DIGITAL PLANT IMAGES AS SPECIMENS: TOWARD STANDARDS FOR PHOTOGRAPHING LIVING PLANTS

STEVEN J. BASKAUF[1, 3] AND BRUCE K. KIRCHOFF[2]

Abstract. Although specimens in natural history collections have traditionally been limited to physical objects, sets of images can serve many of the purposes of specimens if the images are collected in an appropriate manner. Image specimen sets should include standardized high resolution digital images of taxonomically important features of the organism, and the time, date, and location of image collection. Suggested image standards are presented here for woody and herbaceous angiosperms, gymnosperms, ferns, and cacti. Adoption of image standards will facilitate the creation of educational resources that can be made widely available through recently-developed electronic delivery methods such as the Internet and portable electronic devices.

Keywords: plant image standards, specimen, photography, morphology.

"Who, I ask, in their right mind would condemn a picture which, it is clear, expresses things much more clearly than they can be described with any words of the most eloquent men? Indeed nature was fashioned in such a way that everything may be grasped by us in a picture: in fact, those which are explained and depicted to the eyes on panels or paper adhere to the mind more deeply than those described by bare words. It is certain that there are many plants which cannot be described by any words so as to be recognized, but which, being placed before the eyes in a picture, can be recognized immediately at first sight."[4]

—Leonhard Fuchs (Fuchs 1542)

Paradigm shift in imaging of live plants

The rise of electronic communication and predominance of the Internet has resulted in a major change in the way information is presented and stored. Students and faculty have come to expect instant access to information. As the costs for storing and delivering information has gone down, portable electronic devices such as handheld video players, video-enabled mp3 players, cellular phones capable of delivering images, and notebook computers have become more sophisticated and more widely available. This has created new opportunities for education and research.

This shift in orientation toward presentation of information through electronic means has created a demand for high-quality images. At the same time, the cost of digital cameras, the most effective way to produce these images, has dropped to an affordable level. As a result, the number of images available to students and faculty is much higher than at any time in the past.

The paradigm shift in accessibility of digital images is an opportunity to re-examine our assumptions about the ways we collect and present botanical information. Historically, botanists have collected, pressed and dried plant specimens as a mechanism of recording botanical diversity. The cost of creating and maintain a comprehensive collection of living plants was simply prohibitive. Dried herbarium specimens became the standard.

With the advent of color photography, taxonomists and foresters created collections of 35 mm slides, primarily for use in teaching, but also to document living collections (Douce et al. 2001). While herbaria and botanical gardens may have maintained small slide collections, these collections remained of minor importance outside teaching and documenting the collections. One limit on their use was portability. Both herbarium specimens and 35 mm slides are physical objects and can only be used in a one place at a time. However, standard procedures for the exchange and use of herbarium specimens allowed them to circulate to a much greater extent than slides.

As the Internet began to grow, photographers quickly realized that slide images and specimens could be shared more widely if they were digitized

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[1] Department of Biological Sciences, VU Station B 351634, Vanderbilt University, Nashville, TN 37235-1634, U.S.A.
[2] Department of Biology, PO Box 26170, University of North Carolina, Greensboro, NC 27402-6170, U.S.A.
[3] Author for correspondence: steve.baskauf@vanderbilt.edu

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and made electronically available. Some of the first images of this type were sold commercially (Biodisk 1996) or distributed on CD-ROM to support forestry extension (Bargeron et al. 2006, p. 3). In 1995, production of a single digital image from a 35 mm slide took approximately 30 minutes and cost one to three dollars. (Bargeron et al. 2006, p. 50) When the cost of film scanners and digital cameras went down, many botanical images became available for free, either on the Internet or on a companion CD distributed with a textbook. Unfortunately, images derived from existing resources retain some of the less desirable characteristics of their predecessors. Imaged herbarium specimens, like the original herbarium sheets, appear flat, dry, and discolored. Digital images overrepresent the most photogenic species, and present few (sometimes only one) features of each plant.

In order to address these problems we need to re-examine our assumptions about how we collect and use digital images. We should consider collecting images systematically as we do with physical specimens. Systematic collection would facilitate using the images in ways that live up to Fuchs' expectations, in ways that take advantage of our remarkable abilities to process visual information (Gauthier and Tarr 1997; Gauthier et al. 1998; Gauthier and Tarr 2002; Gauthier et al. 2003; Bukach et al. 2006a; Bukach et al. 2006b). We use these abilities every time we recognize a pattern or identify some important feature, but our use of botanical images has not, in general, been informed by what we know about these abilities. Rather than taking a few images solely to reflect and illustrate the characters that we describe verbally, systematic collection of images would allow us to form a mental image of the plant holistically as we are able to do with a whole, living plant.

In the remainder of the paper we consider ways in which collections of digital plant images might be taken so as to facilitate their use as specimens. In this paper we use the term "specimen" to mean a group of objects that samples representative features of a particular living plant and acts as a permanent record of that individual's occurrence. These photographic specimens can serve as important supplements to herbarium collections by providing teaching and identification resources that are easily accessible to the public.

Collections of digital images as specimens

If collected in an appropriate manner, sets of digital images can supplement herbarium collections by fulfilling some of the same roles as herbarium specimens. Herbarium specimens have important roles in assisting in plant identification, and teaching taxon recognition. They are particularly effective in these roles when they represent all parts of the plant. If specimens have been collected from across the geographic range of the taxon, and have been collected over a long period of time, they also provide a record of the spatial and temporal variation in the taxon. This record is important not only because it provides historical and ecologically important data, but because it provides information useful in the identification of unusual specimens.

