

# FieldPrism: A system for creating snapshot vouchers from field images using photogrammetric markers and QR codes



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## Abstract

**Premise:** Field images are important sources of information for research in the natural sciences. However, images that lack photogrammetric scale bars, including most iNaturalist observations, cannot yield accurate trait measurements. We introduce FieldPrism, a novel system of photogrammetric markers, QR codes, and software to automate the curation of snapshot vouchers.

**Methods and Results:** Our photogrammetric background templates (FieldSheets) increase the utility of field images by providing machine-readable scale bars and photogrammetric reference points to automatically correct image distortion and calculate a pixel-to-metric conversion ratio. Users can generate a QR code flipbook derived from a specimen identifier naming hierarchy, enabling machine-readable specimen identification for automatic file renaming. We also developed FieldStation, a Raspberry Pi-based mobile imaging apparatus that records images, GPS location, and metadata redundantly on up to four USB storage devices and can be monitored and controlled from any Wi-Fi connected device.

**Conclusions:** FieldPrism is a flexible software tool designed to standardize and improve the utility of images captured in the field. When paired with the optional FieldStation, researchers can create a self-contained mobile imaging apparatus for quantitative trait data collection.

## KEY WORDS

digital specimen voucher, field images, fieldwork, machine learning, mobile imaging, photogrammetry, QR code flipbook, snapshot vouchers

In contemporary specimen collection, the integration of multiple digital data sources necessitates the utilization of advanced processing techniques to consolidate notes, observations, photographs, and specimens into a comprehensive and cohesive data set. Fortunately, software packages can streamline this cumbersome task. There are apps to help organize field observations (Maya-Lastra, 2016; Powell et al., 2019; Seltzer, 2019), manage ecological surveys (Aanensen et al., 2009; Anastácio et al., 2017; Esri, 2019; Nowak et al., 2020), and measure specimens (Easlon and Bloom, 2014; Schrader et al., 2017; Weaver et al., 2020). However, the curation of digital images captured during fieldwork has received little attention.

Researchers frequently photograph specimens to document an occurrence or observation, but these images can often also be rich data sources of trait measurements for the original collector or other researchers. For example, herbarium specimen vouchers are widely used in the natural sciences to chronicle climate change (Calinger, 2013; Willis et al., 2017b; Jones and Daehler, 2018; Meineke et al., 2018), ground plant systematics and taxonomy (Stuessy, 1975; Wen et al., 2015; Espinosa and Pinedo Castro, 2018), inform conservation initiatives (Greve et al., 2016; Nualart et al., 2017; Lughadha et al., 2018; Rocchetti et al., 2021), and provide a wealth of trait data for phylogenetic and phenological studies (Savolainen et al., 1995; Edwards and Smith, 2010; Bakker, 2017; Willis

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et al., 2017a; Mishler et al., 2020; Folk et al., 2021). Vouchers are particularly useful because of their standardization and availability. However, herbarium specimens are not without their challenges. Preservation and mounting techniques can often distort or obscure phenological and morphological traits, particularly those related to three-dimensional structure, while colors may also fade and change as specimens dry and age (Willis et al., 2017a). In addition to vouchers, images taken at the time of collection can serve as supplementary information to the extended specimen record, allowing for a more complete understanding of specimens and their conditions at the time of collection (Baskauf and Kirchoff, 2008; Gómez-Bellver et al., 2019; Hardisty et al., 2022). Platforms like iNaturalist have led to an explosion of digital-only records that are regularly used to study phenology, species distributions, conservation, and climate change, and can be linked to physical vouchers (Heberling and Isaac, 2018). If these field images were standardized and metrically validated, they could also be used for quantitative trait data collection.

Several authors have established standardized protocols for capturing images of live plants that can serve as a supplement or substitute for physical herbarium specimens. The term “photo vouchers” is defined by Funk et al. (2017) as a collection of photographs of a plant that facilitates identification and documents its presence when the collection of a physical specimen is not possible. Gómez-Bellver et al. (2019) provide a definition for “fusion vouchers” as a compilation of images attached to a standard herbarium sheet that enhances a physical specimen by providing supplementary contextual information when its size, structure, toxicity, fragility, or special status requires further representation. While these protocols provide valuable context and content that can provide a more comprehensive understanding of plant habit, color, structure, and identification, they offer limited utility for measuring morphological traits. Quantitative traits are increasingly used in a wide array of biological research, but most field images lack photogrammetric scale bars required for accurate measurements.

To enable quantitative trait data collection from field images, we introduce a new specimen documentation method called “snapshot vouchers.” This method involves capturing images of living plant organs against a photogrammetric background, enabling precise measurement of morphological traits. Snapshot vouchers can enhance physical vouchers or serve as digital-only records. By incorporating a photogrammetric background, iNaturalist photos can also qualify as snapshot vouchers.

To realize the full potential of snapshot vouchers and field images we created FieldPrism, a flexible software and hardware suite designed to streamline image processing and management. FieldPrism addresses common workflow bottlenecks by providing automatic image skew, yaw, and pitch correction; pixel-to-metric conversion; file renaming; and metadata collection tools. Optionally, FieldPrism can also address the administerial task of organizing and

renaming hundreds or thousands of uninformatively named image files, an otherwise laborious and error-prone procedure (Forssman et al., 2016). Handwritten labels in images are not readily machine readable, so we employ QR codes to discriminate between collections. QR codes are a popular organizational tool in biological research and have been used to manage DNA extraction from herbarium specimens (Folk et al., 2021), manage museum collections (Sendino, 2013), link specimens with their digital metadata (Diazgranados and Funk, 2013), and link iNaturalist records to physical specimens (Heberling and Isaac, 2018).

Given the unpredictability of specimen collection in the field and the wide range of project scopes and complexities, we saw the need for a flexible and scalable system for identifying snapshot vouchers. This motivated the development of our QR code flipbook where users can assign QR codes to different species, sites, days, leaves on a plant, or other collection identifiers. For example, the QR codes for numbers 1–5 may correspond to five different species, while the codes for letters A–E may correspond to different locations. When the user takes a picture of species 1 at location A, they simply flip to those codes, take the picture with those codes in view, and continue collecting. Alternatively, QR codes can directly contain predefined collection identifiers, like the species name, collector's name, or location. FieldPrism will organize and rename the photos accordingly. The flipbook can then be reused on another trip where the numbers and letters will refer to other species and locations.

Archival images of herbarium specimen vouchers typically include a scale bar, which is a key feature often missing or incorrectly utilized in field images because they are often skewed and not rectilinear. If the camera is not positioned perpendicular to the subject or the scale bar is not on the same plane as the subject, its usefulness in obtaining accurate measurements is significantly limited. Additionally, converting pixel distance into metric distance requires a manual process, such as using ImageJ (Rueden et al., 2017) to measure the scale bar. With FieldPrism, we developed a simple photogrammetric background template that, in conjunction with our machine learning and computer vision algorithms, allows for the automated conversion of pixels to metric units. By using this template, FieldPrism can correct a variety of image distortions, including skew, yaw, and pitch, and produce a rectilinear snapshot voucher that compensates for cases in which the camera was not positioned perpendicularly to the subject.

Our tools can be used either independently or together depending on the project requirements. For instance, the QR code flipbook can be used to organize snapshot vouchers on a specimen collection trip, but it may not be necessary for an iNaturalist collection. FieldPrism methods are compatible with any digital camera, including smartphones. However, for additional utility, we developed a mobile imaging apparatus called FieldStation that enhances imaging ergonomics, operates without an internet connection, captures GPS coordinates, and saves all data

redundantly to multiple USB storage devices. FieldStation's monitoring and control interface is accessible via any smartphone, tablet, or computer, but it can also be operated without a monitor using physical controls and audio feedback. With the goal of supporting the generation of quantitative trait data, FieldPrism uniformly curates snapshot vouchers and emulates the standardization of physical herbarium specimen vouchers.

## METHODS AND RESULTS

Below, we provide an overview of each FieldPrism component and outline possible use cases. First, we describe the photogrammetric background template, which is foundational for producing snapshot vouchers. Then, we explore three possible ways to use our QR code system as part of a specimen identification hierarchy and how to organize the QR codes in a flipbook. Finally, we describe the FieldStation and the FieldPrism software and test our methods under a variety of conditions.

### Photogrammetric background template

In many disciplines, scale bars and rulers routinely accompany the subject matter to provide a notion of scale or enable pixel-to-metric conversion *a posteriori*. We developed a photogrammetric background template (FieldSheet) to enable precise pixel-to-metric conversion and image distortion correction (Figure 1, Figure 2A). The simplest FieldPrism collection workflow involves attaching a FieldSheet to a clipboard, placing the subject onto the FieldSheet, and taking a photo with a digital camera (e.g., a smartphone; Figure 1A). The FieldSheet consists of four markers, each containing four 1-cm squares, and includes a 10-cm line for reference. Users can print copies of our FieldSheet using any standard printer onto six common page sizes: A3, A4, A5, Tabloid, Letter, and Legal. FieldSheet templates can be downloaded from <https://www.fieldprism.org>, or users can customize FieldSheets by editing the “FieldSheetBuilder.yaml” configuration file (see Data Availability Statement). If even larger templates are required, the four corner markers can be cut out and mounted on a larger surface, with care to maintain rectilinear placement. This custom size is supported in the FieldPrism software by updating the “custom” template dimensions. We validated a large custom FieldSheet using a 55 cm × 71 cm white hobby poster board with FieldSheet markers pasted in each corner.

