

Image Use in Field Guides and Identification Keys: Review and Recommendations

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Abstract:

Background and aims. Although illustrations have played an important role in identification keys and guides since the 18th century, their use has varied widely. Some keys lack all illustrations, while others are heavily illustrated. Even within illustrated guides, the way in which images are used varies considerably. Here, we review image use in paper and electronic guides, and establish a set of best practices for image use in illustrated keys and guides.

Scope. Our review covers image use in both paper and electronic guides, though we only briefly cover apps for mobile devices. With this one exception, we cover the full range of guides, from those that consist only of species descriptions with no keys, to lavishly illustrated technical keys. Emphasis is placed on how images are used, not on the operation of the guides and key, which has been reviewed by others. We only deal with operation when it impacts image use.

Main points. Few illustrated keys or guides use images in optimal ways. Most include too few images to show taxonomic variation or variation in characters and character states. The use of multiple images allows easier taxon identification and facilitates the understanding of characters. Most images are usually not standardized, making comparison between images difficult.

Although some electronic guides allow images to be enlarged, many do not.

Conclusions. The best keys and guides use standardized images, displayed at sizes that are easy to see and arranged in a standardized manner so that similar images can be compared across species. Illustrated keys and glossaries should contain multiple images for each character state so that the user can judge variation in the state. Photographic backgrounds should not distract from the subject and, where possible, should be of a standard colour. When used, drawings should be prepared by professional botanical illustrators, and clearly labelled. Electronic keys and guides should allow images to be enlarged so that their details can be seen.

Article:

INTRODUCTION

Illustrations have played an increasingly important role in field guides and identification keys since their introduction in the 18th century. Due to publishing constraints, the first field guides and keys had a limited number of images (Scharf 2009). Technological advances in publishing and computer technology have made highly illustrated guides more prevalent. Many modern keys, both written and computer-based, include multiple illustrations and/or high-quality photographs. These images are used in conjunction with written descriptions to reduce ambiguity in identifications (Hawthorne 2006). After a brief summary of constraints on image use in early

guides, we present some common uses of images in modern guides and highlight several modern guides which utilize images in unique and innovative ways. Based on our review of the literature and on our reading of the cognitive psychology literature, we formulate a set of best practices for image use in field guides (Table 1) and highlight these practices in the guides that we review. In a companion paper we extend these principles to purely visual guides (those that contain little or no text), and illustrate the principles with a visual key to the Fagaceae of the southeastern USA (Kirchoff *et al.* 2011).

Table 1: Best practices in image use in guides and keys. This formalization is based on our review of the guides and keys included in this paper. References to Best Practices in the text refer to this table

1. Taxon descriptions and morphological terms should be illustrated with multiple images so that the user can form an adequate concept of the taxon or term. It is not possible to form adequate concepts from a single illustration (Wisniewski 2002).
 - a. Taxa should be illustrated with multiple standardized photographs (re. Best Practice 4).
 - b. When used in glossaries, each term should be illustrated with several drawings chosen to show variation in the named structures. If space is a consideration, each drawing can be used to illustrate several terms, with arrows or other indicators used to direct the user's attention to the relevant portions of the image.
 - c. When used in keys, characters and character states should be illustrated with multiple images, with arrows or other indicators used to direct the user's attention to the relevant portions of the image. All character states should be illustrated so that the user can make an informed choice among the alternatives.
2. Coloured marginal bands on a printed page provide a simple index that allows quick access to species descriptions, and makes the guide easier to use. Combinations of coloured marginal bands can be used as a type of multiple access key, with specific taxa identified by a unique pattern of bands.
3. Iconic symbols simplify access to species descriptions by providing symbolic representations of characteristic features. When used in combination with coloured marginal bands they can create a hierarchical index to the taxa. They can also be used at the end of couplets to allow the user to quickly find the next couplet, which is marked with the same icon.
4. Photographic standards should be developed for each type of plant structure used in the guide (Ramirez *et al.* 2007; Baskauf and Kirchoff 2008).
 - a. Backgrounds should not distract from the main subject of the photograph.
 - b. When plates are used, photographs should be arranged in standardized ways so that users can easily find comparable structures.
 - c. Professionally prepared botanical illustrations should be used where standardized photographs are not possible, or are impractical for technical reasons. Drawings are often better at representing a typical example than are photographs, which must, of necessity, represent the state in a specific plant.
 - d. In electronic guides it should always be possible to enlarge the photographs so that details can be easily seen.
5. Scale bars should be used with discretion. They are very seldom needed on every illustration and, when used indiscriminately, can distract the user's attention from the salient features.
 - a. When used to represent the length of an organism or part, scale bars should represent the range of lengths that a user is likely to encounter (Garrison 2010).
 - b. When used in plates, the size of the scale bar should be adjusted so that the represented length remains invariant among the set of images.
 - c. Scale bars should usually be included in visual guides to microscopic features that differ in size (pollen, etc.). In these cases, bars with graduated scales often provide the most useful information (Vasanthy *et al.* 2007).

CONSTRAINTS ON IMAGE USE IN EARLY FIELD GUIDES AND KEYS

Early field guides and identification keys contained few, if any, images. Scharf (2009) reviewed the use of images in these guides and concluded that this lack was not because early authors did not recognize the importance of image use, but was rather due to publishing constraints (Scharf 2009). During the 18th and 19th centuries the costs of printing prevented the lavish use of illustrations. Two forms of printing were available during this time, copperplate engravings and woodcut illustrations. Prints made from copperplate engravings were of higher quality and more detailed than those printed from woodcuts. However, copperplate engravings were more expensive than woodcuts. A publisher was faced with the choice of using many lower quality woodcut illustrations, or a small number of higher quality copperplate engravings. Because the woodcut illustrations lacked the detail to convey the necessary information, most publishers preferred using copperplate engravings. As a consequence, these illustrations were used sparingly to illustrate only the most necessary technical details (Scharf 2009). Many guides during this time did not include images at all.

Although technological advances have made the use of images more common, the full benefits of image use have yet to be realized. In this paper we focus on image use in field guides and keys. Although most of our examples will be botanical, we review image use in several zoological keys that make particularly good use of images. We will not deal extensively with other aspects of these guides unless they bear directly on image use. Key structure and use has been reviewed elsewhere (Tilling 1984; Edwards and Morse 1995; Jarvie and Stevens 1998; Pankhurst 1998; Rejmanek and Brewer 2001; Stevenson *et al.* 2003; Gaston and O'Neill 2004; Farr 2006; Walter and Winterton 2007), and will not be reviewed in a systematic way in this paper. A number of studies have also investigated the effectiveness of various types of keys (Stucky 1984; Fermanian *et al.* 1989; Wright *et al.* 1995; Morse *et al.* 1996; Tardivel and Morse 1998; Lawrence *et al.* 2006b; Randler 2008), although no comprehensive methods for assessing usability have been developed. We have not conducted usability studies for this review. Our goal is to produce a set of Best Practices (Table 1) and illustrate their use in the reviewed guides. We have not attempted a comprehensive review of all guides, but have selected guides as examples of the different approaches to organism identification of which we are aware.

Lawrence and Hawthorne provide a particularly good manual on identification guide structure and construction (Lawrence and Hawthorne 2006). They cover not only the structure of both paper and electronic keys, but also character identification (Hawthorne 2006), producing illustrations (Hawthorne and Wise 2006), testing the guide (Lawrence *et al.* 2006b) and the economics of producing a successful guide (Lawrence *et al.* 2006a), among other topics.

COMMON USE OF IMAGES IN PRINTED FIELD GUIDES.

Image use in tripartite guides

The earliest field guides followed a tripartite format, consisting of a key, a species descriptive section and an alphabetized index (Scharf 2009). In addition to these three sections, most modern guides include an introduction and/or glossary, such as that found in *The Jepson Desert Manual* (Baldwin *et al.* 2002) and *Woody Plants of the Southeastern United States: A Winter Guide* (Fig. 1) (Lance 2004). The introduction often covers terminology, and so can also function as an informal glossary. The key and glossary may be illustrated, but images are most commonly found in the descriptive section and introduction, when one is present. Examples of guides that

follow a modified tripartite format and include images in the introduction are *Newcomb's Wildflower Guide* (Newcomb 1977), *Woody Plants of the Southeastern United States* (Lance 2004) and *Field Guide to Native Oak Species of Eastern North America* (Stein *et al.* 2003). None of these guides use images in its keys.

Image use in the introduction/glossary. *Woody Plants of the Southeastern United States* (Lance 2004) makes use of idealized drawings to illustrate basic terminology in the introduction (Fig. 1A). The first group of drawings illustrates possible leaf venation types (pinnate, arcuate, palmate, parallel) with a single drawing for each type. Because multiple images are not used, without prior knowledge of these terms or access to other sources, most users not already familiar with the terms will have a difficult time applying them correctly. This same problem occurs in other groups of drawings, such as those showing the types of leaves (Fig. 1B). As with the venation types, only a single idealized drawing is used to illustrate each term.

This type of restricted image use is problematical because experimental work on the nature of concepts suggests that they are best understood as encoding information about both the prototype of the conceptual category, and examples of variation around this prototype (Wisniewski 2002). If characters are illustrated with only prototypical examples, as they are in most guides, readers are not exposed to a crucial part of the information needed to form an adequate concept of the term. They are exposed to a typical example of the character, but not its variation. The need for multiple illustrations leads to our first best practice recommendation: use multiple images to illustrate taxonomic concepts and morphological terms (Table 1: Best Practice 1). The failure to include variation is the most common failing of both printed and electronic guides, and one to which we will return to frequently in our review.