Sets of images are important because, unlike an herbarium specimen, a single image seldom represents all of the features of a plant. However, if enough features are photographed, a set of images can adequately represent the gross morphology of a species. In the case of trees and other large plants, photographic representation of gross morphology may even be superior to the representations available from herbarium specimens. Images easily capture some information about taxa that can be preserved only with difficulty in an herbarium. For instance, the irregular "ropey" trunk of *Carpinus carolinana* Walter (Betulaceae) is one of its most distinctive features. It can be easily seen in photographs, but is difficult to preserve in an herbarium. Likewise, the overall shape of a tree cannot be captured in an herbarium specimen.

As aids to identification, sets of images are probably superior to herbarium specimens. Color and habit are better represented in images than in pressed specimens, as is the living form of the plant. If one can already recognize a species from living material he or she may be able to recognize it as an herbarium specimen, but when attempting

[4] "Quis quaeso sanae mentis picturam contemneret, quam constat res multo clarius exprimere, quam verbis ullis, etiam eloquentissimorum, deliniari queant. Et quidem natura sic comparatum est, ut pictura omnes capiamur: adeoque altius animo insident quae in tabulis aut charta oculis exposita sunt et depicta, quam quae nudis verbis describuntur. Hinc multas esse stirpes constat, quae cum nullis verbis ita describi possint ut cognoscantur, pictura tamen sic ob oculos ponuntur, ut primo statim aspectu deprehendantur."

to identify a plant for the first time a dried plant glued to a piece of paper is less likely to be helpful. A set of photographs including pictures of the flower, leaves, stem and the whole plant is much more likely to allow novices to make correct identifications (Kirchoff 2007, 2008).

With regard to their use in learning, images may also be superior to herbarium specimens. Images depict the three-dimensional orientation of features more accurately than do pressed specimens. They represent features that are difficult or impossible to preserve in specimens, such as fleshy fruits or the shape of an entire tree. They also more accurately represent color. Although a single image cannot capture all of this variation, a set of images can.

As records of occurrence, digital images can be as good as physical specimens, assuming that they capture sufficient information to allow unambiguous identification. Time and date are automatically recorded in the EXIF (Exchangeable Image File standard) (JEITA Technical Standardization Committee on AV & IT Storage Systems and Equipment 2002) information stored as a part of JPEG and many RAW images, the most common formats used in digital cameras. Although not yet readily available, GPS (Global Positioning System) enabled cameras can automatically embed spatial coordinates in the EXIF data as well. The ability to embed metadata in the image file ensures that the information remains with the photograph.

As research tools, digital image specimens have several disadvantages when compared to physical specimens. Any features of the plant that are not photographed at the time of collection cannot be recorded at a later time (e.g., microscopic morphology of hairs). Because image specimens are not physical objects, it is not possible to extract DNA or other chemical components from them. These disadvantages can be eliminated if the photographer is able and willing to collect a physical specimen from the same plant, and if a reference to that physical specimen is included in the metadata associated with the image.

Technically speaking, sets of images are information derived from an object rather than a part of the object itself, and as such they may not meet the strict definition of a "specimen." However, when collected in an appropriate manner, sets of images serve many of the same purposes as physical specimens. Thinking of image sets as specimens can influence the way that we collect and organize images, which may increase their value as tools for education and research.

Rationale for collection of digital images as specimens

Although sets of digital images can serve some of the same functions as physical specimens, images of live plants have not typically been collected in this manner. Large plant image collections, such as CalPhotos (Biodiversity Sciences Technology Group 1995–2008) and plants.usda.gov (PLANTS Web Development Team 2006), have been assembled by absorbing smaller image collections and through coordinated contributions from many individuals. Because the images come from multiple sources, their quality and the data associated with them is not uniform. Ornamental and photogenic species are over-represented, and species that are not charismatic or that are difficult to identify are under- or unrepresented. Often photographs of some features, such as bark or twigs, are not included. In other cases, several features may be combined in a single image. This lack of standardization makes comparison of taxa difficult. Image quality varies, and images may not be available at high resolution. Finally, date and location information may be poor or non-existent.

The systematic collection of standardized digital images will address most of these problems. Standardized, systematic representation of features will allow comparison among taxa, and presentation of the variation among and within individuals. The capability to easily observe this variation allows users to recognize the plants in a visually natural way (Kirchoff 2007, 2008). The presence of many detailed images from the same individual also allows verification of the taxonomic identity, resulting in the production of a reliable collection of images. Occurrence data associated with these image sets adds to the distribution database for the species. If well done, sets of digital images would complement, but not replace, traditional physical specimens in herbaria.

The Bioimages Project

The genesis of the image standards described below was in the Bioimages Project (Baskauf 2003–2008). Begun in 2003, Bioimages is a web-accessible collection of live-plant images from the central-southern United States. To establish an initial list of target species, the flora lists of several natural areas in middle Tennessee were combined. Image collection began with woody plants, and extended to herbaceous plants the following year. As image collection progressed, standards were developed for groups of species sharing common sets of features. These groups are woody angiosperms, herbaceous angiosperms, gymnosperms, ferns, and cacti. Within each group, features are divided into major categories. Within the major categories, subcategories were developed as necessary to show details of the feature, such as different views, components, sizes, or developmental stages. The features listed in the image standards below were chosen because they represent parts of the plant that are readily visible, can be diagnostic in at least some groups, and can generally be photographed in the field with a handheld camera without destruction of the plant.

In order to assure correct identification, as many features as possible were photographed of the same individual. Particular individuals were marked and, if necessary, revisited to photograph different phenological stages. By photographing sets of features from the same individual, the identity of less diagnostic features could be verified by examination of images of more diagnostic features. This was not always possible when the same plant could not be revisited, when it was in a different reproductive stage, or when features could not physically be reached to photograph (e.g. flowers or cones high in large trees). In such cases, several individuals were photographed in order to get a complete set of features, with care taken to image at least one diagnostic feature for each individual.