When printing FieldSheets, it is critical to verify that the printer did not improperly scale the PDF. Users can manually measure the 10-cm line or compare the size of a credit card with the accompanying size validation sheet and set the printer to 100% scaling if necessary. After verification, the FieldSheet can be attached to a clipboard and is ready for use. We recommend printing FieldSheets on waterproof paper or the waterproof shipping labels (e.g.,

Avery 5526 Waterproof Film Shipping Labels; Avery Products Corporation, Brea, California, USA) and sticking the whole sheet onto a plastic or metal clipboard. Make sure that the subject of each photograph is positioned at the center of the FieldSheet and does not cover the markers, and take care to ensure that it is in the same plane or as close as possible, especially for subjects with three-dimensional structure. Images that include our FieldSheet can be processed with the FieldPrism software to produce curated snapshot vouchers.

### Cameras

To ensure that FieldPrism is broadly accessible, we validated the FieldPrism software with images taken using smartphone cameras (Android and Apple), mirrorless and digital single-lens reflex (DSLR) professional cameras with a variety of lenses, and an OAK-1 machine vision camera (Luxonis, Littleton, Colorado, USA) (Table 1). Each camera produced usable snapshot vouchers. While FieldPrism can correct skewed images, it cannot correct distortion introduced by fisheye or wide-angle lenses. Wide-angle lenses should be avoided because they produce curvilinear images that distort metric increments across the image. If the manufacturer provides a lens distortion correction profile, it should be applied to the batch of images prior to using FieldPrism to correct skew, yaw, and pitch distortions. If the specimen contains small features or if the FieldSheet is far from the camera and occupies a fraction of the frame (see Figure 3, row 4), then consider using a camera with a sensor resolution greater than 20 megapixels to retain detail.

### QR codes and specimen identification hierarchy

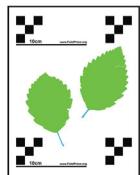
To fully take advantage of our QR code system for generating unique specimen names for collections projects, users must define a specimen identification hierarchy before venturing into the field. A specimen identification hierarchy is a modular organizational scheme that enables users to define short identifiers that can be easily translated into QR codes (Table 2). A project's specimen identification hierarchy is prepared as a CSV file where each column corresponds to a hierarchical level and each row is an identifier component of the parent hierarchical level. We recommend using no more than six hierarchical levels because using more would make the QR code flipbook impractical, but there is no upper limit to the number of variants (rows) per level.

Users have three options for defining a specimen identification hierarchy: (1) predefining the names of specimen identifier components, (2) using placeholder values for specimen identifier components when the names of specimens or locations cannot be anticipated, or (3)

## A Informative backdrop

### Use cases

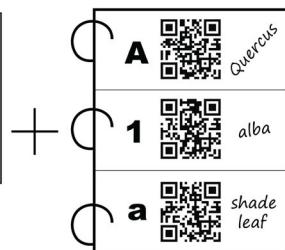
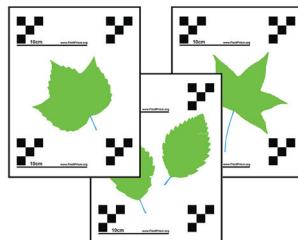
- iNaturalist
- Citizen science initiatives
- Field documentation
- Specimen collection
- Bring your own camera



## B Field collection

### Use cases

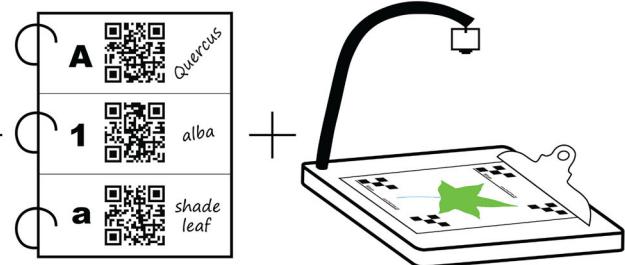
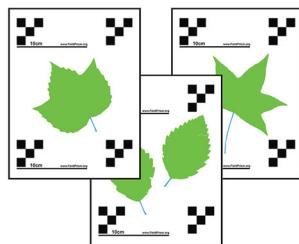
- Collection trips
- Many specimens
- Common garden
- Greenhouse experiments
- Bring your own camera



## C Field collection with FieldStation

### Use cases

- Collection trips
- Many specimens
- Common garden
- Greenhouse experiments
- GPS location
- Additional standardization
- Ergonomics
- Data redundancy

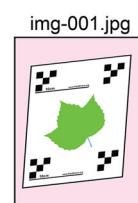
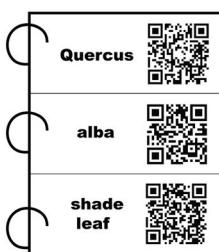


## D Image curation with FieldPrism software

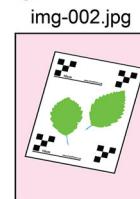
### Use cases

- Image distortion correction
- Rename image files from QR codes
- Convert pixel distance to metric distance
- Create uniform images
- Prepare images for trait measurements

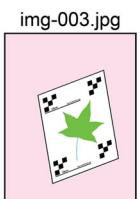
### Determinate naming



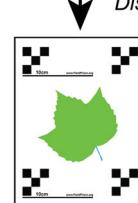
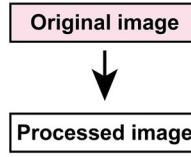
Original file names



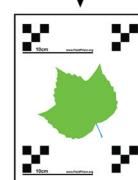
img-002.jpg



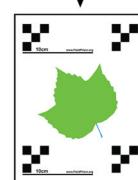
img-003.jpg



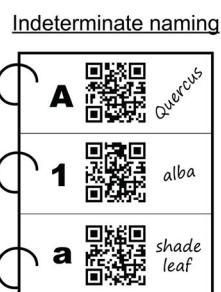
Viburnum\_acerifolium\_sun.jpg



Alnus\_rubra\_shade.jpg



Liquidambar\_styraciflua\_sun.jpg



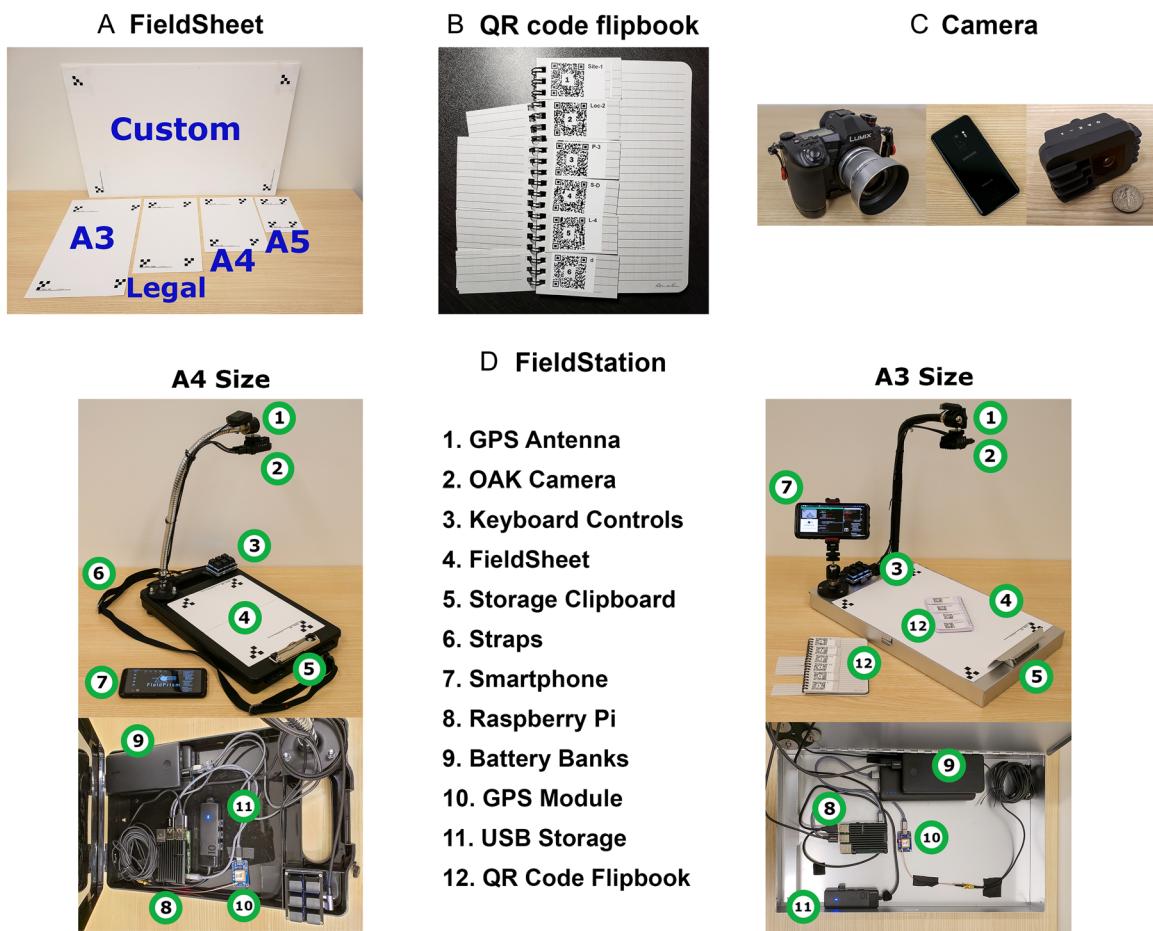
**FIGURE 1** Four different ways to use FieldPrism. (A) Including FieldSheets in citizen science initiatives, iNaturalist collections, or general field images can extend the utility of the images beyond their original scope. (B) Pairing a QR code flipbook with FieldSheets enables specimen curation and machine-readable identification for a variety of research. (C) Our mobile imaging system, FieldStation, improves imaging ergonomics, logs GPS coordinates, saves data redundantly, and increases standardization. (D) Our FieldPrism software can correct image and calculate a pixel-to-metric conversion ratio for any image that includes a FieldSheet. QR codes within an image can be decoded to generate a unique specimen identifier for renaming image files.