Newcomb's Wildflower Guide (Newcomb 1977) and the *Jepson Desert Manual* (Baldwin *et al.* 2002) both provide additional examples of the common use of illustrations in modern tripartite guides. In these guides, illustrations are used in the introduction/glossary, located at the beginning of the book, and within the descriptive sections. In Newcomb (1977) the first image is a map of the area covered by the guide. This is a common feature of field guides, and allows the user to quickly assess if the guide is relevant to his or her search. The equivalent map occurs on the inside of the back cover of the *Jepson Desert Manual*. The glossaries in both books use mostly written descriptions, but do include groups of black and white drawings to illustrate terms. For instance, the first group of images in Newcomb (1977) compares regular to irregular flowers with several drawings of each flower type. The use of several drawings for each character state helps the user become familiar with the variation in the term.

The best illustrations in glossaries and introductory sections are often detailed, labelled drawings by professional botanical illustrators. High-quality professional drawings are usually better than photographs at representing prototypical category members. Photographs must, of necessity, be of a specific plant, and so cannot easily represent the category prototype. Botanical illustrations can be drawn to illustrate a term, not a specific plant. It is also possible to illustrate multiple terms in a single drawing by using arrows to indicate the relevant portions of the drawing, thus showing the relationship between related terms and saving space in printed guides (Table 1: Best Practice 1b). The glossary of the *Jepson Desert Manual* uses professionally prepared illustrations

to good effect, although the glossary would be even better if every term were illustrated (Baldwin *et al.* 2002).

Image use in the species description sections. The descriptive sections of both *Newcomb's Guide* (Newcomb 1977) and the *Jepson Desert Manual* (Baldwin *et al.* 2002) contain descriptions of each species covered in the key, and include a drawing of each. The coverage of the *Jepson Desert Manual* is, of course, much more thorough than *Newcomb's Guide*, as the latter is intended solely for a non-professional audience. In both books, each species is listed with its common and scientific names, and is described in a few sentences, and an illustration is provided on a separate page. Some of the illustrations are in colour, but most are black and white line drawings. The colour photographs in the *Jepson Desert Manual* are grouped into a separate section in the middle of the book. This arrangement will be discussed more fully below. Although the identification key in *Newcomb's Guide* is original in its mechanism, it does not include illustrations and will not be reviewed here.

Image use in field guides without identification keys

A common type of field guide deviates from the tripartite format in that it provides an introduction/glossary, a descriptive section and an alphabetized index, but does not include a key. The use of images in these guides can range from sparse illustrations, to many high-quality photographs. Since these guides do not contain keys, their taxonomic coverage is usually limited to the most common and charismatic species of a region. A few of the guides that follow this format include *Wild Flowers of North Carolina and Surrounding Areas* (Justice and Bell 1968), *Coastal Plants from Cape Cod to Cape Canaveral* (Stuckey and Lofland 2000), *The National Audubon Society Field Guide to North American Wildflowers, Eastern Region* (Niering *et al.* 1995), *An Instant Guide to Trees* (Lawrence and Fitzsimons 1999), *Peterson Field Guides: Eastern Trees* (Petrides and Wehr 1998), *Wildflowers of the Smokies* (White *et al.* 2003), *Wildflowers of the Blue Ridge Parkway* (Alderman 1997), *Weeds of the South* (Bryson and DeFelice 2009) and *Plants and Flowers of Hawi'i* (Sohmer and Gustafson 1987). Representative examples of these guides are discussed below.

Wild Flowers of North Carolina and Surrounding Areas (Justice and Bell 1968) has an introduction/glossary that provides the user with background information on plant structure and function, comparable to the glossary in *Newcomb's Guide*, but with few illustrations. *Wildflowers of the Smokies* (White *et al.* 2003) uses a similar format, but contains more extensive information on ecology, where to find wildflowers and the basics of wildflower identification. Both books contain maps of the covered areas.

Wildflowers of the Smokies (White *et al.* 2003) is organized by flower colour and, within a colour, by similarity in flower or plant structure (simple flowers, daisy-like flowers, vines, etc.). Marginal coloured bands are used to arrange the species by flower colour, and thus provide a rudimentary index to the guide. These types of coloured marginal bands can be used to good effect even in complex guides. Their use forms the content of our second Best Practice (Table 1). We return to the use of marginal bands when we discuss their use in the *Flora Da Reserva Ducke* (Ribeiro *et al.* 1999). The species descriptions in *Wildflowers of North Carolina* (Justice and Bell 1968) are not organized hierarchically.

As is typical for this type of guide, the descriptive sections of both books provide high-quality colour photographs of the species, along with their common and scientific names, and species descriptions. Because there is little structure to the guide, users must rely on a visual search to identify an unknown. The marginal bands in *Wildflowers of the Smokies* make this search easier, but ultimately the user must hunt through a set of images to find his or her unknown. Once a tentative identification has been made, the written descriptions can be used to verify the match.

The visual searches required by this type of guide would be easier if they included more than a single photograph per species. Single photographs seldom represent all of the characters needed for an unambiguous identification, and can never represent the range of variation in the characters that are represented (Table 1: Best Practice 1). A partial exception to these general rules occurs when the images are beautifully composed to show the most characteristic features of the plant. This type of exceptional photography occurs in *Wildflowers of the Appalachian Trail* (Adkins *et al.* 1999), though another guide by the same authors falls short of this high standard (Adkins and Cook 2005).

Like *Wildflowers of the Smokies* (White *et al.* 2003), *An Instant Guide to Trees* (Lawrence and Fitzsimons 1999) uses coloured bands, here supplemented with symbols, to divide its species into easy to recognize groups. The coloured bands are used at the top of each page to allow the user to quickly distinguish between types of trees. Broadleaved trees are identified by green bands, conifers by blue bands, palms by orange bands and other species by grey bands. Included with the bands is a leaf symbol, denoting the leaf type of the species in each category. Simple, compound, needle-like leaves, etc. are indicated by symbols. For example, if the user has an unknown that is a broadleaved tree with compound leaves, he or she can quickly flip to the green banded pages with the compound leaf symbol at the top. Once in the correct section, the user must resort to a visual search to identify the unknown. This simple use of iconic symbols to index the species is expanded in other guides, reaching a high plateau in the *Field Guide* series and in the *Flora Helvetica* CD, both discussed below. Like coloured marginal bands, iconic symbols can provide important assistance in navigating a guide. Our third Best Practice relates to the use of iconic symbols (Table 1).

Weeds of the South and *Weeds of the Midwestern United States and Central Canada* (Bryson and DeFelice 2009; Bryson *et al.* 2010) are related guides with a similar organization to the other books discussed in this section. These guides contain simple illustrated glossaries, and group species descriptions by family. Although they contain traditional text-based dichotomous keys to the families, these keys will only be useful to experts. Most users will have to resort to a visual search to identify an unknown. The species description pages of these weed guides contain technical descriptions of the plants and multiple, often standardized photographs of each species (Table 1: Best Practice 4), including a seedling photograph. The use of standardized photographs allows easy comparison among similar parts, and aids species identification. The use of standardized photographs has been suggested as a method of documenting species occurrence, and has been linked to the documentation of morphological character states for phylogenetic analysis (Ramirez *et al.* 2007; Baskauf and Kirchoff 2008).

The National Audubon Society Field Guide to North American Wildflowers, Eastern Region (Niering *et al.* 1995) provides a variation on the type of guide that lacks a key. In this guide, as in

all Audubon Society guides of its age, species photographs are grouped into a single section at the centre of the book. This pattern of grouping the colour photographs is also found in the *Jepson Desert Manual* (Baldwin *et al.* 2002) and *The Field Guide to the Orchids of Costa Rica and Panama* (Dressler 1993), both technical guides that contain keys. In the Audubon guide, page numbers linking the photographs and written descriptions are given in both locations to assist the user in connecting the two. Printed beneath each photograph are the page number of the species description, the common name of the plant, its typical height, and the dimensions of the flower. Popular guides that follow this pattern include few, if any, illustrations in their descriptive sections. Because all photographs are grouped into one section, the publisher is able to print the text in less expensive black and white, while providing high-quality colour photographs on glossy paper in the image section. This technique saves on printing costs, and allows the user to remove the photographs (at the cost of severely damaging the book) for ease of use in the field (Stevenson *et al.* 2003). Although it saves money, grouping the photographs removes important information from the species description section, and makes the guide more difficult to use.

Printed guides available for download. With the advent of the internet and inexpensive colour printers, it has become possible to produce low-cost specialty guides and distribute them at no charge over the internet. Guides of this sort are designed to be printed, not used on-line. The *Rapid Color Guides* and *Chicago Wilderness Guides* are visual identification guides of this sort. Both are produced by the Field Museum of Natural History in Chicago. These guides range from simple two-page identification guides (Foster *et al.* 1998, 2003) to a 140-page key and guide to the damselflies of Cook and surrounding counties (Garrison 2010). The *Rapid Color Guide* series contains 224 guides to tropical plants, and 72 to tropical animals (mammals, fish, amphibians and reptiles, insects, scorpions, mollusks, birds). The *Chicago Wilderness Guide* series includes two guides to plants (sedges, shrubs), and six to animals of the Chicago region (amphibians and reptiles, mussels, fish, Odonata, damselflies). Both series are in full colour, and can be downloaded in pdf format for printing and laminating. The laminated guides are meant to be carried and used in the field.

