ARTICLES

Plant Collections Online: Using Digital Herbaria in Biology Teaching

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Abstract: Herbaria are collections of preserved plants specimens, some of which date back to the 16th century. They are essential to botanical research, especially in systematics. They can also be important historical documents. The collections of Lewis and Clark, Carolus Linnaeus, and Charles Darwin, to name a few, are primary sources for the study of these individuals' work. Now many of these herbarium specimens are being scanned and the images are freely available on the Web. This article deals with how these online collections may be used in teaching about biology and its history. It will highlight the JSTOR Plant Science project which is making available electronically about two million plant specimens, many historically significant, as well as the entire runs of important plant journals. In addition, it will discuss other valuable online resources including how links to social media can bring the history of botany to 21st-century students.

Key words: botany, herbarium, history of biology, online resources, systematics

INTRODUCTION

Collecting specimens is a major part of what biologists have done in the past and what they do today. Amassing plant and animal specimens is key to taxonomic and anatomical work, and collecting gene sequences obtained from specimens is central to present-day biological inquiry. Though in many ways these two approaches are different ways of doing biology, it's becoming more common for both sequence data and organism specimen data to be stored electronically and accessed via the Internet which allows for interesting comparative work that would have been difficult, if not impossible, in the past. Having data accessible online means that it's available not only to researchers but to students as well. And just as museum curators are necessary so collections can be presented to nonspecialists in an intelligible form, teachers need to be curators of such data collections so students can understand the valuable information available in them (Siemens, 2008). Many resources are available for dealing with gene sequence data; however, the focus here is on herbaria, collections of preserved plant specimens, which were first created in the 16th century, often became neglected in the 20th century, and are experiencing a resurgence, in part because of efforts to digitize these collections. After describing what herbaria are and how they are used, this paper will explore how herbaria, both real and virtual, can play an important role in teaching about biology and its history.

What Is a Herbarium?

It's not uncommon for someone to take a flower and press it between the pages of a book in order to preserve it. The paper absorbs the water in the flower and pressing prevents the petals from curling up as they dry. Once dried, the flower will last indefinitely because the lack of water inhibits bacteria and fungi from causing deterioration. This practice is similar to that used in preparing herbarium specimens which are pressed and then mounted on acid-free paper, most often with glue or linen tape, utilizing more sophisticated equipment. Some specimens cannot be preserved in this way. Fruits, for example, may have to be stored in alcohol and large nuts in boxes; they simply cannot be flattened between two pieces of paper. However, all specimens must be carefully labeled as to species, date and place of collection, and name of collector.

Looking at a herbarium specimen of, for example, the pitcher plant, *Darlingtonia californica* Torr. (Figure 1), can be disappointing for a nonbotanist. What was a stately plant in shades of green, yellow, and red (Figure 2), is now a mass of brownish material. The vitality has left the plant, but the important taxonomic information is still there in terms of what a botanist needs to know in order to identify the species. As natural history developed in the 18th century, descriptions of plants and animals became focused on a few key properties to the exclusion of others. The great taxonomist Carolus Linnaeus saw four qualities as particularly significant: the form of the elements of the organism, the quantity of the elements, the manner in which they are distributed in space relative to each other, and the relative magnitude of the elements. For a plant, all these are usually present on a herbarium sheet. It might be argued that a clear photograph of a plant would be an excellent substitute for a herbarium sheet and actually provide more information, such as that on position of elements in space and color,

Fig. 1. Herbarium sheet of *Darlingtonia californica* Torr.; the specimen was collected on the United States Exploring Expedition (1838-1842) in the United States National Herbarium.

particularly for the flower which is usually the part of a plant that varies the most in color. Indeed, photographs are very useful in plant identification guides. However, photographs often misrepresent scale, may not display all of a plant's identifying features, and obviously aren't sources for chemical or microscopic analysis.