PROPOSED PHOTOGRAPHIC STANDARDS

The features listed in bold are primary, and should be photographed if at all possible. Secondary features listed in normal text are desirable, but generally carry less taxonomically distinguishing information and may be omitted if time or resources are limited. In some genera or families, the secondary features are important for distinguishing among species, and in those cases should be considered primary. The features specified in these standards should be considered basic – if other features are unique, characteristic, or diagnostic for a taxon, they should be photographed as well. All photographs should show the indicated features in the full frame. These standards are suggested as a goal, not a *sine-qua-non* of image collection.

I. Woody angiosperms (Figs. 1, 2, 7)

A. Whole tree (or vine)
   1. **entire tree - summer** (Fig. 1A)
   2. entire tree - winter
   3. view up trunk, if tree is large (important in conditions where the whole tree cannot be photographed)

B. Bark (vertical orientation)
   1. **of a large tree** (Figs. 1B, 7)
   2. of a medium tree or the bark of a large branch oriented vertically
   3. **of a small tree, or the bark of a small branch oriented vertically** (Fig. 1C)

C. Twig
   1. **horizontal view showing the orientation of the petioles and axillary buds** (Figs. 1D, 7)
   2. **horizontal view of a winter twig showing a terminal bud and several axillary buds** (Fig. 1E)
   3. close-up of winter twig showing leaf scar and lateral bud (vertical orientation) (Fig. 1F)
   4. close-up of winter twig showing terminal bud (vertical orientation)

D. Leaf
   1. **upper (adaxial) surface of whole leaf oriented with apex downward; part of the lower (abaxial) surface of another leaf should be visible** (Figs. 1G, 7)
   2. **margin of upper surface of leaf; part of the lower surface of another leaf with major veins visible should be shown behind the upper surface** (Figs. 1H, 7)
   3. several leaves showing their orientation on the twig

