By utilizing both R and LaTeX and having publicly available source code on GitHub, this program allows
260 users immediate familiarity with the system for troubleshooting issues and implementing upgrades and
261 modifications in project branches. LaTeX, a software system used for typesetting, was developed to allow
262 users to focus on the content rather than the style of the rendered documents. Indeed, using the default
263 LaTeX settings along with standard templates allows users to produce aesthetically pleasing results (Figure
264 4). However, LaTeX also offers a rich suite of customizable parameters that offer users a wide variety of ways
265 to modify labels that are under-explored in the package. Very good documentation of LaTeX capabilities

266 is offered in multiple areas; for instance, via the Overleaf project. While the templates in the package are
267 quite simple, LaTeX also offers the ability to use custom fonts, to alter font weights and colors, alter line
268 spacing, to include images (e.g. dot maps) and customize labels beyond what the default templates support.

269 BarnebyLives allows for the usage of ‘domains’ (i.e., custom geographic extents), which analysis is restricted
270 to, allowing users to specify any portion of the United States for setting up their instance. However, many of
271 the environmental and geographic variables that BarnebyLives collects information on are tailored to Western
272 North America. Several of the variables that BarnebyLives collects and displays on labels relate to topics
273 in which more senior Western curators are interested, that is, the administrative information on Township
274 Section and Range (or ‘TRS’) or the agency administering public land, but are considered less valuable—or
275 even unavailable or inapplicable—in other geographic regions. Environmental variables such as slope, aspect,
276 and geology are prominent drivers of plant distributions in semi-arid environments and warrant inclusion on
277 herbarium labels for specimens from Western environments, but curators may consider them superfluous for
278 other environments. Accordingly, users may consider developing new functionality that either removes or
279 supplements the default variables to better reflect regional needs.

280 Accessioning often relies on the use of the Microsoft Office suite of programs and may utilize other costly
281 software such as ArcPro or Adobe Acrobat. While BarnebyLives does not have its own graphic user inter-
282 face, the functionality of commonly used Interactive Development Environments (IDE’s), such as RStudio,
283 Positron, VisualStudio (VS) Code, now offer functionality to readily view and filter datasets using familiar
284 spreadsheet-like formats, making them more accessible to many users. While other software packages often
285 cost money, these are also free, and we recommend that users install an open-source PDF viewer such as
286 Okular to review their rendered documents.

287 [Figure 4 about here.]

288 CONCLUSIONS

289 BarnebyLives is an R package that can be used to rapidly acquire relevant geographic and taxonomic data.
290 It can also perform specialized spell checks and assorted curatorial tasks to produce both digital and analog
291 data. The package relies on no licensed software, such as the Microsoft Office suite, and is suitable for install
292 on all major operating systems (Windows, Mac, Linux), requiring only a small amount of use of the command
293 line, which may be called from RStudio or Positron rather than a ‘traditional’ terminal. Further while the
294 software is intended for use in the context of producing herbarium labels, it’s basic functionality to resolve

295 taxonomic names, and query environmental attributes may make it useful for various land management
296 agencies which require these utilities for various research activities.

297 AUTHOR CONTRIBUTIONS

298 The project was conceptualized by R.C.B. The program was written by R.C.B. Data collection and analysis
299 were performed by R.C.B. R.C.B. & J.B.F wrote the manuscript, and both authors approved the final version
300 of the manuscript.

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306 DATA AVAILABILITY STATEMENT

307 The BarnebyLives R package is open source, the development version is available on GitHub (<https://github.com/sagesteppe/BarnebyLives>). The package includes seven use-case vignettes (tutorials) available
308 on a Github Pages site (<https://sagesteppe.github.io/BarnebyLives/>). The first vignette “*Preparing to use*
309 *BarnebyLives!*” shows how to set up an instance for a certain geographic area (domain). The next vignette
310 “*BarnebyLives! Running pipeline*” showcases the core functionality of the package for processing data entered
311 on a spreadsheet. “*Printing herbarium labels and exporting a digital copy of data*” demonstrates how to export
312 data in both digital and analog formats while “*Rendering a shipping manifest*” details how to produce a
313 shipping manifest for gifting or transferring material to an herbarium. The remaining vignettes detail
314 different aspects of label usage, such as including maps and logos in “*Labels with graphics*”, and customization
315 for example the position of template elements “*Customizing a label template*”, and fonts in “*Customizing*
316 *label fonts*”.