applying a hybrid implementation with some predefined names and some placeholder names. Placeholder components allow for indeterminate imaging schemes. For example, a field expedition is unlikely to know which species or how many individuals they will need to photograph. In this case, a placeholder QR code “A” could represent “*Quercus macrocarpa*” (Table 2B). While in the field, write down “*Quercus macrocarpa*” next to the “A” QR code in the flipbook and then add this alias to the naming hierarchy CSV file as the alias to “A”; FieldPrism will then know to translate “A” accordingly. A mixture of determinate and indeterminate components can also be used in a

hybrid format. Additional specimen identification hierarchy examples can be found in Table 2.

## QR code flipbook

After defining a specimen identification hierarchy, the FieldPrism QR code generator will create printable PDFs containing either 24 or 40 QR codes per sheet depending on the length of the label text. To create a flipbook, users cut out each QR code and attach them to a small memo-sized notebook so that each page contains only one variant per



**FIGURE 2** FieldPrism components. (A) Five premade FieldSheet options are available, ranging in size from A5 to A4, Legal, A3, and even a custom poster board, to demonstrate non-standard use cases. (B) An example of a QR code flipbook with six hierarchical levels printed on waterproof package labels attached to a waterproof memo-sized notebook. (C) Three of the cameras used to validate FieldPrism, from left to right, are a Lumix G9, Samsung Galaxy S9+, and OAK-1. (D) Two FieldStation mobile imaging systems are shown, one designed for A4 or Letter-sized FieldSheets (left) and the other for A3 or Tabloid-sized FieldSheets and equipped with a smartphone monitor holder (right). The internal components, such as the Raspberry Pi 4, battery banks, GPS module, and USB storage devices, are also visible in the bottom half of both images. Numbers in the images correspond to specific components.

**TABLE 1** A list of cameras used for development and testing. For validation testing, cameras with manual modes were set to an aperture of f/5.6, ISO 800, and a shutter speed of 1/125 s.

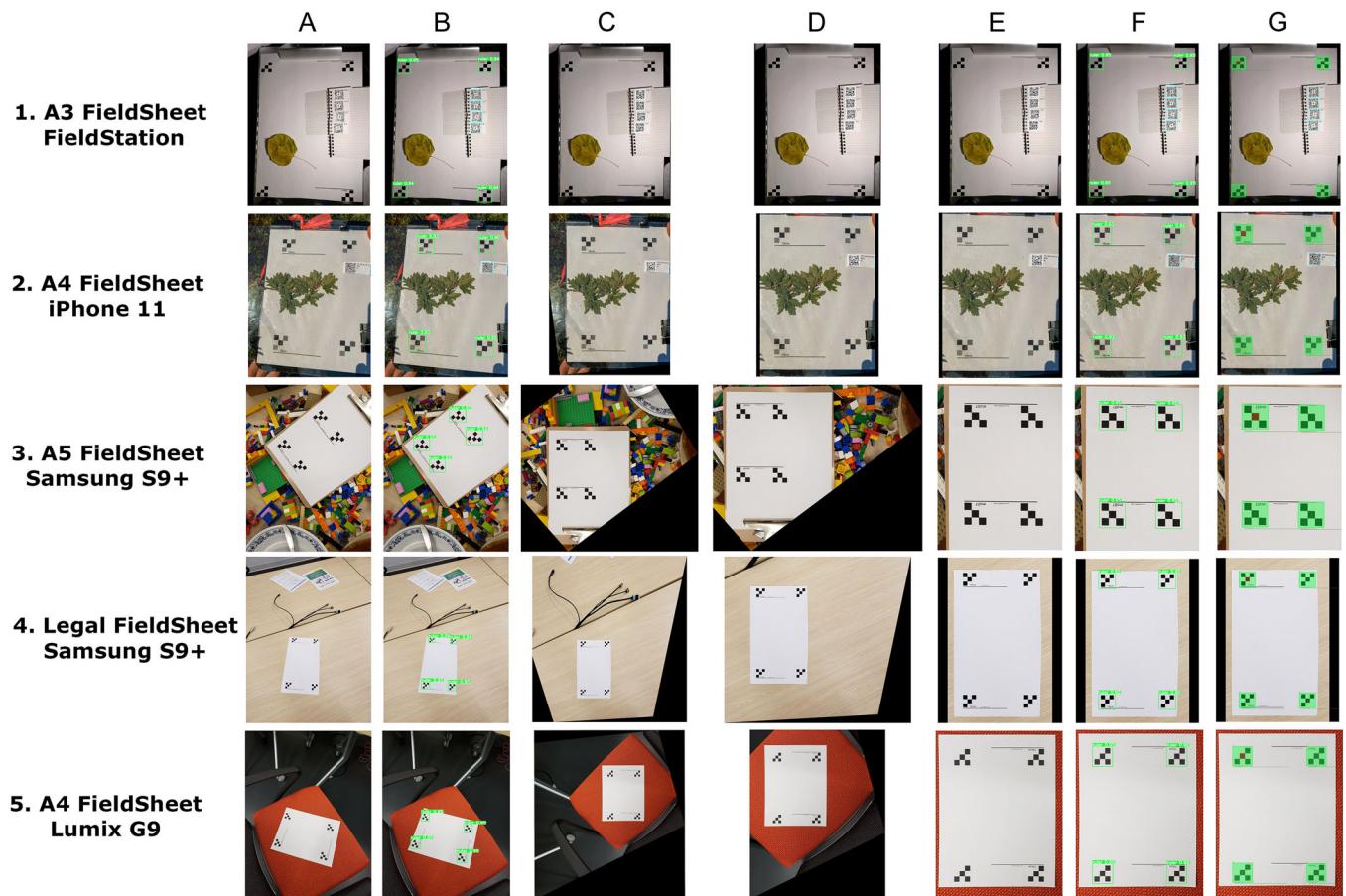
Camera	Megapixels	Focal distance (mm) <sup>a</sup>	Horizontal field of view (degrees)	Aperture	ISO	Shutter speed (s)
OAK-1	12	35*	54	f/2.0	Auto	Auto
Samsung Galaxy S9+	12	26*	65	f/1.5-2.4	Auto	Auto
Panasonic Lumix G9	20.3	50*	40	f/5.6	800	1/125
Canon R5	45	50	40	f/5.6	800	1/125
Nikon D850 <sup>b</sup>	45	50	40	f/5.6	Auto	Auto
iPhone <sup>b</sup>	12	26*	65	f/1.8	Auto	Auto

<sup>a</sup>Focal distances with an asterisk are the full-frame equivalent focal distances, as those cameras have smaller sensors.

<sup>b</sup>Images taken by these cameras were used to train the machine learning algorithm but were not part of validation testing.

hierarchical level (Figure 2B). Users then cut the notebook page between each QR code. The result is an organized flipbook that can display any combination of variants in the defined naming hierarchy. We strongly recommend

printing QR codes onto the previously mentioned waterproof package shipping labels. These labels prevent ink bleeding, are weather resistant, and conveniently attach to Rite-In-The-Rain notebooks (Rite in the Rain, Tacoma,



**FIGURE 3** Tracking five images taken with five different cameras and four different FieldSheet sizes as they are processed by FieldPrism. Processed images (columns B–G) are unmodified FieldPrism output images. Row 2 shows an image from our field test using a prototype FieldSheet and QR code, provided by colleagues at the Morton Arboretum. (A) The original unprocessed image. (B) Overlay image showing photogrammetric markers and QR codes identified by our machine learning network. (C) Distortion-corrected image. (D) Top-left justified distortion-corrected image. (E) Uniformly justified distortion-corrected image. (F) Uniformly justified distortion-corrected image with machine learning prediction overlay. (G) Uniformly justified distortion-corrected image with pixel-to-metric conversion verification overlay. Using the conversion ratio, a red 1-cm square and green 10-cm line are overlaid on the FieldSheet for visual confirmation. Users can select between image versions C, D, and E as the final corrected image. Options C and D maintain the original pixel resolution of the image, while option E allows users to configure the final image dimensions (e.g.,  $3000 \times 4000$  pixels), producing a uniform processed data set.

Washington, USA). Printing QR codes with toner onto regular paper is discouraged due to smearing. We provide two predefined QR code templates that will accommodate most use cases, but users can edit the “FieldSheetBuilder.yaml” configuration file to customize the QR codes (e.g., shrinking the codes to fit 64 per sheet).