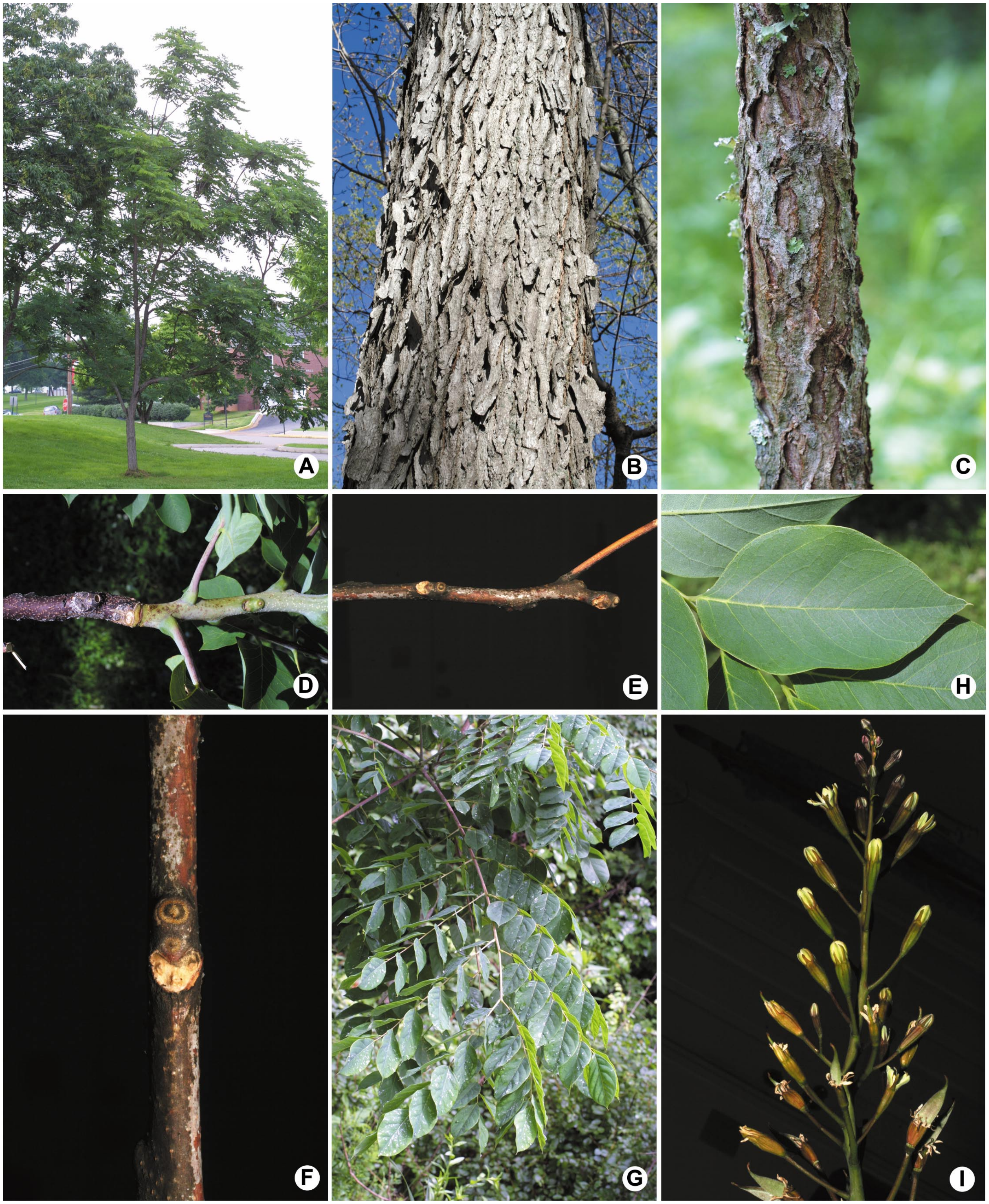

FIG. 1. Standardized images of a woody angiosperm, *Gymnocladus dioica* (L.) K. Koch (Fabaceae), Kentucky Coffee Tree. **A**. Entire tree in summer. **B**. Bark of a large tree. **C**. Bark of a small tree. **D**. Horizontal view of a twig showing the orientation of the petioles and axillary buds. **E**. Horizontal view of a winter twig showing a terminal bud and several axillary buds. **F**. Vertical close-up of winter twig showing a leaf scar and lateral bud. **G**. Whole leaf (upper, adaxial surface) with apex downward. **H**. Margin of leaflet; part of the lower (abaxial) surface of another leaflet with major veins visible shown behind. **I**. Whole inflorescence.

FIG. 2. Standard images of *Gymnocladus dioica* (L.) K. Koch (Fabaceae) continued. **A**. Lateral view of flower. **B**. Frontal view of flower. **C**. Lateral view of fruit. **D**. Open fruit. **E**. Seed. **F**. Young fruit.

E. Inflorescence and flower. If imperfect, photograph flowers of both sexes.
1. **whole inflorescence** (Fig. 1I)
2. **lateral view of flower** (Fig. 2A)
3. **frontal view of flower** (Fig. 2B)
4. ventral view of flower showing perianth
5. if the flower is large, a close-up of its interior

F. Fruit
1. as borne on the plant (Fig. 7)
2. **lateral view** (Figs. 2C, 7)
3. section of fruit, or open fruit if dehiscent (Fig. 2D)
4. seeds (Fig. 2E)
5. young fruit (Fig. 2F)

II. Herbaceous angiosperms (Fig. 3)

A. Whole plant
1. juvenile
2. **in flower** (Fig. 3A)
3. in fruit

B. Stem
1. **showing orientation of leaf bases or petioles (vertical orientation)** (Fig. 3B)

C. Leaf
1. **basal leaves, or leaves on the lower stem, with apex down** (Fig. 3C)
2. **on the upper stem, with the apex up** (Fig. 3D)
3. margin of upper surface of leaf; part of the lower surface of another leaf with major veins visible should be shown behind the upper surface

D. Inflorescence and flower. If imperfect, flowers of both sexes.
1. **whole inflorescence** (Fig. 3E)
2. **lateral view of flower** (Fig. 3F)
3. **frontal view of flower** (Fig. 3G)
4. ventral view of flower showing perianth
5. if the flower is large, a close-up of its interior

E. Fruit
1. as borne on the plant (Fig. 3H)
2. **lateral view**
3. cross section of fruit, or open fruit if dehiscent (Fig. 3I)
4. seeds
5. young fruit

III. Gymnosperms (Fig. 4)

A. Whole tree
1. **entire tree** (Fig. 4A)
2. looking up trunk, if tree is large (important in conditions where the whole tree cannot be photographed)

B. Bark: same as woody angiosperms
1. **of a large tree** (Fig. 4B)
2. of a medium tree, or the bark of a large branch oriented vertically
3. **of a small tree, or the bark of a small branch oriented vertically**

C. Twig
1. horizontal view after needles/scales have fallen
2. **horizontal view showing attachment of needles or scales** (Fig. 4C)

D. Leaf
1. **entire needle (or scales), apex down** (Fig. 4D)
2. fascicle base showing number of needles per fascicle, and scales if present
3. many needles (or scales) showing orientation on twig (Fig. 4E)

E. Cone
1. male cones (Fig. 4F)
2. **female cone, mature, open** (Fig. 4G)
3. female cone, closed (Fig. 4H)
4. female cone, receptive (Fig. 4I)
5. one year-old female cone (in species requiring two years of cone development) (Fig. 4J)
6. seeds

IV. Ferns and other vascular non-seed plants (Fig. 5)

A. Whole plant
1. entire plant, vegetative (Fig. 5A)
2. **entire plant showing reproductive structures**

B. Leaf (frond)
1. **upper surface of entire frond** (Fig. 5B)
2. **lower surface of entire frond**
3. margin of upper surface of frond (if entire), or pinna (if compound) with lower surface of another frond/pinna visible behind upper surface (Fig. 5C)
4. stem/base of frond (Fig. 5D)