The structure of these guides varies tremendously. At one end are guides such as *Conspicuous Plants of the Understory* (Foster *et al.* 1998) that contain only a single image of each species, have no key or glossary, and cover only the most common species. These guides are similar to the commercial laminated field cards produced by Mountaineers Books (MacGowan 1995). Some of the slightly more elaborate guides contain multiple images per species, but still lack a key and glossary (Farínaccio and Mello-sSilva 2007). At the opposite extreme is *Damselflies of Chicagoland: A Photo Field Guide* (Garrison 2010), a tripartite guide that makes innovative use of images. This guide is discussed more fully in the section on the innovative use of images.

Intermediate between these extremes are guides that have multiple images per species, group the species by similarity, provide a key to the similarity groups and have an index (Balaban *et al.* 2007; Kluse *et al.* 2008). For instance, *Sedges (Carex spp.) of the Chicago Region* (Balaban *et al.* 2007) uses a visual key to species groups similar to that in *Insects: Their Natural History and Diversity* (Marshall 2006), discussed below.

Image use in guides with illustrated identification keys

An important use of images in field guides is as a supplement to the identification keys. Some of the most usable guides of this type include illustrations in their keys to aid in distinguishing between the character state choices. The use of illustrations makes the characters and character state definitions easier to understand. Some guides that provide this type of illustrated key include *Field Guide to the Orchids of Costa Rica and Panama* (Dressler 1993), *Field Guide to Native Oak Species of Eastern North America* (Stein *et al.* 2003), *Insects: Their Natural History and Diversity* (Marshall 2006) and *A Field Guide to Western Reptiles and Amphibians* (Stebbins 1985).

The *Field Guide to the Orchids of Costa Rica and Panama* (Dressler 1993) includes an introduction with a small number of black and white illustrations, and a number of illustrated keys (Fig. 2). Most illustrated couplets show both alternative states; however, not all couplets, or even all keys, are illustrated. The fact that the states are illustrated with only a single drawing is a slight drawback, but space constraints likely made it impossible to show more than one drawing per state. Another slight drawback is that the illustrations only rarely include indications of the part of the drawing on which to focus (Table 1: Best Practice 1c). They therefore may be confusing for inexperienced users. Despite these minor drawbacks, the inclusion of illustrations makes the keys much easier to use, and is a significant advance over solely text-based keys.

The *Field Guide to Native Oak Species of Eastern North America* (Stein *et al.* 2003) also uses images within its leaf keys, as well as in an illustrated reference guide to leaf structure at the back of the guide. This guide follows the tripartite format and provides multiple colour photographs of each species in its species descriptions (Table 1: Best Practice 1a). Line drawings of leaves and leaf silhouettes are provided in most couplets of the key, as well as at the end of each path (Table 1: Best Practice 1c). For example, within the Red Oak key one of the couplets differentiates between ‘leaf blade widest beyond midleaf’ and ‘leaf blade widest at or below midleaf’. Alongside the couplet are two leaf silhouettes, one of a leaf with its broadest section beyond midleaf, and one of a leaf with its broadest section below midleaf. Including these simple, non-detailed silhouettes allows the user to quickly understand the terms and apply them to his or her specimen. Although arrows are not used to indicate a specific part of the image (Table 1: Best Practice 1c), the need for these indicators is obviated by the visual guide to leaf terms that immediately precedes the key. Although the use of multiple illustrations per character state would have improved the key even more (Table 1: Best Practice 1c), lack of space on the page makes the inclusion of multiple images problematical.

A second notable aspect of the *Field Guide to Native Oak Species* is the inclusion of the leaf reference guide at the back of the book (Stein *et al.* 2003). The charts in this section are groupings of the black and white leaf illustrations from the descriptive section, printed with the scientific name of the species and the page number where the images are found. The charts are divided into red and white oak species, and then further divided by the localities where the species commonly occur. The charts are useful because they show interspecific variation in oak leaves at a glance (Table 1: Best Practice 1). The charts do not, however, provide a sufficient number of images to account for intraspecific variation, an important consideration when identifying oaks.

Insects: Their Natural History and Diversity (Marshall 2006) is a zoological guide with illustrated, graph-like keys (Fig. 3). Like many insect guides, *Insects* is broad in its coverage and does not include species keys or descriptions. It does, however, have family descriptions that include multiple high-quality colour photographs of many of the species (Table 1: Best Practice 1a). Including multiple photographs for each family allows the user to form a better concept of the family than if only a single illustration were provided. Twenty-seven graphical family keys are included at the back of *Insects*, broken down by order and stage (adult vs. nymph; Fig. 3). Each key ends with a family name and the page number of the family description and illustrations. Black and white drawings are used to illustrate some character states, and the specific aspects of the drawing to which the state refers are sometimes indicated by labels (Fig. 3). The use of arrows aids the user by allowing a quick understanding of what the drawing is intended to show (Table 1: Best Practice 1c). However, the alternative state is only occasionally illustrated, leaving its structure to the user's imagination.

INNOVATIVE USES OF IMAGES IN FIELD GUIDES

The field guides discussed in this section are idiosyncratic both in their organization and their use of images. Although they all provide excellent examples of one or more best practice, they may violate others. In the following sections we review three types of innovative guides, pointing out their best practices.

Nature Study Guild's 'Finder' series

We will focus on three titles within the Nature Study Guild's Finder series: *Fern Finder* (Hallowell and Hallowell 2001), *Winter Weed Finder* (Miller 1989) and *Tree Finder* (Watts 1991). Other titles in the series have similar features. These pocket-sized guides utilize monochrome illustrations in both a common manner (distribution maps, an illustrated glossary, keys) and in an innovative way through use of iconic symbols. Each guide consists only of a short introduction/glossary, an identification key and an alphabetical index. There are no species descriptions. The decision to omit descriptive sections was most likely made to keep the finders small; they fit perfectly into a back pocket for easy portability in the field. The glossaries are compact and rely more on illustrations than written description to define terms. At the end of each path through a key, the user is provided with the common name, scientific name and a single illustration of the species.

The common use of images in the Nature Guides will be illustrated with several examples. The *Fern Finder* provides glossary illustrations that show the parts of a fern, the different frond shapes, frond divisions, blade margins, plant growth forms, as well as 'other features' (Hallowell and Hallowell 2001). The illustrations are not detailed, and only one illustration is provided for each term. The use of a single diagrammatic illustration works well for users who are already familiar with the term, but is unlikely to provide sufficient information to allow a novice to understand the term for the first time. For example, it would have been useful, though less compact, if *Winter Weed Finder* (Miller 1989) had provided several illustrations of opposite branching, to reduce the risk of misidentifying the condition. *Tree Finder* (Watts 1991) addresses this problem in some of its definitions by including several drawings of the character state. For instance, in explaining variability in tree shape due to life stage, drawings are provided for modifications by wind, people and 'other forces'. Drawings of leaf shape variants are also included.

A unique and innovative aspect of the Guides, especially of *Fern Finder* (Hallowell and Hallowell 2001) and *Tree Finder* (Watts 1991), is the use of iconic symbols in their keys (Table 1: Best Practice 3). The keys themselves follow the usual dichotomous (sometimes trichotomous) format. The user chooses between two or three options and follows the page numbers to the next choice. What these guides have done differently is to include stylized, iconic symbols of the character states alongside the page numbers (Fig. 4A). For instance, the presence of a continuous marginal line of sori is illustrated by a closed circle, while interrupted marginal sori are illustrated by a broken circle (Fig. 4A). The symbols, along with the page number of the previous couplet, are used to prefix the next dichotomy (Fig. 4A). The page numbers tell the user on which page the next couplet occurs, while the symbols allow the user to quickly focus on the appropriate couplet on that page. This use of symbols conveys information in a compact format, and allows the user to quickly navigate the key.

In both the *Fern* and *Tree Finder*, icon-like symbols are also used to convey habitat information (Watts 1991; Hallowell and Hallowell 2001). *Fern Finder* extends this practice by conveying information about wet or dry habitats through the inclusion of a 'W' or 'D' beside the symbols (Fig. 4B). The habitat symbols are used at the end of each path through the key, along with a drawing of the species (usually of a leaf), and a map of its geographic distribution (Fig. 4A). A species that occurs in more than one habitat is provided with symbols for each habitat (Fig. 4B). *Winter Weed Finder* (Miller 1989) does not use the symbol system found in the other guides, but does provide multiple illustrations of character states in the first several couplets (Table 1: Best Practice 1c).

Damselflies of Chicagoland: a photo field guide

Damselflies of Chicagoland (Garrison 2010) is a book-length guide that is part of the *Chicago Wilderness Guide* series. It contains an introduction/glossary, basic keys to groups, species description pages and an index. Although it makes good use of beautiful, usually standardized, photographs in its species descriptions and glossary (Table 1: Best Practice 4), its most innovative use of images is in the coloured marginal bands on each page (Fig. 5). Different bands are placed on the margins of facing pages in the species description section of the guide (Table 1: Best Practice 2). The coloured band on the left page shows the months when the species is found in its adult form. The band at the upper right on the facing page is a scale bar. When printed at full size on 8.5 × 11 paper, the solid and hashed bands represent the minimum and maximum body sizes of the species (Fig. 5; Table 1: Best Practice 5). The author has, in effect, placed a ruler on every page, but unlike normal rulers each of the scales is tailored to the size of a specific species (Table 1: Best Practice 5b). Use of these size markers makes it easy to determine if the unknown is within the expected size range of that species. Finally, the coloured triangle at the bottom right of the right page indicates to which group the species belongs. Although keys are provided only to the main groups, not to the species, the information in the marginal bands makes identifying an unknown much easier.