Types and History

Type specimens are the most important herbarium sheets in any collection. A type specimen is the particular plant upon which the botanist who names the species and publishes its description bases that description (Bridson & Forman, 1998). Often several specimens are collected from the same plant, or several plants are collected from the same area at the same time as the type is collected. These are mounted on separate sheets, designated as isotypes, and often sent to other institutions as insurance that if the type is destroyed, there will be a similar specimen available to represent the species. The oldest known herbarium specimens are from the mid-16th century. Some herbaria were part of the cabinets of curiosity that were popular among moneyed Europeans during the Renaissance and morphed into massive collections during the Enlightenment. One of the most notable compilations was that of the British physician, Hans Sloane; it became the foundation of the British Museum's collection (MacGregor, 1994).

As with many collectors, Sloane eventually became overwhelmed by specimens and when Carolus Linnaeus consulted the herbarium on a trip to London in 1732, he considered it in "complete disorder" (Dandy, 1958). Just the storage method used presented a problem. Bound in 265 volumes, the specimens could not be rearranged as species were reclassified. Linnaeus saw this system's flaws and stored his specimens on separate sheets kept in folders with other specimens of the same genus and laid on shelves in cabinets he had specially made for the purpose where all the genera of a family were stored together. In this way he could easily move sheets around if he decided a particular specimen

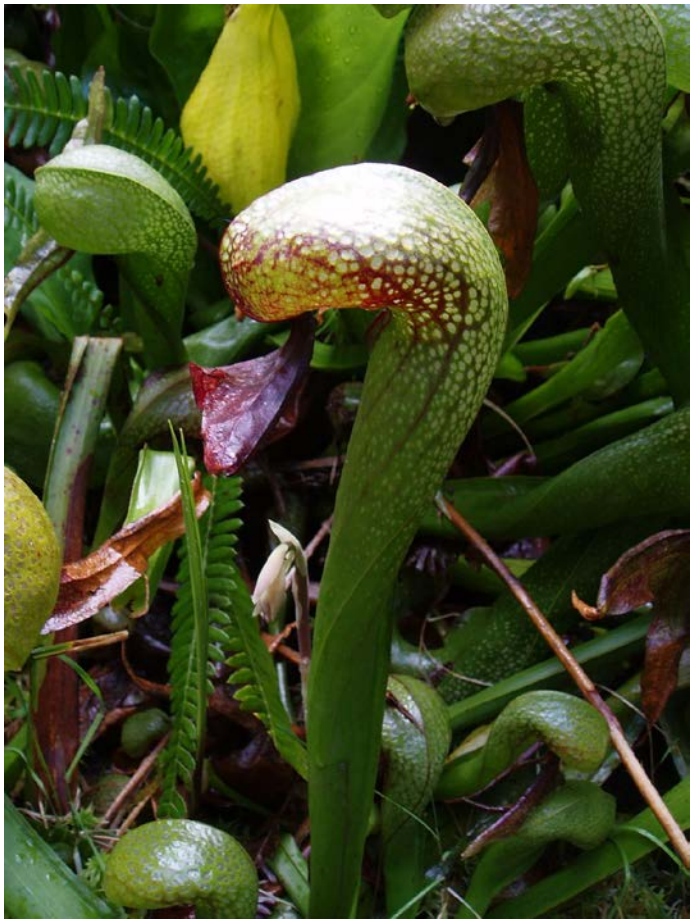

Fig. 2. *Darlingtonia californica* Torr. The image published into the public domain by Adam Harris on Flickr: EOL Images.

belonged to a different family. It is essentially this system that is still used today.

Linnaeus's classification enterprise was driven by the need to organize information about the ever-increasing number of plants arriving in Europe during the Age of Exploration. These collecting efforts are reflected in herbaria, especially in Europe. The specimens of one collector are usually spread over many herbaria. In the past, there were professional plant collectors who sold sets of specimens to interested botanists. Even today most collectors gather more than one specimen of a particular species; these are the capital of the plant collector and of the botanist. One student likened herbarium sheets to baseball cards. Indeed, there is a similarity in that the most valuable sheets are often those of rare species, or are very old, or were collected by someone like Charles Darwin, obviously the Babe Ruth of biology. While a single sheet isn't often sold as a baseball card may be, collections are sold and have been for centuries; that's how Sloane acquired many of his specimens.