C. Sporangia
1. **spore-bearing structure** (Fig. 5E)

D. Gametophyte
1. microscopic view of gametophyte

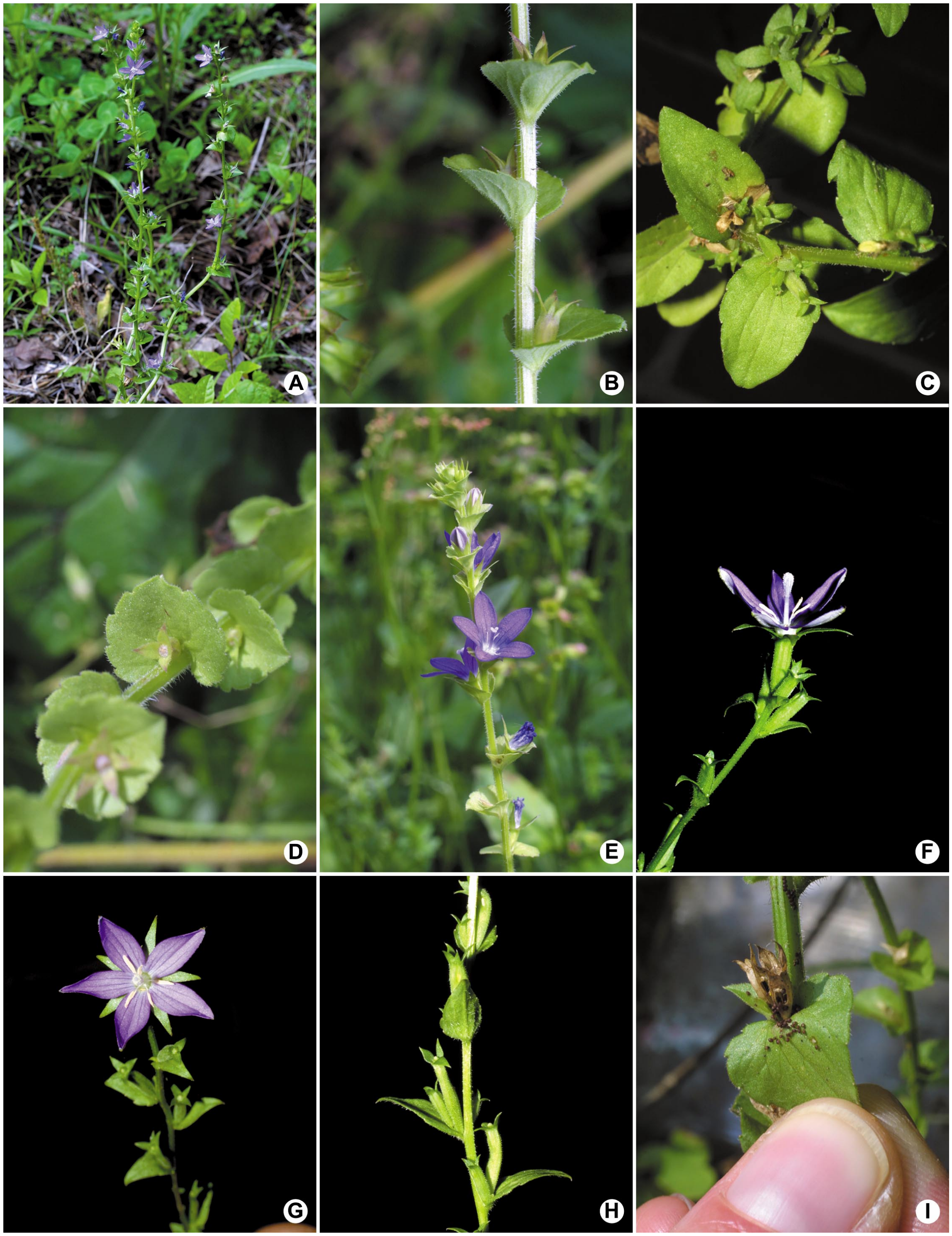

FIG. 3. Standardized images of an herbaceous angiosperm, *Triodanis perfoliata* (L.) Nieuwl. (Campanulaceae), Clasping Venus' Looking-Glass. **A**. Whole plant in flower. **B**. Vertically oriented stem showing orientation of leaf bases or petioles. **C**. Leaf on the lower stem with apex oriented toward the bottom of the photograph. **D**. Leaf on the upper stem with apex oriented toward the top of the photograph. **E**. Whole inflorescence. **F**. Lateral view of flower. **G**. Frontal view of flower. **H**. Fruit as born on the plant. **I**. Dehiscent fruit.