Flora Da Reserva Ducke

The *Flora Da Reserva Ducke* (Ribeiro *et al.* 1999) follows a traditional tripartite format, but relies heavily on coloured illustrations, mainly photographs, both in its glossary and in the family descriptions. The guide is innovative not only in its use of images, but also in the structure and

mechanism used to identify species. Although we will focus mainly on the use of images, some details of the identification methods will be presented where they impact image use. Anyone who is preparing a field guide would be well advised to study the methods used in this flora.

The *Flora* is arranged in a modified tripartite format consisting of five sections: an introduction/glossary, a short guide to families (Diagramas de família, pp. 85–93), a descriptive section that incorporates a rapid guide to species identification and an innovative key, and an alphabetical index. All photographs in the *Flora* are in colour, and highly detailed. Many of them are standardized (Table 1: Best Practice 4).

The introduction and glossary use large numbers of illustrations to describe characters and character states. Characters such as petiole structure, leaf shape and root type are all introduced with multiple images (Table 1: Best Practice 1b), as well as verbal descriptions. The character states are given descriptive titles (e.g. lenticels in vertical lines) and are described in short paragraphs elucidating their distribution (e.g. occurs in various families) and variations (e.g. associated with fissures in the bark). Each state is illustrated with multiple images, usually photographs. For instance, the character ‘lenticel distribution’ is divided into three character states: dispersed (17 photographs), in horizontal lines (11 photographs) and in vertical lines (11 photographs). The use of multiple images accounts for variation in each state and allows the user to form an accurate concept of the character (Table 1: Best Practice 1). The use of this number of images is unprecedented in print or electronic guides, and is one of the great strengths of the *Flora*.

Although most characters are illustrated with multiple images, there are notable exceptions. The characters and character states associated with leaf shape are illustrated with only a single image each (occasionally two). Although photographs are used, it is still very difficult to distinguish some of the character states based on the limited number of images. For instance, it is virtually impossible to distinguish elliptical from oblong leaves based on the four images that are provided (Ribeiro *et al.* 1999). The photographs suggest that the difference is in the form of the apex, but more images would be necessary for the user to be able to easily distinguish these shapes in the field.

In addition to illustrated definitions, the glossary contains two plates showing the distribution of compound leaf types in the covered families (Fig. 6). Multiple images are used for each character state, one image per family (Table 1: Best Practice 1b). The images have been placed on a standard white background so that the user's focus is not distracted by the background (Table 1: Best Practice 4a). The use of non-distracting backgrounds is essential in complex plates of this type. These plates serve both as introductions to character state variation, and as guides to family identification. They contribute to both the glossary and key. Using them the user can quickly identify a family with compound leaves (Fig. 6). A similar plate organization is used in the Diagramas de família (pp. 85–93), but without the extensive use of images that characterizes the compound leaf plates. The same hierarchical organization is used again in some of the more complex family guides, where images are grouped into hierarchical character states (Fig. 7). These guides serve as introductions to the characteristics of the family, as well as partial keys. For each family, multiple photographs of common characteristics, such as flowers, fruits and

inflorescences, are given in a format (Fig. 7) that prefigured the junior author's work on character cladograms (Kirchoff *et al.* 2007).

The species section of the *Flora* serves both a descriptive function and as the final step in the keys (not covered here). The images in this section are standardized and highly detailed (Table 1: Best Practice 4). Some are so small (1 cm square) that they can be difficult to see, but most still provide useful information (Fig. 8). The use of standardized images allows quick and accurate comparisons among species (Baskauf and Kirchoff 2008). For each species, a group of 4–8 photographs of leaves, stems, buds and other characteristic features is provided (Fig. 8). The number of photographs is generally constant within a family, but varies among families. Within a family the photographs have a uniform organization, so that the user can quickly compare species (Fig. 8; Table 1: Best Practice 4b). Although only one photograph of each character is given per species, the fact that the same photographs are available for every species mitigates the problems that this might otherwise cause. The photographs provide an easy means of assessing interspecific variation.

The final image innovation of this remarkable guide concerns the use of coloured marginal bands (Table 1: Best Practice 2) similar to those used in *Wildflowers of the Smokies* (White *et al.* 2003) and *An Instant Guide to Trees* (Lawrence and Fitzsimons 1999). However, unlike these simple guides, the *Flora* uses a complex system of colour-coded bands to provide a character index, and a rapid guide to species. A series of coloured marginal bands are located on the right margin of each page (Fig. 8). The vertical position of a band identifies the character, while its colour indicates the character state. Taxa with the most frequent state receive a white band. The other states are represented by other colours. The size of the band indicates the number of species that have that state. An index page summarizes the meaning of the bands (Ribeiro *et al.* 1999, p. 95). The book's contents can be folded (with some difficulty) so that the index page lies adjacent to a page margin, and the characters identified.

Overall the *Flora Da Reserva Ducke* is the most exciting and innovative field guide that has come to our attention. Its excellent use of multiple high-quality photographs and its innovative mechanism of species identification set a very high standard. It is the only printed guide of which we are aware that uses multiple images to illustrate interspecific variation in character states. Its production was an impressive achievement.

IMAGE USE IN INTERACTIVE IDENTIFICATION GUIDES

Although identification guides have traditionally been printed, advances in computer and hand-held technology have allowed the development of interactive identification keys (Edwards and Morse 1995; Jarvie and Stevens 1998; Stevenson *et al.* 2003; Gaston and O'Neill 2004; Kress 2004; Brach and Song 2005; Calvo-Flores *et al.* 2006; Farr 2006; Morris *et al.* 2007). The computer's ability to store and quickly access high-quality images has been influential in the transition from written to electronic keys (Lyons *et al.* 2006a, b). With this ability comes the possibility of creating keys that include many more images than paper keys, which are constrained by printing costs. Electronic delivery also makes it possible to change the scale at which images are displayed. Small images can be quickly displayed, and then enlarged on a separate screen so that their details can easily be seen (Table 1: Best Practice 4d).

In this section we consider how images are used in interactive identification guides. We first look briefly at guides that are beginning to appear on hand-held devices such as the iPhone. Although these guides are still in their infancy, their easy portability gives them enormous potential (Kress 2004). Although a full review of hand-held guides, or even of image use in these guides, is beyond the scope of this paper, we look briefly at how the developers of some of the more common hand-held guides present their products.

Guides on hand-held devices

With the number of iPhone applications at 300 000 and growing (Apple 2010) and no comprehensive index available, it is almost impossible to accurately estimate the number of species identification guides that are available for the iPhone, to say nothing of the Android OS. Searches of the iPhone Store and Android Market resulted in a list of over 102 identification apps by 18 developers (Table 2). There are seven developers with a single app, leaving 11 responsible for the remaining 95 apps (Table 2). The pattern for most developers seems to be to create a single application environment and fill it with varying content. For instance, apps within the Falcon Guides Scats and Tracks series, the Peterson Field Guide series, and the Audubon Guides series differ only in their content, not the basic layout or operation of the apps (Wildsight Productions 2008–2009; Green Mountain Digital 2010; Natural Guides LLC 2010a). When apps are based on printed guides, they appear to function mainly as electronic books with their content mirroring that of the printed versions, and with only rudimentary search/keying functions (Green Mountain Digital 2010; Natural Guides LLC 2010a). Some stand-alone guides are merely collections of images with no search function or index (Hunter 2008). The ability to easily deliver multiple images per species, and to allow the images to be enlarged, appears unevenly implemented across the apps. Most guides seem to have relatively simple search functions, although some of the singleton guides appear to approach multiple access keys in their operation (AVAI Ventures 2010). A good example is HoliMoli! Media's Florafolio (HoliMoli! Media 2010). Florafolio provides an icon-driven interface through which users can search by flower colour, leaf shape, autumn foliage colour and other attributes. Searches are hierarchically arranged so that the app functions as a true key. HoliMoli! Media claims that this search engine is 'best in class', and our brief review of the existing apps found nothing to contradict this claim. However, if we enlarge our scope to cover the computer-based tools discussed below, better search engines do certainly exist.

Computer-based guides

Although the number of computer-based guides has been increasing steadily over the past few years, no standard presentation format has emerged. Each guide is unique in presentation mode, and thus in its use of images. For these reasons we consider each guide individually, and present more detail on their operation than we did in previous sections.

Virginia Tech Weed Identification Guide. The *Virginia Tech Weed Identification Guide* (Bradley and Hagood 2001) provides a good example of the common use of images in a computer-based identification key. The *VT Weed Guide* provides a key to weedy grasses, a species descriptive section that includes both grasses and broadleaf weeds, and an alphabetized index hyperlinked to the descriptive section. The alphabetized index is linked from a sidebar on the first page, allowing the user quick access to the descriptive pages. The species descriptions provide character-by-character written descriptions, accompanied by colour photographs

Table 2: A partial list of identification guides for hand-held devices as of December 2010.

The list was assembled from searches of the iPhone Store, Android Market and web searches for the best nature apps. Most listed programs are for the iPhone, although some are also available for the Android OS. Code Slinger programs are only available on the Android.