## FieldStation

Holding a clipboard while setting the QR code flipbook, adjusting the specimen, and taking a photo with a smartphone or professional camera is an ungraceful ballet at best and may even require two people. To ameliorate poor ergonomics, we created FieldStation, a mobile imaging apparatus that can be used in conjunction with the FieldPrism software and FieldSheets (Figure 2D). FieldStation is built around a Raspberry Pi 4 Model B

(<https://www.raspberrypi.com>; Raspberry Pi Foundation, Cambridge, United Kingdom) and an OpenCV OAK machine vision camera and can be assembled using off-the-shelf components in less than two hours for approximately \$600 USD, depending on the configuration (Appendix S1; see Supporting Information with this article). We used a storage clipboard to contain the Raspberry Pi, batteries, USB storage, and GPS module. A microphone stand is attached to the top of the clipboard to hold the OAK-1 camera and GPS antenna. A mini six-key keyboard is used to control the camera and GPS. For monitor-free use, headphones can be plugged into the Raspberry Pi; different tones will sound to indicate successful operations or errors. Camera straps are attached to the sides of the clipboard, improving ergonomics by allowing the user to wear the imaging apparatus, leaving hands free for other tasks, and ensuring that the camera is aligned with the FieldSheet.

**TABLE 2** Three example tables used to build QR codes for the QR code flipbook. The cells shaded gray represent the exact text input used in the FieldPrism QR code generator. Entries below headers following the pattern “Level\_1” are encoded directly into the QR code. Entries below headers following the pattern “Level\_1\_Alias” will be used to generate the final specimen identifier and filename by translating the encoded value (the cell to the left). (A) The “determinate” table demonstrates a workflow where all names are known prior to collection, aliases are not used. (B) The “indeterminate” table demonstrates a workflow where QR codes contain placeholder values; alias names are assigned to each placeholder value at the time of collection and are added to the corresponding alias cell after collection. (C) The “hybrid” table demonstrates a workflow that uses a combination of determinate and indeterminate labels.

QR code usage	Columns representing hierarchical levels					
A. Determinate <sup>a</sup>	Level_1	Level_2	Level_3	Level_4	Level_5	Level_6
A. Determinate <sup>a</sup>	Site-1	Day-1	Collector-1	Quercus macrocarpa	sun	abaxial
	Site-2	Day-2	Collector-2	Quercus alba	shade	adaxial
	Site-3	Day-3	Collector-3	Quercus velutina		
	Site-4		Collector-4	Quercus rubra		
B. Indeterminate with Alias <sup>b</sup>	Level_1	Level_1_Alias	Level_2	Level_2_Alias	Level_3	Level_3_Alias
B. Indeterminate with Alias <sup>b</sup>	A	Quercus macrocarpa	1	sun	a	abaxial
	B	Quercus alba	2	shade	b	adaxial
	C	Quercus velutina	3	both	c	both
	D	Quercus rubra	4	unknown		
	E	Quercus gambelii				
	F	Quercus bicolor				
C. Hybrid <sup>c</sup>	Level_1	Level_1_Alias	Level_2	Level_2_Alias	Level_3	Level_3_Alias
C. Hybrid <sup>c</sup>	Site-1	Site-1	A	Quercus alba	sun	sun
	Site-2	Site-2	B	Quercus rubra	shade	shade
	Site-3	Site-3	C	Quercus gambelii		
	Site-4	Site-4	D	Quercus bicolor		

<sup>a</sup>Example reconstructed determinate image identifiers: Site-2\_Day-3\_Collector-4\_Quercus velutina\_sun\_adaxial, Site-3\_Day-2\_Collector-3\_Quercus rubra\_shade\_adaxial.

<sup>b</sup>Example reconstructed indeterminate image identifiers: Quercus alba\_sun\_adaxial, Quercus velutina\_shade\_.

<sup>c</sup>Example reconstructed hybrid image identifiers: Site-2\_Quercus alba\_shade, Site-3\_Quercus rubra\_sun.

## Using FieldStation

The FieldStation GUI allows the user to control and monitor the imaging process. A focus check window shows a cropped portion of the live camera feed, while the larger window displays the saved image. In the right panel, various verification statuses are displayed. We use Laplacian variance to detect blurry and out-of-focus images and give the user a chance to take a sharp photo. The suffix “\_b” is optionally added to all blurry photos for quick quality control. GPS information is also displayed here and can be refreshed independently of capturing an image. FieldStation can save all images and metadata to four USB storage devices simultaneously for data redundancy.

## FieldPrism software

FieldPrism is a simple-to-use Python program that can be run from the command line and customized with a configuration file. The source code, user manual, and

FieldStation build guide are freely available at <https://www.fieldprism.org> and <https://github.com/Gene-Weaver/FieldPrism> (see Data Availability Statement). We also provide FieldSheets (six sizes), size-check templates, example naming hierarchy files, and example images at [https://www.fieldprism.org/demo/FieldPrism\\_Kit.zip](https://www.fieldprism.org/demo/FieldPrism_Kit.zip). The software can be installed on Windows, Linux, and OS X systems inside of a Python virtual environment. Full installation instructions are available at our GitHub repository. To process images with FieldPrism, adjust settings in the “FieldPrism.yaml” configuration file and then run the “FieldPrism.py” file. We outline the steps of the FieldPrism software below.

### Step 1: Preprocessing and supported image formats

Before running FieldPrism, it may be useful to perform some preprocessing on the images. FieldPrism does not adjust color, brightness, or contrast, so if lighting conditions were poor at the time of collection, then batch-processing tools like Adobe Lightroom (Adobe, San Jose, California, USA) can be used to improve the quality of the images.

Similarly, if the camera lens has a manufacturer-provided lens distortion correction profile, then it should be applied to the batch of images at this stage. All images should be exported as full-resolution JPG files. If the collection project is intended to emulate fusion or photo vouchers, or if color accuracy is important, then an archival-grade color correction card should also be included in the image, affixed to the clipboard (Funk et al., 2017; Gómez-Bellver et al., 2019).

#### *Step 2: Identifying photogrammetric markers*

After preprocessing images, FieldPrism needs to identify the photogrammetric markers. Prior to processing, FieldPrism will rotate all images into a portrait orientation, which is necessary to determine the orientation and skew of the FieldSheet in each image. FieldPrism will also check for corrupt image files and illegal characters in file names, replacing illegal characters with a dash or underscore.

We trained a custom implementation of a YOLO-v5 object detection machine learning network (Jocher et al., 2022) to locate photogrammetric markers on the FieldSheet. We compiled 1119 images taken with six different cameras (Table 1) that contained examples of all five versions of our FieldSheet, indoor and outdoor locations, very dim to very bright lighting conditions, full QR code sheets, QR code flipbooks, and examples of ideal and poor imaging scenarios. To bolster the reliability and generalizability of our network, we used transfer learning to extend the capabilities of a YOLO-v5 network that was trained on 6394 fully annotated herbarium specimen images from an unpublished data set. This data set is composed of angiosperm images sampled from all contributing herbaria in the Global Biodiversity Information Facility (GBIF; <https://www.gbif.org/>); the images were annotated to identify archival components including rulers, labels, maps, photographs, attached items, barcodes, color correction cards, and weights. The full list of sampled herbaria data sets is available in Appendix 1. The FieldPrism YOLO-v5 variant locates QR codes, photogrammetric markers, and (optionally) text labels.

#### *Step 3: Distortion correction*

With bounding box predictions around each of the four photogrammetric markers, FieldPrism calculates centroids and determines the orientation of the FieldSheet within the image based on the relative marker locations. It then calculates the perspective transformation required to deskew the FieldSheet and apply a geometric transformation to the entire image, creating a distortion-corrected image. If all four photogrammetric markers cannot be identified, then the image cannot be deskewed, but all identified photogrammetric markers are processed in step 4 to attempt to calculate the pixel-to-metric conversion ratio.

#### *Step 4: Pixel-to-metric conversion*

Using the distortion-corrected image, FieldPrism reidentifies the four photogrammetric markers with the trained YOLO-v5 network. Within each predicted bounding

box, FieldPrism progressively implements image binarization (the process of segmenting an image into zeros and ones given a color or intensity threshold) through a range of threshold values until the binary image matches a known, ideal binary representation of the photogrammetric markers. In the user manual, we outline a progressive process that attempts metrological conversion despite poor image quality (e.g., uneven lighting).

#### *Step 5: Locate and decode QR codes*

Using the trained YOLO-v5 network, FieldPrism places bounding boxes around all QR codes in both the distortion-corrected images and the images that failed the correction process. The QR codes contain metadata indicating the hierarchical level to which the specimen identifier component belongs, together defining the specimen identifier contained within the set of QR codes. Users can define error handling for indecipherable QR codes, but the default setting in FieldPrism reconstructs the specimen identifier with placeholder values like “Level-2” to fill in for the unrecoverable specimen identifier component. These placeholder values aid quality control and make it simple to correct the final names. If the project utilized an indeterminate hierarchical naming structure, at this stage specimen identifiers are converted to the final informative file name using the alias table. If multiple images contain the same set of identifiers, then FieldPrism can append either a number or the original filename to the end of the specimen identifier.