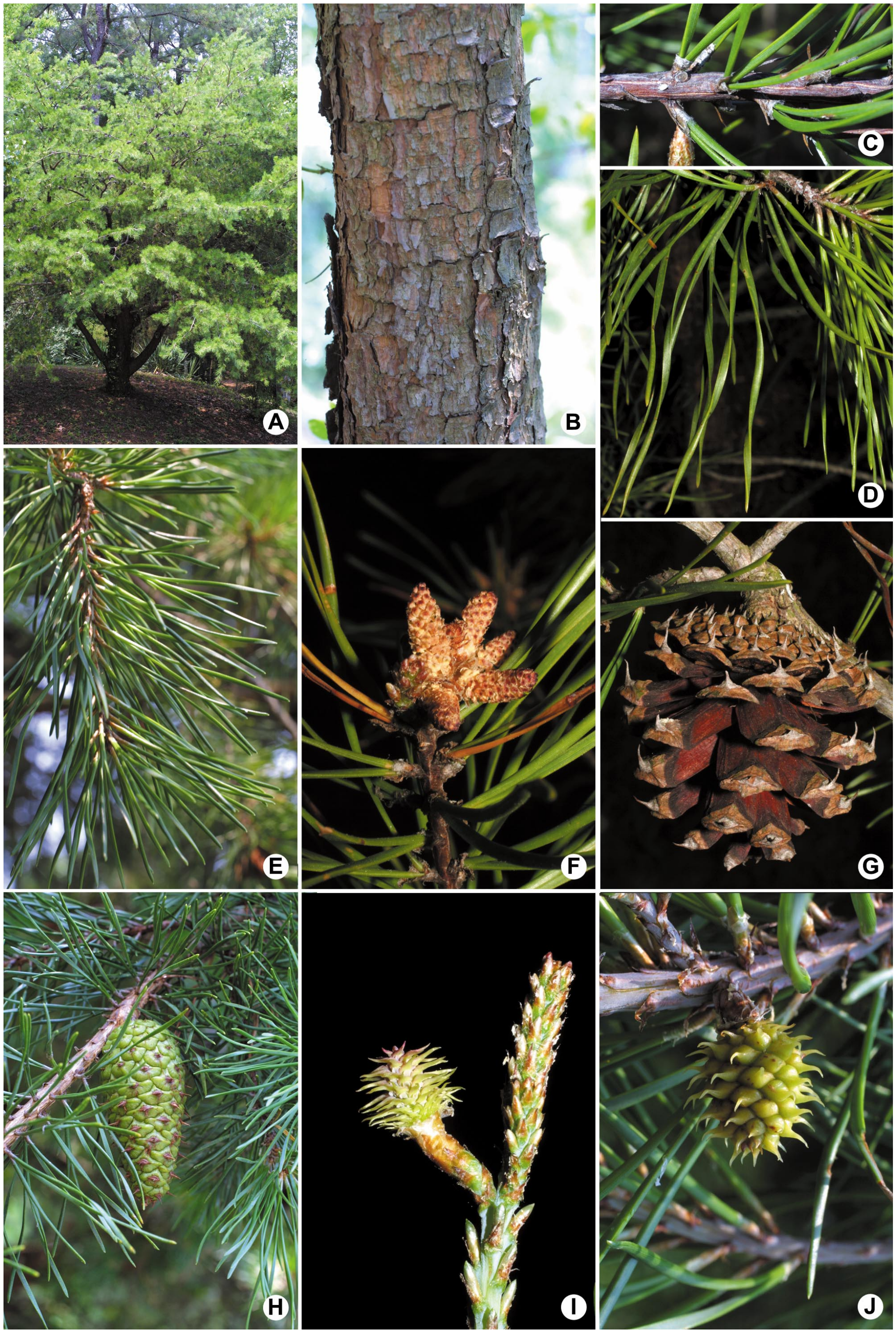

FIG. 4. Standardized images of a woody gymnosperm, *Pinus virginiana* Mill. (Pinaceae), Virginia Pine. **A**. Whole tree. **B**. Bark of a large tree. **C**. Horizontal view of a twig showing attachment of the needles. **D**. Entire needle with the apex oriented toward the bottom of the photograph. **E**. Many needles showing their orientation on twig. **F**. Male cone. **G**. Mature, open female cone. **H**. Female cone, closed. **I**. Female cone, receptive. **J**. One year-old female cone.

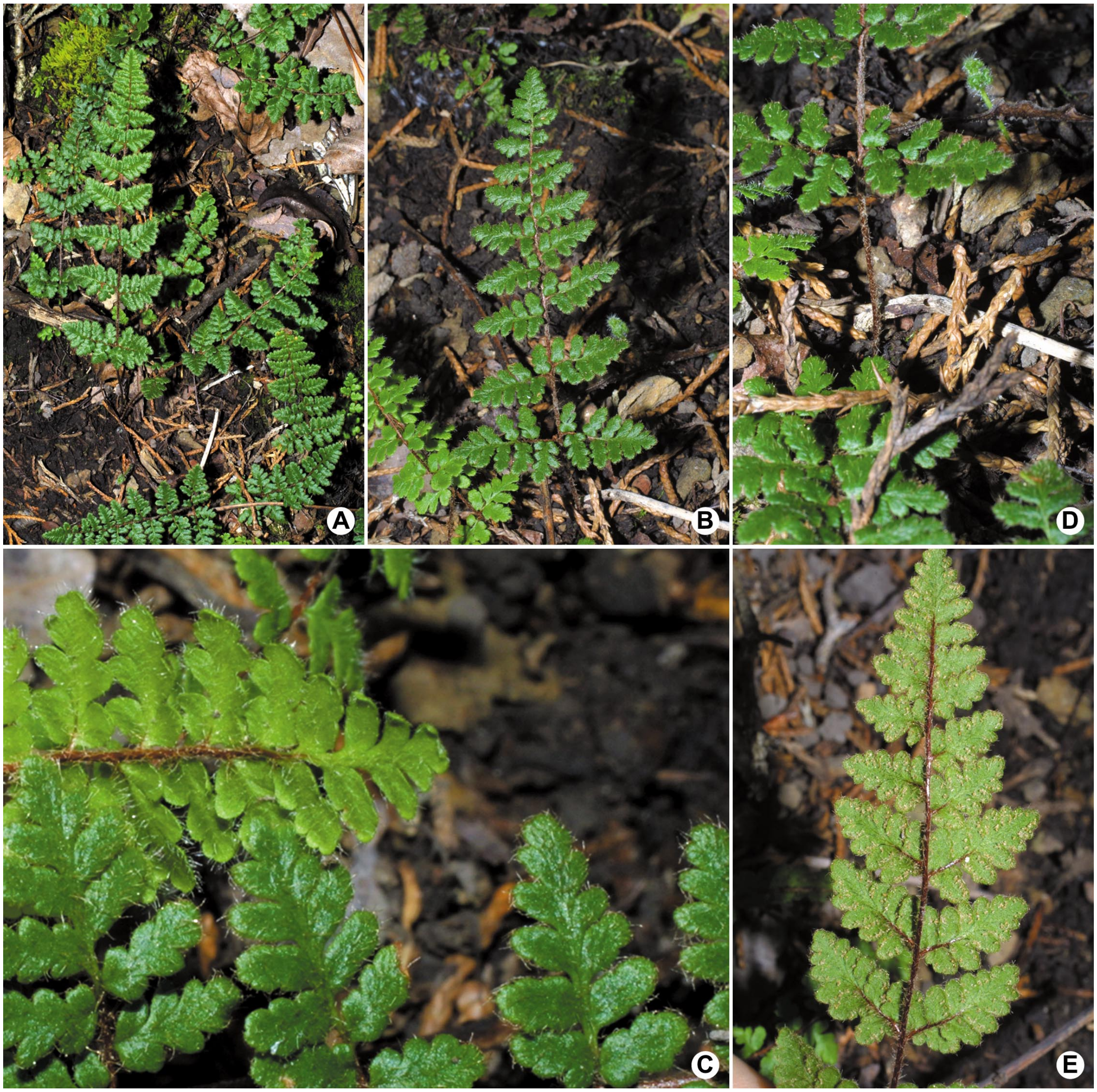

FIG. 5. Standardized images of a fern, *Cheilanthes lanosa* (Michx.) D.C. Easton (Pteridaceae), Hairy Lipfern. **A**. Entire vegetative plant. **B**. Upper surface of entire frond. **C**. Margin of pinna with lower surface of another pinna visible behind. **D**. Base of frond. **E**. Sporangia on back (abaxial side) of leaf.