Developer	Name of Guide	Citation
AVAI Ventures, Inc. Christoph Duyster	Botany Buddy Dogs Horses Identify Tree Mammals Snakes	AVAI Ventures (2010) Duyster (2010)
Code Slinger	North American Birds	Code Slinger (2010)
Cool Ideas LLC	North American Fish Guide British Wildlife eGuide Collins Bird eGuide e.Frogs e.Mammals e.Snakes e.Wildlife e.Trees of Southern Africa Michael Morcombe eGuide to the Birds of Australia Neville Coleman's Marine Life eGuide Sasol e.Birds of Southern Africa Sibley Birds of North America Tracks and Signs	Cool Ideas LLC (2010)
Green Mountain Digital	Audubon Birds Audubon Birds and Butterflies Audubon Birds California Audubon Birds Central Park Audubon Birds Florida Audubon Birds Mid Atlantic Audubon Birds New England Audubon Birds Southwest Audubon Birds Texas Audubon Butterflies Audubon Fishes Audubon Insects and Spiders Audubon Mammals Audubon Mushrooms Audubon Nature California Audubon Nature Desert Southwest Audubon Nature Florida Audubon Nature New England Audubon Nature Pacific Northwest Audubon Nature Texas Audubon Owls Audubon Reptiles and Amphibians Audubon Trees Audubon Wildflowers	Green Mountain Digital (2010)
HoliMoli! Media Hunter Research & Technology Isoperla Ltd	Florafolio-Native plants of the Northeast Butterfly Collection FishID HerptileId TreeID WinterTreeID	HoliMoli! Media (2010) Hunter (2008) Isoperla Ltd (2010)
Jeff Schloemer	Animals of North America Fishes of the World Flowers of Eastern North America Flowers of Europe and Asia Mammals of Africa Mammals of North America Reptiles of the World Shrubs and Vines of North America Trees Trees of North America	Schloemer (2010)
Levitate LLC	Animals Birds! Bugs	Levitate LLC (2010)

	Butterflies	
	Fish	
	Flowers	
	Frogs & Friends	
	Horses	
	Lizards	
	Reptiles	
	Sea Creatures	
	Shells	
	Tropical Birds	
	Turtles	
MEDL Mobile, Inc.	FishID	MEDL Mobile (2010)
	TreeID	
Mitch Waite Group	iBird (various versions)	Mitch Waite Group (2010)
MyNature Inc.	MyNature Tree Guide	MyNature Inc. (2010)
Natural Guides, LLC	Birds	Natural Guides LLC (2010a)
	Local Birds of Northern California	
	Local Birds of Southern California	
Natural Guides, LLC	Scats and Tracks of Alaska	Natural Guides LLC (2010b)
	Scats and Tracks of Backyard	
	Scats and Tracks of Desert Southwest	
	Scats and Tracks of Great Lakes	
	Scats and Tracks of Great Plains	
	Scats and Tracks of Mid-Atlantic	
	Scats and Tracks of Midwest	
	Scats and Tracks of North America	
	Scats and Tracks of Northeast	
	Scats and Tracks of Pacific Coast	
	Scats and Tracks of Rocky Mountains	
	Scats and Tracks of Southeast	
Natural Guides, LLC	Birds	Mezak (2009)
pullUin Software	National Geographic's Handheld Birds	pullUin Software (2010)
Rogers Plants Ltd.	Wild Mushroom of North America and Europe	Bryam (2010)
Tony Valois	SMM WildFlowers (Santa Monica Mountains Wild Flowers)	Valois (2010)
Wildsight Productions	Peterson Field Guide to Backyard Birds	Wildsight Productions (2008-2009)
	Peterson Field Guide to Birds of Prey	
	Peterson Field Guide to Warblers	
	Peterson Field Guide to Backyard Birds	
	Peterson Field Guide to Birds of Prey	
	Peterson Field Guide to Warblers	

detailing various aspects of the plant. The photographs are sufficiently large to be easily seen, but cannot be enlarged. Even though multiple photographs are used, the primary emphasis is on the written descriptions, a common practice in printed identification guides.

The grass identification key in the *VT Weed Guide* provides several entry points for identifying an unknown. The more traditional method proceeds through the choice of alternative character states from a series of drop-down lists (Fig. 9). The second method functions more like a multiple access key, allowing the user to choose where to begin. The two methods can be combined so that a user can begin in the traditional manner and then jump to the multiple access portion of the key to choose other characters, or modify those he or she has already chosen. The user can also display the remaining species at any point to see a list of species that meet the previously selected criteria. These features allow the user a good deal of control over the identification process. Once he or she has arrived at a tentative identification, he or she is able to quickly jump to the descriptive page to check the identification.

Many steps in the key are supplemented with images that help the user understand the character states (Fig. 9; Table 1: Best Practice 1c). However, not all character states are illustrated, and no images are provided for some characters. The images that are present cannot be enlarged. These deficiencies make the key a bit more difficult to use than if a richer set of illustrations were

provided. A novice user must search for other sources of information if he or she does not understand a character.

Virginia Tech twig and leaf keys. The *VTree ID* pages (Seiler and Peterson 1998–2010) offer three different identification keys: a dichotomous leaf key, a dichotomous twig key and a multichotomous tree key. All three keys utilize images, as do the species descriptive pages.

The multichotomous tree key provides a series of questions for the user to answer, most of which are accompanied by small, thumbnail-size photographs. One photograph is, in general, provided for each character state, which accounts for variability in the character, but not the character state (Table 1: Best Practice 1c). The photographs are small to the point of being difficult to see, and cannot be enlarged.

The key begins by asking the user to specify the state, or planting zone of the unknown. A link provides information on zones from the US National Arboretum, including a zone map (Cathey and Jordan 2001). Like all choices in the key, these can be left blank. Other characters include growth habit/size, habitat, fruit type, flower colour and leaf type. Depending on which leaf type is selected, the user may also be provided with characters of conifer or broadleaf leaves, broadleaf leaf arrangement or broadleaf twigs. Once the user has selected the characteristics of the specimen, he or she is provided with a list of all selected characters and a list of possible species matches, if any. The user can then modify any character state from a drop-down list adjacent to the character name. Once a tentative identification has been reached, he or she can click on the species name and be directed to the species description page. This page provides general information on the plant as well as a plate of standardized photographs showing the fruit, bark, leaf, etc. (Table 1: Best Practice 4b). There is one photograph of each part. A set of links to similar species is also provided. The plates are very useful in helping the user confirm the identity of his or her specimen, although there are too few photographs to show variation, and they cannot be enlarged.

The dichotomous leaf and twig keys are very similar in format, as well as in their use of images. As in the multichotomous key, the user begins by specifying the state or planting zone. The introductory page also provides a brief illustrated glossary of common terms in the form of a labelled photograph with arrows illustrating the relevant parts of the illustration (Fig. 10). These visual glossaries are quick and easy ways for users to become familiar with the necessary terms, although they do not show variation in the characters. This shortcoming is partially compensated by the inclusion of photographs in every couplet, as described below (Table 1: Best Practice 1c). These photo-glossaries are comparable to the illustrated introductions/glossaries found in many written keys, though they are less detailed.

Each step of the dichotomous (occasionally trichotomous) keys provides photographs of the alternate character states (Table 1: Best Practice 1c). Multiple photographs are only occasionally provided, but the photographs are large enough to be easily seen. Clicking on an image does not enlarge it, but takes the user to the descriptive page for that species. For instance, clicking on the image of *Thuja occidentalis* used to distinguish scale from needle-like leaves takes one to the species page for northern white-cedar. While interesting, this is unlikely to be useful to a novice user who would be better served by seeing more variation in the character states. The use of

images in each couplet overcomes some of the limitations of the glossary, as the user is able to see two additional character state variants for each character.

As the user works through the key, two lists are provided: one showing all previously selected characteristics (at the top of the page) and one showing species that match the list of selected characteristics (at the bottom). The list of selected characters allows the user to jump back to a particular point in the key and change a selection. The list of possible matches tells him or her how close he or she is to a final identification. Unfortunately, the key does not always allow a user to narrow the list to a single species. Instead, he or she must often browse through a set of species pages to decide which species matches his or her specimen. The fact that the species pages are well illustrated makes this a more tractable process (Table 1: Best Practice 1a).

Woody Plants in North America. *Woody Plants in North America* (Seiler *et al.* 2006) is a companion guide to the *VTree ID* pages (Seiler and Peterson 1998–2010), on three CD-ROMs. Its structure does not, however, repeat that of the web pages. The CDs include four sections: morphology, quiz, angiosperms and gymnosperms. The morphology section describes basic tree structure with textual descriptions and photographs that illustrate common botanical terms. This section is equivalent to the illustrated introduction/glossary of printed guides but, because the material is delivered digitally, *Woody Plants* is able to provide a colour photograph or drawing to illustrate each term (Seiler *et al.* 2006). Coloured arrows, circles and squares are used in the drawings to reduce ambiguity (Table 1: Best Practice 1b). This interactive guide does not include an identification key, but it does include a link to the three keys found on the *VTree ID* pages (Seiler and Peterson 1998–2010).

The quiz section of *Woody Plants* (Seiler *et al.* 2006) provides species identification quizzes. The user specifies whether he or she wishes to be quizzed on angiosperms or gymnosperms, and may narrow the range of the quiz to only include specific families. Each quiz provides a photograph of a plant for the user to identify by typing the common and scientific names. If the user is unsure of a name, he or she may request more clues in the form of additional photographs. The quizzes are a great learning tool, and an important addition to the program.

The angiosperm and gymnosperm sections contain species descriptions. The user can find species by selecting the appropriate family, genus and species from successive menus or by selecting a state, hardiness zone, or species name (via a search function). Each species page is illustrated with numerous high-quality photographs that are displayed one at a time in a special window (Fig. 11). Clicking one of the icons at the right of the screen changes the type of image displayed. Multiple images are usually available for each category (Table 1: Best Practice 1a). The categories are leaf, flower, fruit, twig, bark, form, look-a-likes and distribution map. The look-a-likes category provides images of similar species that could easily be confused. The inclusion of these look-a-likes is an important feature that is missing from most guides. The fact that all species are illustrated with multiple photographs makes distinguishing among similar species relatively easy.