#### *Step 6: Apply user-configurable processing options*

Distortion-corrected images can be processed to meet different user requirements. Step 3 outputs an image that retains most of the content and similar dimensions to the unprocessed image (Figure 3C). Users can opt for a top-left justified image, which maintains some of the original background and the same pixel density as the unprocessed image (Figure 3D). Alternatively, users can specify image dimensions for the whole data set (e.g., 3000 × 4000 pixels). All images will be scaled and cropped, resulting in a set of uniform images, regardless of the original skew or distance from the camera (Figure 3E).

## Results

We validated the performance of our FieldSheets and QR codes by photographing a full sheet of QR codes placed in the center of an A3-sized FieldSheet starting at the intended working distance and increasing up to 6 m from the FieldSheet. The intended working distance varies by camera and lens combination but is the distance where the FieldSheet photogrammetric markers nearly fill the frame (Figure 3E). In a university conference room with controlled bright lighting, we taped the FieldSheet to a whiteboard and removed most distracting items. For this test, we used four cameras including a Canon R5 (45 megapixels; mirrorless camera; Canon, Tokyo, Japan), a

Panasonic Lumix G9 (20.3 megapixels; mirrorless camera; Panasonic, Osaka, Japan), a Samsung Galaxy S9+ (12 megapixels; smartphone; Panasonic, Suwon, South Korea), and the OAK-1 (12 megapixels; machine vision camera), which is the camera used by our FieldStation system. For this test, all cameras used built-in autofocus. We also printed the QR code onto three different kinds of paper using the same laser toner printer: standard copier paper, Avery 5353 Copier Shipping Labels, and Avery 5526 Waterproof Film Shipping Labels. Our performance metrics were the proportion of successfully decoded QR codes, converted photogrammetric markers, and distortion corrections at each distance.

## QR code validation

FieldPrism decoded 99.5% of QR codes in images taken at the intended working distance (less than 1 m from the subject), indicating that a variety of possible equipment configurations will produce good results (Appendix S2A). At 1 m, the high-resolution Canon R5 and Lumix G9 each achieved a similar success rate of 99.1%. However, this success rate drops sharply to only 15.6% at 1 m for the pair of 12-megapixel cameras. Beyond 1 m, the high-resolution cameras achieve some success, but the low-resolution cameras fail. Image resolution and distance from the subject strongly impact the success of QR code decoding.

## FieldSheet validation for distortion correction

All camera and paper combinations performed exceptionally well at the intended working distance, with successful distortion correction at 1 m from the FieldSheet (Appendix S2B). Beyond 1 m, the two high-resolution cameras performed best, with correction achieved up to 4 m from the FieldSheet. None of the cameras could correct images beyond 4 m.

## Metric validation

With the same data set, we also calculated the proportional error between the 10-cm scale bar printed on the FieldSheet and the 10-cm scale bar predicted by FieldPrism. For this test, we used the default pixel-to-metric conversion settings in the FieldPrism configuration file, which requires all four photogrammetric markers to be located and successfully yield a conversion ratio. Four ratios are averaged per image to produce the predicted 10-cm scale bar. Image distortion correction was successful for the images in this set, so it did not include any images taken more than 4 m away from the FieldSheet (Appendix S2C). Across all combinations of paper, distance, and cameras, we found that on average FieldPrism underestimated the true conversion ratio by 0.97 mm per 10 cm or an error rate of less than 1% (Table 3).

**TABLE 3** Validating the accuracy of pixel-to-metric conversion. The results show that (1) images from all four cameras had an error of roughly 1 mm per 10 cm, (2) standard printer paper performed best with an error of only 0.5 mm per 10 cm, and (3) error decreased with distance. However, only the two high-resolution cameras contributed to the 2-m and 3-m calculations, partly explaining the lower variance.

Variable	Error (mm)	Standard deviation	Sample size
<b>Camera</b>			
Canon R5 (45 MP)	-0.96	0.77	22
Lumix G9 (20 MP)	-0.99	0.44	12
OAK-1 (12 MP)	-1.02	1.68	13
Samsung Galaxy S9+ (12 MP)	-0.91	0.51	12
<b>Paper type</b>			
Print paper	-0.58	0.34	20
Package label	-1.30	1.30	19
Waterproof package label	-1.06	0.76	20
<b>Distance from FieldSheet</b>			
Minimal	-1.56	1.30	22
1 m	-0.70	0.50	21
2 m	-0.69	0.13	10
3 m	-0.52	0.18	6
<b>Overall</b>	-0.97	0.93	59

Note: MP = megapixel.

## Field testing

With the help of early testers at the Morton Arboretum (Lisle, Illinois, USA), we validated a prototype implementation of our FieldSheets and QR code system by collecting images of *Quercus havardii* Rydb. in Texas (Figure 3, row 2; Appendix S3). The prototype system used a single QR code per specimen and had grayscale photogrammetric markers. Collected specimens were flattened on the FieldSheet using a thin piece of transparent acrylic. This test led to several improvements, including the development of the QR code flipbook, because managing individual barcodes was too cumbersome and limited flexibility while collecting specimens. The grayscale markers also made pixel-to-metric conversion inconsistent and dependent on lighting conditions, prompting the shift to solid black markers. Despite these issues, the FieldPrism software corrected image distortion for 205 of the 208 imaged specimens. The three failures were due to intense sun glare directly over the photogrammetric markers, caused by the transparent acrylic (Appendix S3C). FieldPrism identified the locations of 100% of the barcodes and successfully decoded 70.2%. The decoding failures were caused by inconsistent lighting

(e.g., half of the QR code was in full sun while half was in shadow) or three-dimensional distortion of the QR code (e.g., curled paper). For the best results, we recommend printing all material on waterproof paper and attaching QR codes to a notebook to minimize three-dimensional distortion. Controlling lighting can be difficult, but FieldPrism can compensate for poor lighting so long as shadows do not bisect the QR codes.

## GPS accuracy

To validate the accuracy of the FieldStation GPS module and active antenna (Appendix S1), we compared its accuracy to a consumer-grade handheld GPS receiver, the Garmin GPSMAP 66sr (Garmin, Olathe, Kansas, USA), in a lightly wooded, hilly park near the University of Michigan campus. Two people walked 1 m apart on a path through the park for 20 min. FieldStation recorded GPS coordinates every 20 s, and Garmin recorded every 15 s while in motion. Qualitatively, we observed virtually no drift with the Garmin points, but we did observe drifting points of up to 4 m off the path for the FieldStation GPS. Then, we placed both GPS devices in the same location and recorded coordinates concurrently for 15 min at the previously mentioned rates. While stationary, the FieldStation GPS module achieved greater precision than Garmin. The minimum bounding polygon that contained all Garmin coordinates ( $n = 67$ ) was  $6.94 \text{ m}^2$ , while the FieldStation bounding polygon ( $n = 38$ ) was  $1.76 \text{ m}^2$ . The circular error probability (CEP; the radius of a circle within which 50% of the coordinates are expected to fall) was 0.70 m for the Garmin and 0.57 m for the FieldStation. The root mean square accuracy at the 95% confidence level (RMS; a measure of the average deviation between a set of coordinates and their centroid for both horizontal and vertical distances) was 1.70 m for the Garmin and 0.97 m for the FieldStation. The FieldStation active external antenna seemed to aid stationary accuracy, while Garmin's GPS correction algorithms improved performance while in motion. For additional GPS performance and device comparisons, please refer to U.S. Forest Service Missoula Technology and Development Center (MTDC) test reports (USDA Forest Service, 2023).

## FieldStation battery life

We tested battery life by instructing different configurations of the FieldStation to capture GPS data and three photos per minute until the battery drained. Battery testing revealed that the OAK camera and the Raspberry Pi should be powered with two separate battery banks. By powering the Raspberry Pi with a 26,000 mAh battery and the OAK-1 camera with a 20,000 mAh battery, we achieved between 17 and 20 h of continuous run time, yielding more than 3000 photos.

## CONCLUSIONS

To enhance the quality and usefulness of field reference images and increase their potential for downstream applications, the FieldPrism workflow generates curated snapshot vouchers. FieldPrism standardizes images, emulating traditional herbarium specimens, with the goal of enabling accurate morphometric and phenological measurements using other tools like ImageJ or LeafMachine2 (Rueden et al., 2017; Weaver and Smith 2023). FieldPrism methods can greatly improve the utility of field images with minimal effort (Figure 1). For example, the immense trove of observations submitted to the iNaturalist portal is a valuable source of biological data, but citizen science initiatives like iNaturalist could greatly enhance the utility of the collected photographs (Heberling and Isaac, 2018). While there are more than 7 million plant observations in iNaturalist, a scale bar rarely makes an appearance (Seltzer, 2019). Our FieldSheet is a powerful enhancement tool for citizen science initiatives like iNaturalist. The inclusion of a photogrammetric scale bar extends the utility of crowdsourced images beyond the scoring of the presence or absence of traits and could produce a valuable data set of accurately measured traits at an unprecedented scale. FieldPrism is a valuable resource for organizing and standardizing field images, an important first step in collecting data and measurements from images.

## AUTHOR CONTRIBUTIONS

W.N.W. planned and designed the project, wrote the software, built the FieldStation hardware, and wrote the initial manuscript. S.A.S. contributed to project planning and design, imaging, and testing. Both authors contributed to revising and editing the text and approved the final version of the manuscript.

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## OPEN RESEARCH BADGES



This article has earned Open Data and Open Materials badges. Data and materials are available at <https://zenodo.org/badge/latestdoi/549185805> and <https://github.com/Gene-Weaver/FieldPrism>.