V. Cacti (Fig. 6)

A. Whole plant
   1. **entire plant** (Fig. 6A)
B. "Bark"
   1. lower part of stem, if different from photosynthesizing stem (Fig. 6B)
C. Stem
   1. **entire column, stem, or pad** (Fig. 6C)
D. Areole
   1. **areole, showing orientation of spines** (Fig. 6D)
E. Leaf (if present); same as in woody angiosperms
F. Apex
   1. apical region (Fig. 6E)

FIG. 6. Standard images of a cactus, *Opuntia humifusa* (Raf.) Raf. (Cactaceae), Eastern Prickly Pear. **A**. Whole plant. **B**. Lower part of the stem. **C**. Entire pad. **D**. Areole, showing the orientation of the spines. **E**. Apical region of the stem. **F**. Whole inflorescence. **G**. Frontal view of flower. **H**. Fruit on plant. **I**. Lateral view of fruit.

G. Flower; same as woody angiosperms
  1. **whole inflorescence** (Fig. 6F)
  2. **lateral view of flower**
  3. **frontal view of flower** (Fig. 6G)
  4. ventral view of flower showing perianth
  5. if the flower is large, a close-up of its interior

H. Fruit
  1. on plant (Fig. 6H)
  2. **lateral view** (Fig. 6I)
  3. cross section of fruit, or open fruit if dehiscent
4. seeds
5. young fruit

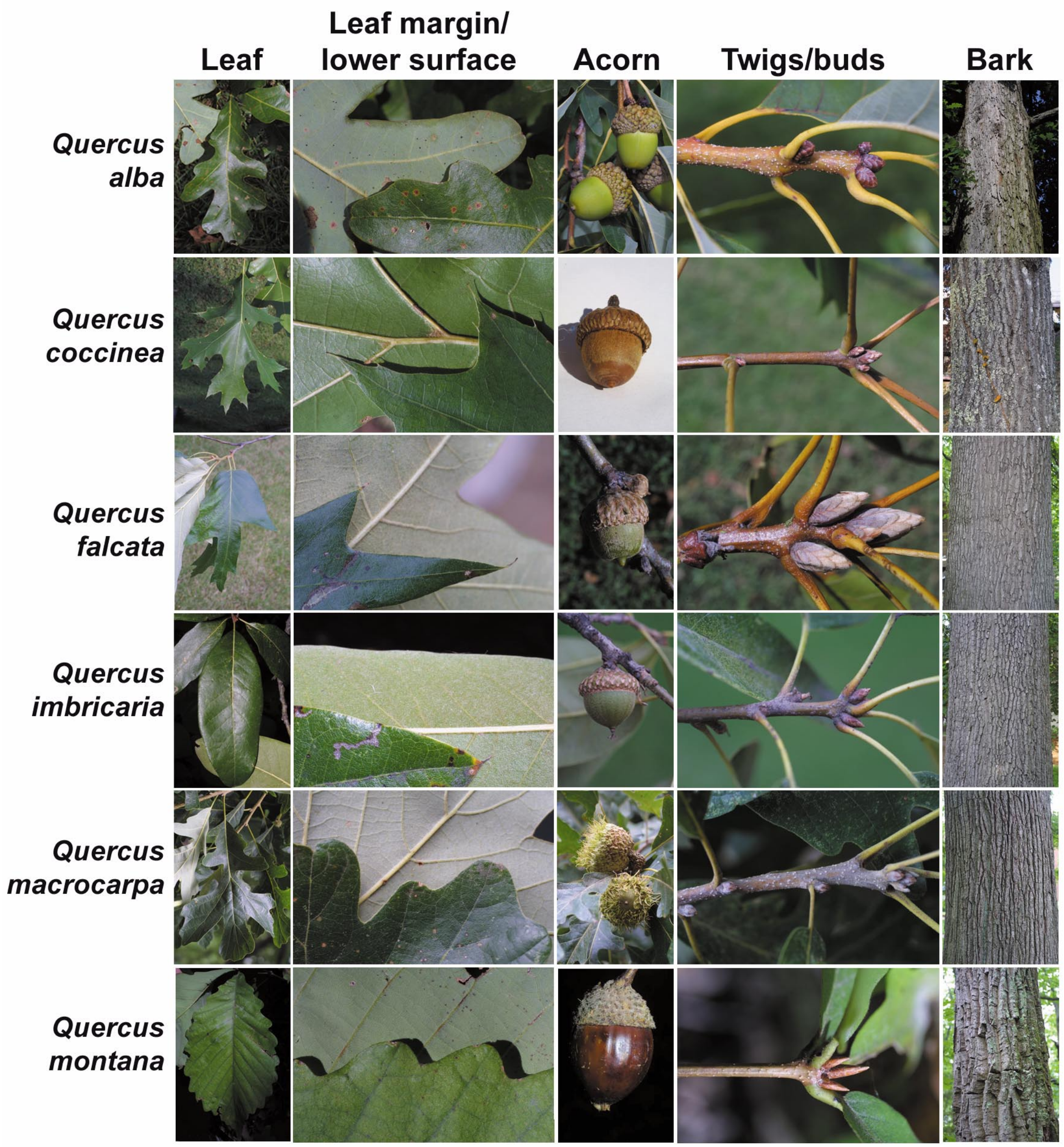

FIG. 7. Use of standardized photographs to compare five features (leaf, leaf margin/lower surface, acorn, twigs/buds, bark) of six oak species (*Quercus alba* L., *Q. coccinea* Münchh., *Q. falcata* Michx., *Q. imbricaria* Michx., *Q. macrocarpa* Michx., *Q. montana* Willd.).