Fish Identification Database. The University of Wisconsin's *Fish Identification Database* (Lyons *et al.* 2006a, b) is a well-designed computer-aided fish identification tool that relies heavily on images, and uses little written description. Its species key illustrates some of the best

image use that we have found in any guide. The site has two main components: a taxonomic key and a multiple access query system. The taxonomic key is divided into two dichotomous sections: one for families and one for species. The user first identifies the family of his or her unknown and then uses this information as the first step in the species key. At each step of the species key, the user is given a pair of opposing character states to choose between. Multiple photographs are provided for each state (Table 1: Best Practice 1c). The photographs are sometimes labelled (Table 1: Best Practice 1c), and can be enlarged (Table 1: Best Practice 4d). Mousing over an image pops up a reminder of this fact. Written character state descriptions are given in a side panel, while the main part of the screen is occupied by the photographs (Fig. 12A). The text not only describes the character states, but highlights the character state variability shown in the photographs. The inclusion of multiple photographs illustrating this variability is very helpful, especially for novice users (Table 1: Best Practice 1c). As we have seen, most identification guides do not include multiple images of character states. The photographs are generally such clear illustrations of the alternative states that the written descriptions will likely serve a subsidiary role for most users. However, their inclusion allows users to check their understanding of the images, and provides a guide to the variability illustrated in the images. They are important additions to the key.

Once the user has narrowed his or her search to a specific species, the key leads to a page with multiple images of the species, and links to all of the images of the species in the database (Table 1: Best Practice 1a). Links to a written description of the species, and to a tabular comparison with similar species, are also included. The images on the main species pages are presented in categories: adult views, other views, body, fins, distinguishing characteristics, breeding adults, juveniles and hybrids. This is a form of standardized plate construction, adapted to the web (Table 1: Best Practice 4b). Multiple images are accessible in each category, providing the user greater access to species variability (Table 1: Best Practice 1a).

The table of similar species is text based, without any images, but includes a qualitative similarity index that helps users evaluate the degree of similarity (similar, very similar, etc.). Although useful, the table would have been even better had it included links to comparative images of the similar species. For instance, knowing that the 'maximum [sucker] disk diameter relative to maximum body diameter in adults' is less for the American Brook Lamprey than the Chestnut Lamprey only provides the user with useful information if he or she knows what each fish looks like. A link to a side-by-side comparison of standardized photographs of each character would easily solve this problem.

The query system in the guide differs from the taxonomic key in that it is multi-access, and provides the user with a continually updated list of species that match the chosen character states. The user begins by selecting a character from a list that includes snout shape, spines, tail shape, body shape, body patterning, distinctive features, and family (Fig. 12B). When a character is selected, a list of possible character states appears in a lower left side window, along with a photograph of the state (Table 1: Best Practice 1c). Clicking on either the state name or the image selects the state and adds it to the list of identification criteria. Unfortunately, there is no way to enlarge the images, or get more information on the states. As states are selected, a list of possible identities is updated and displayed in a frame on the right side of the window. The fact that the states are described in only a few words and with only a single photograph creates some

problems. For instance, the image of the state 'no spines' can appear, to a novice, to show a fish with spines (if he or she mistakes the dorsal fin for spines). Pop-up windows that provide more information on each state would easily solve this problem.

With its emphasis on images over text, the use of multiple images for each character state, and the inclusion of multiple standardized images on the species description pages, the *Fish Identification Database* is unique among the on-line keys that we reviewed. We would like to see more experiments along these lines.

Digital Atlas of Idaho & Keys to Nature Project. The *Digital Atlas of Idaho* (Link *et al.* 2001) is a web-based guide that covers the geology, biology, archaeology, geography and climatology of Idaho. We will focus on this site's coverage of the biology of the state, with special emphasis on the visual key to dragonflies & damselflies. The site's biology section is divided into Insects, Amphibians, Reptiles, Birds, Mammals and Plants. Unfortunately for our purposes, there are no keys to most of the groups in this section.

The plant section of the website is typical in its organization, though a bit lower in quality than the other sections. It includes a basic text-based introduction to plant classification, a checklist of representative Idaho plants hyperlinked to species description pages, a bibliography, and a link to the site glossary (not plant-specific). There is also a link to a now defunct page on plant structure at plants.usda.gov. There are also sections on gymnosperms and on five subclasses of angiosperms, some of which have traditional keys. Images are only used on the species description pages, not in the keys. On the species pages a written description appears in a frame on the left, while images are displayed in a right-hand frame. Some descriptive terms are hyperlinked to images that appear on the right, providing a kind of visual glossary similar to that in the teaching tool *Woody Plants of the Southeastern United States: A Field Botany Course on CD* (Kirchoff 2008).

Other taxonomic sections of the *Digital Atlas* provide information on the evolutionary history of the groups, and some of the descriptive pages allow the user to compare species photographs side by side. Most of the taxonomic sections do not contain keys. However, the *Atlas* does provide visual keys for reptiles, amphibians, butterflies, and dragonflies & damselflies (Lung *et al.* 2001).

At the entry point of the key to dragonflies & damselflies the user is asked to make an initial choice between these two groups (Lung *et al.* 2001). Like all other choices in the key this one is primarily visual, supplemented with text (Table 1: Best Practice 1). The images are large and prominently displayed, while the text is small and easily overlooked (Fig. 13). Choosing one of these groups takes the user to a confirmation page where he or she sees a set of six images that illustrate variation in the chosen group (Table 1: Best Practice 1c). These confirmation pages, in addition to the photographs used in the first couplet, account for a good deal of the variation in the groups, and help the user form an adequate concept of the taxon.

After confirming the group, the user is led through a set of couplets until a final identification is reached. Each couplet contains both text and a photograph, with emphasis on the photograph (Fig. 13). The photographs are of high quality, and are displayed at a size that makes it easy to

see their detail, though they cannot be enlarged. The images are frequently annotated with arrows, circles or text to draw attention to the character state being described (Table 1: Best Practice 1c). However, in at least one case (thorax colour/markings) the annotation indicates the completely wrong part of the damselfly (the anal appendage). When the character states are technical (e.g. characteristics of the anal appendages), drawings are used to supplement the photographs of the alternative states (Table 1: Best Practice 4c).

The species description pages include a full description of the species, references, and at least one photograph. Photographs of both male and female specimens are sometimes shown. Some pages include photographs of specific characteristics, hyperlinked from the descriptive text described above.

The Keys to Nature Project (Alverson *et al.* 2010) uses a similar approach to organism identification, but is unique in that it allows users to construct their own illustrated keys using a series of web-based data-entry forms. All of the keys on the site are to organisms in the Chicago region, an area defined as encompassing 24 counties in four states. The following keys to plants of the Chicago region were hosted on the website as of December 2010: *Violets*, *Asclepias*, shrubs, *Anacardiaceae*, *Araceae*, *Eupatorium*, *Onagraceae*, *Trillium*, and a key to the genera *Ceanothus*, *Physocarpus* and *Ribes*.

Robert W. Freckmann Herbarium: Plants of Wisconsin. The *Plants of Wisconsin* pages on the Robert W. Freckmann Herbarium Website at the University of Wisconsin, Stevens Point provide detailed information on the natural communities, ethnobotany, vascular plants and bryophytes of Wisconsin (Black *et al.* 2003–2010). Links to information on the fungi and lichens of Wisconsin are also provided. The site is so varied in the information that it contains that not all of its features can be reviewed here. We cannot even cover all of the ways in which images are used on the site. The most notable use of images is found within the section on vascular plants, so it is there we will direct our attention.

In the vascular plants section the user may browse taxa by family, genus or common name, or search by a number of criteria including name, blooming time, county, endangered status, or ethnobotanical use. Searching by any of these criteria produces a list of matches, which may extend over many pages when broad search terms are used (such as when requesting a county list). The search results are organized by family and species, include a thumbnail photograph of the species (which cannot be enlarged) and are hyperlinked to species descriptive pages. The descriptive pages contain diagnostic descriptions, often have multiple, more or less standardized images that can be enlarged (Table 1: Best Practices 1a, 4d), and that contain links to other relevant information.

All of the family and genus pages are generated dynamically based on database queries. Selecting almost any link on the site, like selecting characters in the visual identification guides described below, generates search strings that are used to produce the pages.

Also included in the vascular plants section are identification guides to wildflowers, trees, shrubs, vines, ferns, grasses, and aquatic and semi-aquatic vascular plants. Selecting the links to most of these guides generates a database search and takes the user to a results page for taxa that

match the description (trees, shrubs, etc.). However, several of the identification guides also contain traditional written keys (trees, ferns and allies) and/or visual identification guides (wildflowers, trees, shrubs, aquatics, ferns and allies) (Black 2010a, b).

The visual identification guides provide lists of illustrated characters that allow the simultaneous, multi-access, selection of characters (Fig. 14). The characters tend to be holistic aspects of plant form (habit, inflorescence, flowers, etc.), and are divided into broadly defined character states (flowers regular, irregular, slightly irregular). The meaning of some terms (e.g. inflorescence structure, flower symmetry, leaf shape, etc.) is clarified through the use of simple, icon-like, drawings (Fig. 14; Table 1: Best Practice 3). The use of these simple drawings allows users to quickly understand the differences between character states, and makes the guides much more accessible. Novices will still have some difficulty as the illustrations do not show variation, but unlike other character state illustrations the icons are relatively easy to understand. For example, basal leaves are shown by two green ovals inserted at the base of a vertical line (Fig. 14). Even novices should be able to relate to such simple drawings. There are, of course, exceptions (the drawing for peltate leaves, Fig. 14), but on the whole the iconic nature of the drawings helps distinguish the character states.