## DATA AVAILABILITY STATEMENT

The FieldPrism source code, example data sets, FieldSheets, FieldStation build guide, and user manual are available at <https://github.com/Gen-Weaver/FieldPrism> and <https://www.FieldPrism.org>. Video tutorials for using the FieldStation are available at <https://www.FieldPrism.org>.

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## REFERENCES

Aanensen, D. M., D. M. Huntley, E. J. Feil, F. al-Owain, and B. G. Spratt. 2009. EpiCollect: Linking smartphones to web applications for epidemiology, ecology and community data collection. *PLoS ONE* 4(9): e6968. <https://doi.org/10.1371/journal.pone.0006968>

Anastácio, R., J. M. Gonzalez, K. Slater, and M. J. Pereira. 2017. Software for improved field surveys of nesting marine turtles. *Scientific Reports* 7: 10796. <https://doi.org/10.1038/s41598-017-11245-6>

Bakker, F. T. 2017. Herbarium genomics: Skimming and plastomics from archival specimens. *Webbia* 72(1): 35–45. <https://doi.org/10.1080/00837792.2017.1313383>

Baskauf, S. J., and B. K. Kirchoff. 2008. Digital plant images as specimens: Toward standards for photographing living plants. *Vulpia* 7: 16–30.

Calinger, K. 2013. Herbarium specimens reveal the footprint of climate change on flowering trends across north-central North America. *Ecology Letters* 16: 1037–1044. <https://doi.org/10.1111/ele.12135>

Diazgranados, M., and V. A. Funk. 2013. Utility of QR codes in biological collections. *PhytoKeys* 25: 21–34. <https://doi.org/10.3897/phytokeys.25.5175>

Easton, H. M., and A. J. Bloom. 2014. Easy Leaf Area: Automated digital image analysis for rapid and accurate measurement of leaf area. *Applications in Plant Sciences* 2(7): 1400033. <https://doi.org/10.3732/apps.1400033>

Edwards, E. J., and S. A. Smith. 2010. Phylogenetic analyses reveal the shady history of C<sub>4</sub> grasses. *Proceedings of the National Academy of Sciences, USA* 107(6): 2532–2537. <https://doi.org/10.1073/pnas.0909672107>

Espinosa, F., and M. Pinedo Castro. 2018. On the use of herbarium specimens for morphological and anatomical research. *Botany Letters* 165(3–4): 361–367. <https://doi.org/10.1080/23818107.2018.1451775>

Esri. 2019. Field data collection app for mobile workers ArcGIS Field Maps. Website: <https://www.esri.com/en-us/arcgis/products/arcgis-field-maps/overview> [accessed 25 August 2023].

Folk, R. A., H. R. Kates, R. LaFrance, D. E. Soltis, P. S. Soltis, and R. P. Guralnick. 2021. High-throughput methods for efficiently building massive phylogenies from natural history collections. *Applications in Plant Sciences* 9(2): e11410. <https://doi.org/10.1002/aps.3.11410>

Forssman, T., J. Jordaan, K. Forssman, G. Jordaan, and C. Louw. 2016. The application of quick response (QR) codes in archaeology: A case study at Telperion Shelter, South Africa. *Antiquity* 90(353): 1363–1372. <https://doi.org/10.15184/ajy.2016.135>

Funk, V., M. Gostel, A. Devine, C. Kelloff, K. Wurdack, C. Tuccinardi, A. Radosavljevic, et al. 2017. Guidelines for collecting vouchers and tissues intended for genomic work (Smithsonian Institution): Botany Best Practices. *Biodiversity Data Journal* 5: e11625. <https://doi.org/10.3897/BDJ.5.e11625>

Gómez-Bellver, C., N. Ibáñez, J. López-Pujol, N. Nualart, and A. Susanna. 2019. How photographs can be a complement of herbarium vouchers: A proposal of standardization. *TAXON* 68(6): 1321–1326. <https://doi.org/10.1002/tax.12162>

Greve, M., A. M. Lykke, C. W. Fagg, R. E. Gereau, G. P. Lewis, R. Marchant, A. R. Marshall, et al. 2016. Realising the potential of herbarium records for conservation biology. *South African Journal of Botany* 105: 317–323. <https://doi.org/10.1016/j.sajb.2016.03.017>

Hardisty, A., E. Ellwood, G. Nelson, B. Zimkus, J. Buschbom, W. Addink, R. Rabeler, et al. 2022. Digital extended specimens: Enabling an extensible network of biodiversity data records as integrated digital objects on the internet. *BioScience* 72: 978–987. <https://doi.org/10.1093/biosci/biac060>

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(11): e01193. <https://doi.org/10.1002/aps.3.1193>

Jocher, G., A. Chaurasia, A. Stoken, J. Borovec, NanoCode012, Y. Kwon, K. Michael, et al. 2022. YOLOv5 Realtime Instance Segmentation [posted 22 November 2022]. Available at Zenodo repository: <https://doi.org/10.5281/zenodo.7347926> [accessed 23 August 2023].

Jones, C. A., and C. C. Daehler. 2018. Herbarium specimens can reveal impacts of climate change on plant phenology: a review of methods and applications. *PeerJ* 6: e4576. <https://doi.org/10.7717/peerj.4576>

Lughadha, E. N., B. E. Walker, C. Canteiro, H. Chadburn, A. P. Davis, S. Hargreaves, E. J. Lucas, et al. 2018. The use and misuse of herbarium specimens in evaluating plant extinction risks. *Philosophical Transactions of the Royal Society B: Biological Sciences* 374(1763): 20170402. <https://doi.org/10.1098/rstb.2017.0402>

Maya-Lastra, C. A. 2016. ColectoR, a digital field notebook for voucher specimen collection for smartphones. *Applications in Plant Sciences* 4(7): 1600035. <https://doi.org/10.3732/apps.1600035>

Meineke, E. K., C. C. Davis, and T. J. Davies. 2018. The unrealized potential of herbaria for global change biology. *Ecological Monographs* 88(4): 505–525. <https://doi.org/10.1002/ecm.1307>

Mishler, B. D., R. Guralnick, P. S. Soltis, S. A. Smith, D. E. Soltis, N. Barve, J. M. Allen, and S. W. Laffan. 2020. Spatial phylogenetics of the North American flora. *Journal of Systematics and Evolution* 58(4): 393–405. <https://doi.org/10.1111/jse.12590>

Nowak, M. M., K. Dziób, Ł. Ludwisiak, and J. Chmiel. 2020. Mobile GIS applications for environmental field surveys: A state of the art. *Global Ecology and Conservation* 23: e01089. <https://doi.org/10.1016/j.gecco.2020.e01089>

Nualart, N., N. Ibáñez, I. Soriano, and J. López-Pujol. 2017. Assessing the relevance of herbarium collections as tools for conservation biology. *The Botanical Review* 83(3): 303–325. <https://doi.org/10.1007/s12229-017-9188-z>

Powell, C., J. Motley, H. Qin, and J. Shaw. 2019. A born-digital field-to-database solution for collections-based research using collNotes and collBook. *Applications in Plant Sciences* 7(8): e11284. <https://doi.org/10.1002/aps.3.11284>

Rocchetti, G. A., C. G. Armstrong, T. Abeli, S. Orsenigo, C. Jasper, S. Joly, A. Bruneau, et al. 2021. Reversing extinction trends: New uses of (old) herbarium specimens to accelerate conservation action on threatened species. *New Phytologist* 230(2): 433–450. <https://doi.org/10.1111/nph.17133>

Rueden, C. T., J. Schindelin, M. C. Hiner, B. E. DeZonia, A. E. Walter, E. T. Arena, and K. W. Eliceiri. 2017. ImageJ2: ImageJ for the next generation of scientific image data. *BMC Bioinformatics* 18(1): 529. <https://doi.org/10.1186/s12859-017-1934-z>

Savolainen, V., P. Cuénoud, R. Spichiger, M. D. P. Martinez, M. Crèvecoeur, and J.-F. Manen. 1995. The use of herbarium specimens in DNA phylogenetics: Evaluation and improvement. *Plant Systematics and Evolution* 197(1): 87–98. <https://doi.org/10.1007/BF0094634>

Schrader, J., G. Pillar, and H. Kreft. 2017. Leaf-IT: An Android application for measuring leaf area. *Ecology and Evolution* 7(22): 9731–9738. <https://doi.org/10.1002/ece3.3485>

Seltzer, C. 2019. Making biodiversity data social, shareable, and scalable: Reflections on iNaturalist & citizen science. *Biodiversity Information Science and Standards* 3: e10197. <https://doi.org/10.3897/biss.3.46670>

Sendino, M. C. 2013. Use of QR code labels in museum collection management. *Collections* 9(3): 239–254. <https://doi.org/10.1177/155019061300900302>

Stuessy, T. F. 1975. The importance of revisionary studies in plant systematics. *SIDA, Contributions to Botany* 6(2): 104–113.

USDA Forest Service. 2023. MTDC test reports. Website: <https://www.fs.usda.gov/database/gps/mtdcpt/index.htm> [accessed 25 August 2023].

Weaver, W. N., and S. A. Smith. 2023. From leaves to labels: Building modular machine learning networks for rapid herbarium specimen analysis with LeafMachine2. *Applications in Plant Sciences* 11(5): e11548.