318 All data used in this manuscript are available at: https://github.com/sagesteppe/Barneby_Lives_dev/
319 manuscript.

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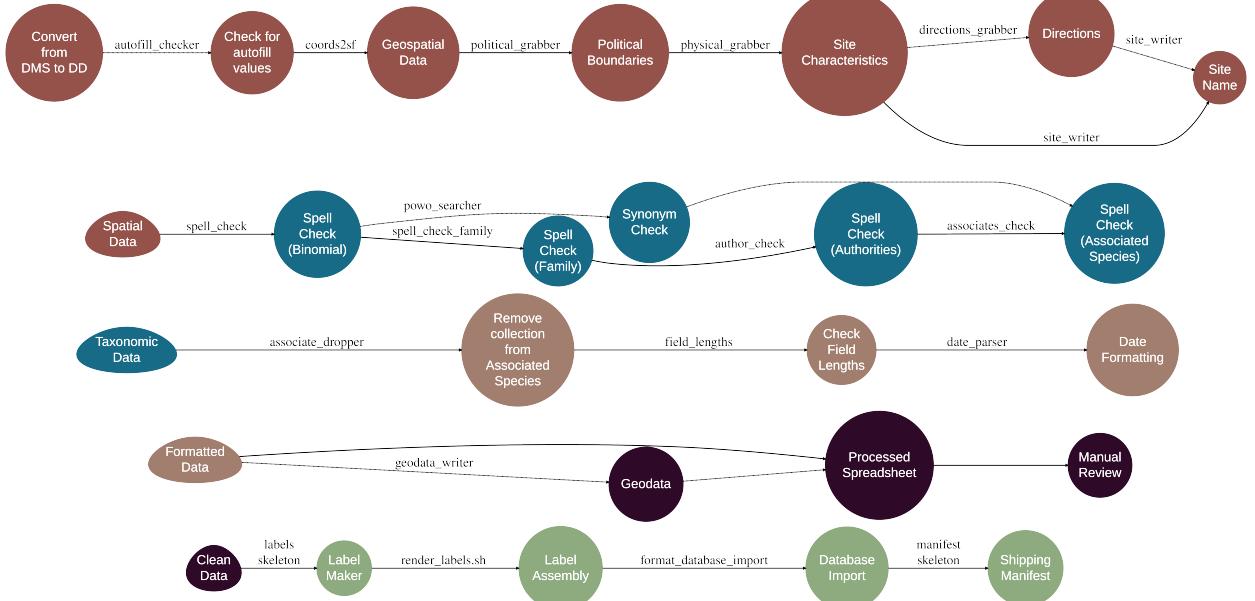
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The top two rows indicate the main data cleaning functionality and are best run in the order outlined above although taxonomic steps may be ran before spatial steps. The third row can be interspersed with the above two, includes creation of labels, which allows for detection of formatting or other issues which were not captured by the pipeline or in earlier manual review. Further support is offered to export data in a format which allows mass upload at the receiving institution, and to create a shipping manifest and transfer notice.

Figure 1: Recommended workflow

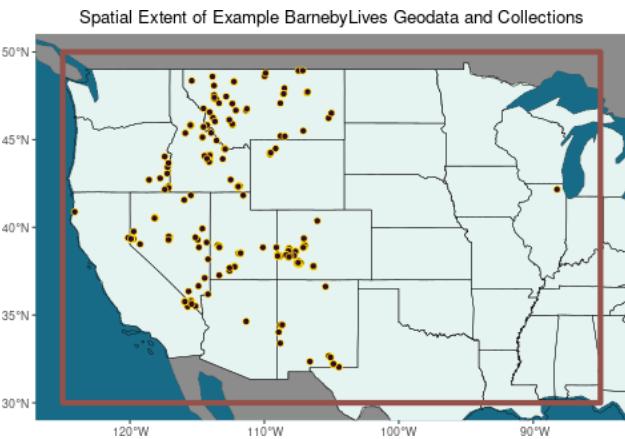


Figure 2: The spatial extent-or domain- (orange), and herbarium collection sites (burgundy) tested in this manuscript.

Data Sources for Package					
Variable	Usage	Source	Name	Data Model	Size (GiB)
County	Political	US Census Bureau	Counties	Vector	0.073
State			States		0.0*
Ownership		US Geological Survey	Protected Areas Database		0.435
TRS			Public Land Survey System		0.816
Place Names	Site Name		Geographic Names Information System		0.081
Mountains	Site Name	EarthEnv	GMBA Mountain Inventory v2		0.004
Elevation	Site Characteristics	Open Topography	Geomorpho90m - Elevation	Raster	4.2
Slope			Geomorpho90m - Slope		4.6
Aspect			Geomorpho90m - Aspect		4.1
Geomorphons			Geomorpho90m - Geomorphons		0.455
Surficial Geology		US Geological Survey	State Geologic Map Compilation	Vector	0.708
Taxonomic Spellings	Spell Checks	World Flora Online	World Flora Online	Text	0.002
Author Abbreviations		IPNI	International Plant Names Index		0.001

*Counties and States are merged into the same dataset while setting up the package. The value for "County" includes State.

Figure 3: Data Sources

Assess, Inventory, and Monitor

ASTERACEAE

Tetraneuris ivesiana Greene

U.S.A., Colorado, Montrose Co., Uncompahgre Plateau, BLM
Uncompahgre FO 48N 11W 35. 0.4mi at 138° from Cottonwood
crk. 38.36884 -108.05796 (NAD83 +/- 5m).

Sandstone soils above cliff face. At 7,930 ft (2,417 m), on a
slope, 15° slo. 257° asp.; geology: Sedimentary, clastic.

Veg.: *Amelanchier alnifolia* var. *utahensis*, *Quercus gambelii*,
Cercocarpus montanus, *Symporicarpos rotundifolius*, *Artemisia*
tridentata var. *wyomingensis*, *Petradoria pumila*, *Gutierrezia*
sarothrae, *Bouteloua gracilis*. Ass.: *Petradoria pumila*, *Eremogone congesta*, *Heterotheca villosa*.

Reed Clark Benkendorf 2759, Hannah Lovell; 28 Jul, 2022. Fide:
Flora of Colorado, det.: R.C. Benkendorf, 31 Dec, 2022.

Figure 4: A label generated from a default template included with the package