The set of selected character states is used to generate a search string and produces an output page like those described above, with the exception that target families, not species, are listed. Clicking on a family name takes one to the list of Wisconsin genera in that family. Clicking on a generic name opens a page listing the Wisconsin species in that genus, with links to Google web and image searches for the genus. All of the family and genus web pages contain thumbnail-sized photographs, which unfortunately cannot be enlarged. One must navigate to the species pages to see multiple, enlargeable images (Table 1: Best Practice 1a).

Though not a key in a traditional sense, the *Plants of Wisconsin* pages provide good tools for plant identification. These tools are similar in conception to those available through the plants pages at CalPhotos (Biodiversity Sciences Technology Group 1995–2010) in that they provide searchable access to a database of curated live plant images, but the Wisconsin pages contain much more taxonomically relevant information and are much more flexible in their means of access.

Although images used on the site would be even better if it were possible to enlarge the thumbnails, and if multiple thumbnails were present on the family and genus pages, the use of images is of a remarkably high quality. The inclusion of links to Google image searches is a nice feature that provides the user with access to many more images than can be housed on the site.

Flora Helvetica CD-ROM. *Flora Helvetica* (Lauber and Wagner 2001) is an interactive guide to the flora of Switzerland that allows the user to search for an identification match with a multi-access key that utilizes icons in a unique way (Table 1: Best Practice 3). The CD contains French and German versions of the program, and runs only on the PC. A Mac version is not available. The multi-access key works somewhat like the search function of the *Plants of Wisconsin*, although the interface is considerably different, and characters can be added at any time during the identification process. All searches are composed by selecting options from drop-down

menus (search by family or genus), or by selecting character states through an icon-driven interface. There is no option to construct text-based searches.

Both general categories (geographic distribution, blooming time, endangered status, etc.) and detailed characteristics (flowers, fruit, leaves, stem, growth type, distribution, blooming time) can be chosen through the icon-driven interface (Fig. 15). Overlap in the categories allows the user multiple methods of selecting characters.

Each category is introduced with a coloured icon and a category name (Fig. 15). Clicking on an icon displays the subsidiary features relevant to that category. For example, selecting the leaf icon displays a choice of 11 features (on two screens), including arrangement, margin, simple leaves, compound leaves, attachment, etc., each illustrated with an icon. The relevant aspects of the icons are coloured red to indicate the part of the character that is being worked with. Feature selection is hierarchical, and continues until the final category choices are displayed (Fig. 15). The final character state is selected by double-clicking on the final icon that corresponds to the character state in the unknown. This adds the state to the character selection box on the right of the screen (Fig. 15). The path to the selected character state is indicated by red boxes drawn around the icons in the path to the final state (Fig. 15). These boxes make it easy for the user to retrace his or her steps through the character state selection process.

After all relevant character states have been selected, clicking on the search button below the selection box runs the search. The program returns a list, with one photograph per species, of all species that match the selected character states. Double-clicking on a photograph displays a synoptic description, a list of the species' character states, a distribution map and an enlargement of the photograph. Only one photograph is provided per species. Unlike other electronic guides, *Flora Helvetica* provides a place where users can add notes to the species descriptions. The notes are stored in a database file in the *Flora Helvetica* installation directory.

The use of coloured icons is a notable characteristic of *Flora Helvetica*'s key (Lauber and Wagner 2001). The icons illustrate the characters and character states and make the key easier for novice users. The use of red highlighting to indicate the relevant part of the icons is particularly useful. The consistent use of red allows the user familiar with the program to simply glance at an icon and understand its meaning, often without having to read the title of the category (Fig. 15).

XID Guides: 1200 Weeds & Miami University Dendrology Expert System. The *XID Guides* are constructed with the expert system, multiple access keying software produced by XID Services, Inc. (Pullman, WA, USA). In addition to the two guides reviewed here, the software has been used to produce keys to the flora of the northwest, California weeds, and old-world *Crataegus* (<http://xidservices.com/links/>). An XID-based key to the plant families of the world is included in the 4th edition of *Contemporary Plant Systematics* (Wodland 2009).

1200 Weeds of the 48 States & Adjacent Canada: An Interactive Identification Guide (Old 2008) uses the XID system and over 6200 images to aid in weed identification. The guide is divided into two main parts: broadleaf plants, and grass-like plants. The broadleaf key offers a total of 59 characters, grouped into nine broad categories. The categories include flowers, fruit, leaves,

stems, family, etc. The category and character lists are displayed in a left-hand frame, while character-relevant information and illustrations appear in a larger, right-hand frame (Fig. 16). When a category name is selected, general information about the category and general definitions of the characters are displayed on the right. For example, when the leaf category is selected, an illustration with illustrated definitions of leaf terms is displayed on the right (Fig. 16A). Selecting one of the characters in a category displays a list of illustrated character states in the right-hand frame. For instance, within the leaf category there are 15 characters including leaf arrangement, leaf type, stipules, tendrils, etc. (Fig. 16A). When leaf arrangement is selected, 10 character state illustrations are shown (Fig. 16B). The simultaneous display of these drawings provides a useful means for the user to compare character states side by side (Table 1: Best Practice 1c). However, only one image of each state is provided, making it difficult for the user if his or her specimen varies from the displayed image. This problem is somewhat mitigated by the frequent use of drawings, which represent typical examples much better than do single photographs (Table 1: Best Practice 4c).

Almost all character states are illustrated, some in ingenious ways (Table 1: Best Practice 1c). For instance, leaf width is illustrated with a sketch of a leaf superimposed on a standard drawing of a human hand. The hand serves as a visual reference for leaf size, which is also given in both metric and English units (Table 1: Best Practice 5).

The bottom left of the computer screen displays a list of the species specified by the selected characters. As the user works through the key and adds characters, the number of species decreases. If more than one species remains after the user has input all of his or her data, the list can be used to compare species descriptions and make a final determination. Clicking on a species name displays a well-illustrated description in the right-hand window. Each species description is accompanied by several photographs, and a distribution map. All of the images are large and easy to see, and they can also be enlarged (Table 1: Best Practice 4d). The species descriptions also include brief non-technical descriptions, a list of species-specific characters and references to the species in common printed weed guides.

The *Miami University Dendrology Expert System (MUDES, Meicenheimer 2007)* also uses the XID system, but is not as mature a product as *1200 Weeds*. A number of features are either inconsistently implemented or appear not to have been completed. For instance, the user must navigate to a subdirectory of the CD to find the xidro.exe file to launch the program. Once launched, the user must select a key/database to open. A key is not opened automatically at startup. Although a new version has been prepared (Meicenheimer 2009), it is not yet readily available. For this reason we restrict many of our comments to the 2007 release.

The CD contains keys to angiosperm and gymnosperm trees, wood, and common plant diseases (Meicenheimer 2007). It also contains a key to determine which key is appropriate for a given specimen, although if a user needs this key *MUDES* is probably not for him or her. Once open, the keys function more or less as in *1200 Weeds*. The main difference is that the character descriptions are illustrated mainly with photographs, not drawings. The photographs are well prepared and labelled, and many rival good drawings in their clarity (Table 1: Best Practices 1c). This is a rare violation of Best Practice 4c. The background of the photographs is often solid black, which allows the user to focus on the structures, not the background (Table 1: Best

Practice 4a). Photographs of this quality can surpass even professional botanical illustrations in their usefulness, as they show direct images of the plants. The photographs of leaf size are particularly good, and have been improved in the 2009 edition (Meicenheimer 2009). Also improved are the references to colour terms, which are now illustrated with graduated colour swatches (Fig. 17). Graduated swatches provide a more realistic mechanism of colour rendition than do solid colours, no matter how displayed.

The character illustrations in *MUDES* are always displayed full size, which can make them difficult to see on a 1024 × 768 pixel computer screen. As with *1200 Weeds*, only a single image of each state is provided, making it difficult for the user if his or her specimen varies from the depiction provided. This is especially problematical for the terms describing leaf bases. It would be very difficult for a novice to determine the difference between a rounded and auriculate leaf base given only the two photographs used in these descriptions.

Each species description page provides multiple, more or less standardized photographs of the plant, arranged into a single plate (Table 1: Best Practices 1a, 4). The photographs are beautifully executed and well displayed. Unfortunately, the plates are too large to be easily seen in the species description window, which cannot be enlarged to full screen.

All in all, the XID keying system is the best electronic system that we reviewed. The slight problems we have identified should be easy to remedy in future releases.

LUCID Keys: Environmental Weeds of Australia. *Environmental Weeds of Australia* is the single example of a LUCID key that we review (Navie and Adkins 2008). We choose this key out of the many available on the recommendation of the LUCID team, due to its extensive use of images. The key covers more than 1000 weeds and includes thousands of images (Navie and Adkins 2008). This program works in basically the same manner as the XID keys, but runs as a Java applet in a web browser, and has a different screen layout.