Weaver, W. N., J. Ng, and R. G. Laport. 2020. LeafMachine: Using machine learning to automate leaf trait extraction from digitized herbarium specimens. *Applications in Plant Sciences* 8(6): e11367. <https://doi.org/10.1002/aps3.11367>

Wen, J., S. M. Ickert-Bond, M. S. Appelhans, L. J. Dorr, and V. A. Funk. 2015. Collections-based systematics: Opportunities and outlook for 2050. *Journal of Systematics and Evolution* 53(6): 477–488. <https://doi.org/10.1111/jse.12181>

Willis, C. G., E. R. Ellwood, R. B. Primack, C. C. Davis, K. D. Pearson, A. S. Gallatin, J. M. Yost, et al. 2017a. Old plants, new tricks: Phenological research using herbarium specimens. *Trends in Ecology & Evolution* 32(7): 531–546. <https://doi.org/10.1016/j.tree.2017.03.015>

Willis, C. G., E. Law, A. C. Williams, B. F. Franzone, R. Bernardos, L. Bruno, C. Hopkins, et al. 2017b. CrowdCurio: An online crowdsourcing platform to facilitate climate change studies using herbarium specimens. *New Phytologist* 215(1): 479–488. <https://doi.org/10.1111/nph.14535>

## SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

**Appendix S1.** FieldStation build guide and alternatives.

**Appendix S2.** Validating QR code and FieldSheet performance at increasing distances.

**Appendix S3.** Three example images from our field test processed with FieldPrism.

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**APPENDIX 1.** A list of the data sets that provided training images for our machine learning algorithm. This unpublished data set of annotated herbarium specimen vouchers sampled up to 50 images per herbarium to capture a diversity of specimen preparation techniques and image quality, yielding 6394 herbarium vouchers to supplement our 1119 FieldPrism training images. The data set is available at <https://doi.org/10.15468/dl.bh9dem>.

Herbarium data set name	Data set DOI
University of Tennessee Vascular Herbarium	10.15468/ok8qvz
Marie-Victorin Herbarium	10.5886/rzav8bu2
Herbarium of Yugra State University	10.15468/z8mpt5
San Diego Natural History Museum	10.15468/lneqwn

Herbarium data set name	Data set DOI
The Vascular Plant Collection at the Botanische Staatssammlung München	10.15468/vgr4kl
University of Florida Herbarium	10.15468/v5wjn7
Steiermarkisches Landesmuseum Joanneum	10.15468/dmdck6
Canadian Museum of Nature Herbarium	10.15468/kowta4
Species recordings from the Danish National portal Arter.dk	10.15468/q3yy4u
Texas Tech University	10.15468/uyakmh
Forest Herbarium Ibadan	10.15468/uhnd5n
University of Graz Institute of Plant Sciences	10.15468/axtkuz
Fresno State Herbarium	10.15468/puyrj8
MAG Herbarium	10.15468/ahqbdc
HVASF herbarium	10.15468/kz6y6z
UiT Tromsø Museum	10.15468/14epds
Terre d'huiles	10.15468/wr1vhv
Charles University Prague	10.15468/8xrt7r
University of Michigan Herbarium	10.15468/nl8bvi
Rio de Janeiro Botanical Garden Herbarium Collection	10.15468/bbsqoa
CRSN herbarium from Kahuzi-Biega National Park	10.15468/bhvjem
University of Lethbridge Herbarium	10.5886/wrt547hq
IAN herbarium	10.15468/cv2dmt
San Diego State University Herbarium	10.15468/8sx2ag
MUFAL herbarium	10.15468/viu6v
Dataflos	10.15468/dcc6j8
Nitraria komarovii	10.15468/jp2qco
UTEP Plants (Arctos)	10.15468/yhb6ky
TRH, NTNU University Museum	10.15468/zrlqok
Flora of the Korean Peninsula	10.15468/0vcvsq
Botanical Museum Berlin-Dahlem	10.15468/ed17cn
University of Tartu Natural History Museum	10.15468/5hqb2z
TKM Herbarium	10.15468/sfxvrv
Museum d'Histoire Naturelle of Aix-en-Provence	10.15468/fqykeb
Institut Scientifique Mohamed V University	10.15468/48pwft
Rhoen and Vogelsberg	10.15468/hbhfi3
George Mason University	10.15468/t8ar55
The Exsiccatal Series	10.15468/qxmief
CSBG SB RAS Digital Herbarium	10.15468/6f3yb
Instituto do Meio Ambiente do Estado de Alagoas	10.15468/mu8w57
Brown University	10.15468/kpsj8r

Herbarium data set name	Data set DOI	Herbarium data set name	Data set DOI
Forest Herbarium Ibadan Nigeria	10.15468/rhbyxz	CSBG SB RAS	10.15468/67ouin
Cal State LA Herbarium	10.15468/36qz6p	CRI Herbarium	10.15468/vvctbg
E. C. Smith Herbarium	10.15468/zc4csq	Jardins botaniques and Conservatoire Botanique of Nancy	10.15468/g1zohr
Clemson University Herbarium	10.15468/srjd22	SVER Herbarium	10.15468/xwzsrg
California Botanic Garden Herbarium	10.15468/0yosx9	Field Museum of Natural History	10.15468/4nodxs
University of California, Los Angeles Herbarium	10.15468/33k42a	Asociacion Jardan Botanico La Laguna	10.15468/gfwydn
Cal Poly State University	10.15468/mypdjd	National Museum of Natural History Luxembourg	10.15468/s2iu7d
Harvard University Herbarium	10.15468/29fhdy	Botanical Collections of the Abo Akademi	10.15468/mpsjrk
Field Museum of Natural History	10.15468/pyjtoc	Natural History Museum, Vienna	10.15468/5sl7sh
Carnegie Museum of Natural History Herbarium	10.15468/d51v1f	KUZ Herbarium	10.15468/4ru3f6
Botanische Staatssammlung München	10.15468/ni5yho	Herbarium Hamburgense	10.15468/31iaih
Royal Ontario Museum Green Plant Herbarium	10.5886/g7j6gct1	Quaid-i-Azam University Herbarium	10.15468/bp6jy3
CEN herbarium	10.15468/wasmx9	Universidade Federal de Parana	10.15468/fpf5j6
NMNH	10.15468/hnhrg3	Dr. Sultan Ahmad Herbarium	10.15468/xaju4z
NEON Biorepository	10.15468/ggrfcb	Ministerio del Medio Ambiente de Chile	10.15468/ezyu58
San Jose State University	10.15468/t3a60p	JOI Herbarium	10.15468/pf6pv2
Sagehen Herbarium	10.15468/f18uov	NSW AVH data	10.15468/jf3yae
University of New Mexico Herbarium	10.15468/dlvoyt	Arizona State University	10.15468/a2o8vy
Artportalen (Swedish Species Observation System)	10.15468/kllkyl	IINCT Herbario	10.15468/iinlqm
Royal Botanic Gardens, Kew	10.15468/ly60bx	Moscow University Herbarium	10.15468/cphnhcc
CAS Botany	10.15468/7gudyo	The New York Botanical Garden Herbarium	10.15468/6e8njc
Norwegian Species Observation Service	10.15468/zjzbzel	San Francisco State University	10.15468/6zdzvc
Universidade Federal do Ceara	10.15468/s8xuen	University of South Florida Herbarium	10.15468/mdnmzb
National Academy of Sciences of Republic of Armenia	10.15468/xn64eb	Towson University	10.15468/podgza
Humboldt State University	10.15468/qguk7r	SAMES herbarium	10.15468/l0hdtn
Tallinn Botanic Garden	10.15468/hfs8d4	Institut Botanic de Barcelona	10.15468/pff0t6
Naturalis Biodiversity Center	10.15468/ib5ypt	Universidade Federal do Oeste do Para	10.15468/ztkde
Brauckmann at the Botanische Staatssammlung München	10.15468/onfqgb	South-Siberian Botanical Garden	10.15468/y6xmme
Komarov Botanical Institute	10.15468/udzn9d	Universidad del Valle de Guatemala	10.15468/u339qt
Genus Medicago in CSBG Herbarium	10.15468/jvrxeh	Universidade Federal de Sergipe	10.15468/9xujh5
Qarshi Botanical Garden	10.15468/pjixa84	California State University, Long Beach	10.15468/3y25yl
Rio de Janeiro Botanical Garden Herbarium	10.15468/7ep9i2	University of Tennessee Fungal Herbarium	10.15468/da30il
Kenai National Wildlife Refuge (Arctos)	10.15468/ycpd7y	Botanische Staatssammlung München	10.15468/sookye
Tropicos Specimen Data	10.15468/hja69f	Herbarium Willing at Herbarium Berlinense, Berlin	10.15468/abcz8i
Queensland Museum	10.15468/lotsye	CRSN Herbarium	10.15468/ra9vp0
Herbarium Horti Botanici Pisani	10.15468/soyil7	University of California, Riverside	10.15468/ai1kou
University of Sargodha Herbarium	10.15468/n4k5s9	South Australian Museum Australia	10.15468/wz4rrh
Rutgers University	10.15468/1n787c	Central Siberian Botanical Garden Herbarium	10.15468/5wcerp

(Continues)