The season, location of the plant, or constraints of time may make it impossible to photograph all of the primary features. Nevertheless, these standards can serve as a touchstone for photographers. The suggested feature orientation is intended to reflect the way that the feature generally appears on the plant. Adopting standard features and orientations allows side-by-side comparison of images, and the creation of standard displays for the identification of closely related species (Fig. 7).

Since the set of images from a given individual is intended to be a photographic specimen, the image set must contain enough images to allow the plant to be unambiguously identified at the species level. To make this possible, as complete a set of primary features as is practical should be taken from the same individual plant. The locality of each individual should also be recorded, preferably as a decimal latitude and longitude using the most current datum standard for GPS (currently WGS 84).

Additional photographic recommendations

Images photographed according to the standards listed above can be used for a variety of purposes, including taxon identification, comparison of similar taxa while learning taxon recognition, and presentation in print publications or posters. Such uses require high quality images that are of sufficient resolution to be enlarged or printed, and which present the subject in a manner that does not detract from the feature being presented. To achieve this level of quality, the following recommendations are suggested:

1. A minimum image resolution of 6.0 megapixels will provide images suitable for most print applications, and for enlargement to allow examination of details present in the image.
2. The use of flash for close-up images produces maximum depth of field, reduces blurring from camera motion, and minimizes distracting background. Flash photography allows for rapid, high-quality photography even under the poor lighting conditions common in forests, and on overcast days.
3. The images will be more useful if they are unmarked with species names, photographer names, image numbers, or copyright notices. These identifiers can be associated with the image when it is presented on the web or in print, or can be embedded in the EXIF data associated with the image.

Other recommendations

If the educational promise of digital plant images is to be fulfilled, many high quality images must be collected and made available. To accomplish these goals, we recommend several additional steps.

1. Photographic standards should be developed for groups not currently represented. For instance, standards designed specifically for Asteraceae, Poaceae, Cyperaceae, and mosses still need to be developed, as do standards for taxa other than plants.
2. The discussion of standards for photographing live plants needs to become part of the broader discussion of standards for sharing digital data. This discussion is ongoing for the sharing of metadata (Dublin Core Metadata Initiative 1995–2008), locating resources through Life Science Identifiers (Taxonomic Database Working Group 2007), and exchanging geographic occurrence information (Wieczorek and Blum 2003–2008). However, these discussions do not yet include standardizing the way in which live plants are photographed. The informal standards outlined here may serve as the starting point for the development of more formal standards by a larger body.
3. The images will be most useful if they are freely available for non-commercial use. The Creative Commons Attribution-Noncommercial 3.0 License (Creative Commons 2008) might be used as a model for plant images that are freely distributed over the Internet. It allows unrestricted non-commercial use while protecting the photographer's copyright by requiring negotiated commercial use. Photographers who are willing to allow commercial use can choose the Creative Commons Attribution 3.0 license or release the images into the Public Domain.
4. Digital image specimen collections should eventually include multiple individuals of each species. This would allow users to consider the range of variation among individuals in a given area, and across the species' geographic range.
5. Methods should be developed to allow for presentation of distance scales beside the images, without disrupting the images themselves. Because the images should be suitable for presentation in learning environments and print applications, placing coins, people, or rulers in the actual image is not recommended. In situations where the inclusion of a scale is essential, it should be possible to collect and archive two images, one with and one without a scale.
6. The images need to be permanently archived to allow resource developers to locate and access the originals. This can be achieved by adapting biodiversity collections software to create suitable databases, or archiving the images in an on-line image repository such as MorphBank, a permanent international repository for images documenting specimen-based research (Morphbank Team 2004–2008).

The future of live-plant images

The recent rapid development of powerful electronic, software, and network tools and the inauguration of ambitious projects such as Discover Life (Polistes Foundation 1997–2008) and the Encyclopedia of Life (Wilson 2003) demonstrate the immense potential of the web to deliver image-enhanced education. The use of increasingly prevalent image-based resources such as handheld video players and the wireless Internet provide an unparalled opportunity to produce image-based content and deliver it to a large audience. However, this opportunity will be unrealized without the thousands of high-quality images required in order prepare the content.

A large collection of publicly available digital live-plant images cannot be created by software or automated processes, nor can it be effectively created from collections of 35 mm slides. There is no shortcut past the hard work of finding, identifying, and photographing plants in the field. This fact has two important implications. It is unlikely that this labor-intensive work will be redone in the future if it is determined that some features or quality is lacking in the extant images. Thus development of standards early in the process is critical. Secondly, locating and identifying the plants themselves is a challenge shared with the collection of physical specimens. This challenge can only be met effectively with the cooperation of herbaria and the professionals associated with them. Identification of specimens can best be accomplished at the time of imaging if the photographer is an expert, or if the photographer accompanies an expert into the field. However, if comprehensive image standards are developed and followed, and if good locality data is recorded, it should also be possible for the specimen to be identified at a later time. Many of the goals and challenges involved in creating new image-based plant educational resources are shared with those of traditional herbaria. Thus these challenges can be best met through collaboration with the existing networks of herbaria.

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