The computer screen is divided into four frames: characters available, characters chosen, weeds remaining, and weeds discarded (Fig. 18). There are nine character groups: distribution, [whole] plant, stem, leaf, flower, fruit, seed, miscellaneous, and grass characters. Each group contains multiple characters, each with several character states. For example, the fruit characters include type, colour, and size, each with multiple character states. When a character is selected the character states are displayed, along with images of each state, in the same window (Fig. 18). The images are either drawings or photographs (sometimes composites of several photographs), but both are seldom used for a single character state. The use of composite photographs allows the user to see variation in the state, and makes it easier to choose the appropriate state (Table 1: Best Practice 1c). All of the images can be enlarged (Table 1: Best Practice 4d), and a separate descriptive window with the image and text can also be opened for the more complex character states. It is often necessary to enlarge the images as their initial display is icon-sized. It can be difficult to see the illustrations at this size, and the character state descriptions, which appear below the icon-sized images, may be truncated due to the lack of space. For instance, the character state names 'once-compound leaves with two leaflets' and 'once-compound leaves with three leaflets' both appear as 'once-compound...' in the icon view. The user must enlarge the image, or open the character state description page, to see the full description.

Unfortunately, when the character description page is opened, the title of the character state is not always the same as that displayed in the ‘characters available’ frame. ‘Once-compound leaves with two leaflets’ and ‘once-compound leaves with three leaflets’ are described as ‘bifoliate’ and ‘trifoliate’ leaves, respectively, when the images are enlarged. This disparity is confusing, and unnecessary.

In general, photographs are used more effectively than diagrams to illustrate the character states. The diagrams tend to be overly simplistic and are not always good representations of the character concept. The photographs tend to be better, especially when multiple photographs are used for each state (Fig. 18). This is another rare violation of Best Practice 4c. There are, however, some problems with the use of photographs in the key. The most egregious of these is the use of the same re-coloured fruit photograph to illustrate different fruit colours. The use of the same re-coloured photograph is misleading as it causes the user to pay more attention to fruit shape than colour, the opposite of what is intended. The user finds himself or herself looking closely at the shape of the fruit to determine if it really is invariant. Contrast this use to the depiction of seed colour with, we hope, unretouched photographs of differently coloured seeds. In this case it is easier to focus on the colour because one is not distracted by the similarity of the photographs. The title of the character makes the intended focus clear.

As characters are selected, species are removed from the ‘weeds remaining’ frame, and added to the ‘weeds discarded’ frame. Species in these frames are listed alphabetically by scientific name, and include the common name, a photograph and an icon link to the species factsheet. The user has the option to show only the images with their (truncated) scientific name. This truncated display makes it easier to compare the images side by side. Clicking on an image enlarges it, while clicking on the icon link opens the species factsheet in a new window. The factsheet includes multiple images that can be enlarged (Table 1: Best Practices 1a, 4d) and details of the weed's origin, habitat, environmental impact, etc., but a standardized description is not always present. The images are of good quality, but are not standardized. The factsheets can be accessed separately from the identification key, if the user knows the name of the taxon.

Pollen Grains of South Indian Trees. We complete or survey with an innovative guide to the pollen grains of South India (Vasanthy *et al.* 2007; Vasanthy and Grard 2008). This guide is intended as a tool for expert pollen identification. It is not for use by novices. It was created with the IDAO (Logiciel d'IDentification Assistée par Ordinateur) software (Prosperi and Grard 2009) from L'Unité Mixte de Recherche, botAnique et bioinforMatique de l' Architecture des Plantes (UMR-AMAP 2007). The same software engine has been used on a number of projects throughout the developing world (CIRAD 2007). Like *Flora Helevitca*, *Pollen Grains of South Indian Trees* uses an icon-driven interface to select characters and character states (Fig. 19; Table 1: Best Practice 3).

When the program starts, the user sees several pollen diagrams with empty boxes indicating characters (Fig. 19A). Clicking on a box opens a new window that contains icons representing the character states for that character (Fig. 19B). Clicking on one of these states highlights it (Fig. 19B), and adds it to the list of selected characters on the main screen (Fig. 19A, red arrow). As characters are added, the program calculates the percentage of selected characters that match

each taxon in its database. Clicking on a results link (not shown) takes one to the list of possible identifications (Fig. 19C). Character and character state selection continues until (ideally) a single taxon with all of the selected character states remains. Clicking on any of the taxon names in the identification list (Fig. 19C, lower left frame) displays a species description window (Fig. 19C, lower right frame) with images of the pollen grains and descriptions of their morphology. The vast majority of the images are of acetolysed pollen grains (i.e. exines). Acetolysed grains are used because of their similarity to sub-fossilized pollen of the Late Quaternary sediments (Vasanthi 1988), and to surface sediment samples (Bonnefille *et al.* 1999), that contain the majority of the grains intended for identification. The images of the pollen grains can be enlarged. Each image contains a ruled scale, an important feature when working with microscopic features (Table 1: Best Practice 5c). The descriptive terms in the species description (Fig. 19C, lower right frame) are hyperlinked to glossary entries that are illustrated with the same icons as for character state selection. The glossary does not seem to be accessible other than through these hyperlinks.

Despite the many advantages of the interface, several shortcomings make the program more difficult to use than seems necessary. The icons are so stylized as to be difficult to interpret. It is often difficult to relate them to the structures visible under the light microscope. They also do not show any variation within a character state, which makes it difficult to determine which state to select when the alternative states are similar (Fig. 19B). *Flora Helevitca* avoids this problem by using icons for distinct alternative states (Lauber and Wagner 2001).

Although the hyperlinked glossary provides a useful service, the use of icons instead of photographs to illustrate the terms reduces its effectiveness. The user must mentally translate between the iconic depictions and their expression in real pollen grains. Contrast this use of icons with the excellent use of photographic images to illustrate characters in *Pollen Terminology: An Illustrated Handbook* (Hesse *et al.* 2009). Despite these shortcomings, the innovative use of the opening screen and the icon-driven interface make this an interesting and promising approach. With some modification, this type of interface should be adaptable to the creation of guides that can be used by novices.

CONCLUSIONS AND FORWARD LOOK: BEST PRACTICES IN IMAGE USE

As we have seen, the methods and quality of image use in guides vary widely. While there are strong points to image use in all of the reviewed guides, some make much better use of images than others. The *Flora da Reserva Ducke* (Ribeiro *et al.* 1999) sets a high standard both in its use of images and in its unique identification system. It offers many good ideas that deserve wider adoption. At the other end of the spectrum of image use are guides that consist only of species description pages, alphabetically arranged, with one image per page.

In general, the best guides are those that include multiple high-quality standardized colour photographs, arranged in standardized plates. Standardized arrangement makes it easy for the user to find comparable pictures of different species. There should always be at least one colour photograph, but better guides will have multiple standardized photographs of each species and character state (Dressler 1993; Seiler *et al.* 2006; Baskauf and Kirchoff 2008). If it is impossible to include multiple images, drawings prepared by a trained botanical illustrator should be used, as they are often better at showing typical examples. The excellent photographs in MUDES are

an exception to this general rule (Meicenheimer 2007, 2009). In electronic guides it should always be possible to enlarge the images so that their details can be easily seen.

Introductory sections and glossaries should be illustrated with either high-quality photographs or professionally prepared drawings. The illustrations should be labelled to clearly show their relevant features (e.g., Baldwin *et al.* 2002). Well-prepared images can often be used to illustrate several terms (e.g., Baldwin *et al.* 2002). Wherever possible, multiple illustrations should be used for each term so that the user can form an adequate concept of the variation he or she is likely to encounter (Wisniewski 2002). Restrictions on the number of images used should be less of a problem for electronic than for printed guides.

In addition to being taken in a standardized manner, photographs should be composed so that the background does not distract from the image. The best quality images always take the background into account, either by placing the objects of interest on a solid colour (e.g., Meicenheimer 2007, 2009) or by composing the picture so that the diagnostic features fill the whole field (e.g., Adkins *et al.* 1999). Although the latter approach does not lend itself to standardization, an exceptional photographer can, with this method, compose images of such high quality that the benefits of standardization are partially nullified.

Characters and character states should also be illustrated with multiple images per state (e.g., Ribeiro *et al.* 1999; Old 2008). Achieving this goal will be difficult in printed guides, but at least one illustration per state should be included even in these guides (e.g., Dressler 1993; Ribeiro *et al.* 1999). As in glossaries, the images should be labelled to direct the user's eye to the relevant features (e.g., Lung *et al.* 2001). This is especially important if the keys are intended for inexperienced users, who will not have the necessary background to pick out the relevant parts of the images.

Iconic symbols and coloured marginal bands can play important roles in making guides easier to use (e.g., Ribeiro *et al.* 1999; Lauber and Wagner 2001; White *et al.* 2003). Although most guides that have employed marginal bands have been intended for novices, the *Flora da Reserva Ducke* has shown that they can be useful in technical guides as well (Ribeiro *et al.* 1999), and *Damselflies of Chicagoland* (Garrison 2010) has used them to good effect to indicate seasonality and size. Likewise, iconic symbols have proven useful in both non-technical (e.g., Watts 1991; Hallowell and Hallowell 2001) and technical (e.g., Lauber and Wagner 2001; Prospero and Grand 2009) guides.

The appearance of well-illustrated guides to plant identification prefigures the production of completely visual keys (Kirchoff *et al.* 2008). At present visual keys exist mainly as prototypes, but their production is now possible. We explore this issue further in a companion paper (Kirchoff *et al.* 2011), where we also suggest a set of best practices for visual (as opposed to illustrated) keys.

CONTRIBUTIONS BY THE AUTHORS

R.L. helped select the guides for review and wrote the majority of the first draft of the manuscript. B.K.K. conceived the project, helped select the guides for review, codified the best practices, and made all changes to the manuscript after the first draft.

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