Herbarium data set name	Data set DOI	Herbarium data set name	Data set DOI
Universidade Tecnologica Federal do Parana	10.15468/4b74v2	Flora of Sumatra: ANDA Herbarium	10.15468/ue7xyn
Newhaven Sanctuary Observations	10.15468/mwgsdh	Universidade Federal da Bahia	10.15468/tbtrr3
Georgian Academy of Sciences	10.15468/6tbhmd	Universidade Federal de Goias	10.15468/fw6hdt
Arkansas Natural Heritage Commission Herbarium	10.15468/v94jsu	Black Hills State University Herbarium	10.15468/ptcrqx
Royal Botanic Garden Edinburgh Herbarium	10.15468/ypoair	Desert Botanical Garden Herbarium	10.15468/abe1lg
University of Jena, Herbarium Haussknecht	10.15468/8arhjc	NSW South Coast	10.15468/px2xfi
University of North Carolina at Chapel Hill	10.15468/63vxjd	MHA Herbarium	10.15468/827lk2
CBNA	10.15468/oc5zh7	Musaum National da Histoire Naturelle, Paris	10.15468/kw8pex
Herbier Louis-Marie	10.5886/3p8ltbg7	Flora Sumatra: (ANDA)-Part 2	10.15468/55evev
Real Jardan Botanico	10.15468/mug7kr	Nova Scotia Museum of Natural History	10.15468/tl3cde
Estonian University of Life Sciences	10.15468/m3x9uu	Universita de Montpellier	10.15468/gvkrn
Herbarium Generale	10.15468/dg4cb4	Meise Botanic Garden Herbarium	10.15468/wrthhx
UC Davis Herbarium	10.15468/on4axg	Melu AVH	10.15468/2yyu7i
Herbier du Quabec	10.5886/jd11sg3p	Fairchild Tropical Botanic Garden	10.15468/hdpruf
BRI AVH	10.15468/jssfsa	SVER Herbarium	10.15468/5npjcc
Eastern Kentucky University	10.15468/fy8dsi	R. L. McGregor Herbarium	10.15468/hptzr
Sociata des Sciences Naturelles et Mathamatiques de Cherbourg	10.15468/lmnzjw	NEON Biorepository	10.15468/bmmg36
Natural History Museum	10.5519/0002965	Institute of Biological Problems of the North, Far East Branch RAS	10.15468/ms9q2t
California State University, Northridge	10.15468/nrcdx7	Universidade Federal do Esparito Santo	10.15468/kasze8
Herbarium Fennoscandicum	10.15468/ekpyfw	Central Siberian Botanical Garden	10.15468/qdfdqq
The New York Botanical Garden	10.15468/5y84ye	Centro de Pesquisas do Cacau	10.15468/vg8rjh
CHAS Botany Collection (Arctos)	10.15468/ji4vbl	Naturhistoriska Riksmuseet	10.15468/jbcfsu
TUL Herbarium	10.15468/ca08cm	University of Vienna, Institute for Botany	10.15468/tnj8wm
Herbarium of Numto Nature Park	10.15468/g4gcrg	California State University San Bernardino	10.15468/t885ps
Staten Island Museum	10.15468/ctqpb5	Estonian Museum of Natural History	10.15468/bquqpv
University of Tartu Natural History Museum and Botanical Garden	10.15468/d59dmk	Flora of the Korean Peninsula	10.15468/fyxnsd
TULGU Herbarium	10.15468/5nret6	University of Balochistan Herbarium	10.15468/qrau0v
University of Kentucky	10.15468/fi4vfu	Royal Botanic Gardens, Kew	10.15468/rvrsru
Coleccian Herbario Federico Medem Bogota	10.15472/ighftu	The James C. Parks Herbarium at Millersville University	10.15468/qdatdf
Herbario Joao de Carvalho e Vasconcellos	10.15468/olfpjv	Earth Sciences Collection (Arctos)	10.15468/4n2ev3
Masaryk University	10.15468/soarvd	Brown University Herbarium	10.15468/njgg1a
B.M. Kozo-Polyansky VSU	10.15468/xyqng3	Botanische Staatssammlung München	10.15468/zdcclb
Bell Museum	10.15468/bihrxd	Bush Heritage - Carnarvon Station Reserve	10.15468/q0dhpr
University of Gothenburg	10.15468/asgd85	Herbarium Berolinense, Berlin	10.15468/dlwwhz
NHMD Vascular Plants Collection	10.15468/4zygkn	University of Manitoba Herbarium	10.5886/2fva5p4r
Naturhistorisches Museum Mainz	10.15468/l0wmu8	University of Colorado Museum of Natural History	10.15468/wyofjv
Universidade Federal do Rio Grande do Norte	10.15468/gtxawd	Museu Paraense Emilio Goeldi	10.15468/rdq4nx
Botanische Staatssammlung München	10.15468/zinzhd	Herbiers Universitaires de Clermont-Ferrand	10.15468/9axq0b
Capture of Primary Biodiversity Data for West African Plants	10.15468/9czcig	Turku University	10.15468/nsyt4y

Herbarium data set name	Data set DOI	Herbarium data set name	Data set DOI
Vascular Plant Herbarium, Oslo	10.15468/wtlymk	University of California Santa Barbara Herbarium	10.15468/qpxmw0
Kathryn Kalmbach Herbarium	10.15468/axrelr	Vascular Plant Herbarium, UiB	10.15468/ofn0lf
Museu Botanico Municipal Curitiba	10.15468/v52pmc	Botanische Staatssammlung München	10.15468/dixlft
North Carolina State University	10.15468/9ufthy	Field Museum of Natural History	10.15468/nxnqzf
Botanische Staatssammlung München	10.15468/lqetda	University of Cincinnati	10.15468/bhgpmpq
Universidade Estadual do Norte Fluminense	10.15468/qsaagd	Rutgers University	10.15468/hhnd4h
CRSN herbarium	10.15468/exh7vo	Universidade Federal Rural do Rio de Janeiro	10.15468/0sv7m
Herbario Museo de La Salle Bogota	10.15472/ppzpea	NEON Biorepository	10.15468/bmmdp5
Universidade Regional de Blumenau	10.15468/vse5f3	Santa Barbara Botanic Garden	10.15468/adb2bb
Appalachian State University	10.15468/ivsxey	Herbarium GAT	10.15468/hiiw6b
Clamence Lortet herbarium	10.15468/e64fbk	Auckland Museum Botany Collection	10.15468/mnjkvv
Yale Peabody Museum	10.15468/hrztgn	University of California Santa Cruz	10.15468/uavt0t
SANT Herbarium	10.15468/dgbpla	CSBG SB RAS	10.15468/be6owh
Cape Breton University Collection	10.15468/7dtqgn	Central Michigan University Herbarium	10.15468/iykbez
UAM Herbarium (Arctos)	10.15468/iawody	Herbarium Senckenbergianum	10.15468/uCMDjy
Universita Lyon	10.15468/7m584w	University of Hargeisa Herbarium	10.15468/qvbvdp
Harvard University Herbaria	10.15468/o3pvnh	Yale Peabody Museum	10.15468/0lkr3w
CSBG	10.15468/c1y9q2	Herbarium Generale	10.15468/83cb4a
Colorado Plateau Museum of Arthropod Biodiversity	10.15468/du1hci	KULPOL Herbarium	10.15468/h9qfje
Coleccian de plantas vasculares del herbario de la Universitat de Valancia	10.15468/xmki52	University of Tennessee	10.15468/64w2b1
NCSM Herbarium Collection	10.36102/dwc.12	Universidade Federal de Rondania	10.15468/5cjyj6
Botanischer Garten und Botanisches Museum Berlin-Dahlem Herbarium	10.15468/tgwryf	University of Cincinnati	10.15468/xkca3p
University of Vermont	10.15468/crnsua	Herbarium of the University of Granada	10.15470/k97bjm
Universidade de Sao Paulo	10.15468/nt6dng	Missouri Botanical Garden	10.15468/mmbcpb
Komi Republic	10.15468/336sdv	California State University Fullerton	10.15468/1uvzxh
Universidade Estadual de Feira de Santana	10.15468/gsy3jn	Universidade Estadual do Oeste do Parana	10.15468/eqp1dr
Natural History Museum Rotterdam	10.15468/kwqaay	Herbarium of Andalas University	10.15468/sncpxn
University of South Carolina	10.15468/fmj4at	Lajitietokeskus FinBIF	10.15468/4g56tp
Northern Arizona University	10.15468/b7tfpa	Chico State Herbarium	10.15468/ckxw7v
CSBG SB RAS Digital Herbarium	10.15468/7anvyu	Berea College	10.15468/hcwetj
CSBG SB RAS Herbarium Collections	10.15468/sunx5n	MEL AVH	10.15468/rhzrxw
McGill University Herbarium	10.5886/srzbj7	Western Carolina University Herbarium	10.15468/sk26v2
Intermountain Herbarium	10.15468/t43wjj	Museu de Biologia Mello Leitao	10.15468/dmkg7b
Universidade Federal de Uberlandia	10.15468/cshs8n	Plant Resources Center	10.15468/g85t8z
Musaum National d'Histoire Naturelle	10.15468/nc6rxy	Allan Herbarium	10.15468/x5ucvh
Universidade Federal do Rio Grande Do Sul	10.15468/suhqjx	University of Vermont	10.15468/zsgioig
Lord Fairfax Community College Herbarium	10.15468/c2gj2t	University of British Columbia Herbarium	10.5886/rtt57cc9
		CSBG SB RAS	10.15468/zw7jnn