Changing Perspectives

By the end of the nineteenth century, the great age of exploration was coming to an end. While there were still many plant species yet to be discovered and many collectors still at work, biology began to move away from taxonomic work as its center to experimental research in cell biology and physiology. Daniel Crawford (2001) argues that with the eventual shift to DNA work, there was less fieldwork and population sampling, and therefore fewer herbarium specimens were created. However, there is now a renewed interest in herbarium collections for a variety of reasons. First, ecologists are coming to appreciate herbaria as essential archives for documenting biodiversity; the only way to know how many species there are and where they can be found is with reliable records such as those in herbaria and other natural history collections (Joppa et al., 2011). Secondly, herbaria are vital for documenting environmental change. For example, flowering plants are usually collected when they are in bloom because flowers are key to identification. If a specimen in flower is collected from a locale in April, and a herbarium specimen of the same species, also in flower and from the same area, was collected 100 years ago in May, then this could represent one more piece of evidence for climate change (Primack et al., 2004). Thirdly, entomologists have used herbarium specimens to discover when a particular beetle species first invaded an area: specimens collected before a certain date contain none of the anti-beetle chemicals present in later ones (Zangerl &

Berenbaum, 2005). In addition, sheets created during plant surveys provide valuable information on how plant communities change over time (Kohler, 2006). These examples indicate that collections become more valuable with time; they are not just libraries of species but time capsules providing historical evidence for what was growing where at a particular moment. Each specimen is unique in this respect; each is irreplaceable.

Recently, herbaria are also receiving attention from molecular biologists. Many plant specimens harbor intact DNA that can be used in genetic studies. Even 200-year-old sheets have yielded DNA which could be sequenced (Andreasen et al., 2009). In addition, in herbaria today, researchers are systematically preserving plant samples for use in sequencing: fresh material is dried in silica gel and then stored at low temperature. This is one more kind of plant specimen found in herbarium collections along with boxes of pinecones and jars of alcohol with fruits or flowers floating in them. There may also be a seed bank where seeds are stored for future germination as a way to preserve the genetic diversity of species. If possible, all these specimen types should remain together in part because the different kinds of collections mentioned at the start of the article—specimens and sequencing data—are like reference libraries where researchers come to consult plant material instead of books. And, like libraries, there is a long tradition of borrowing and lending among herbaria, as researchers in different parts of the world work on plant genera or families representatives of which may be housed in dozens of herbaria.

Digitization

Just as libraries have been at the forefront of digitizing information about their books and the books themselves, the same thing is true of herbaria; both types of institution are dealing principally with two-dimensional material, which makes creating digital images relatively easy. This is a massive undertaking and data on labels are more often digitized than images of specimens. There have been a number of United States grant programs, often through the National Science Foundation (NSF), to support digitization efforts so all the major herbaria have some of their collections online (iDigBio, 2013). On an international scale, the Global Biodiversity Information Facility (GBIF) has created a portal where almost 400 million records about species of all kinds are available electronically (GBIF, 2013). However, there is a threat to herbaria that underlies such massive digitization efforts. As early as 1990, it was suggested that once a herbarium sheet had been imaged and its information digitized, the sheet was no longer needed; it would only be necessary to retain type specimens (Clifford et al., 1990). Needless to say, there were prompt rebuttals to this proposal (Harley, 1990).

Databases are amazing resources not just for botanists, but for teachers and students as well. They can serve as virtual museums of plants and as libraries of information about plants. Because of their fragility and value, herbarium collections are closely guarded, with access sometimes limited to researchers in the field. This is a major reason why collections are being digitized—so the sheets and the information on them can be accessed without damage to the originals. There are also other accessibility issues. Most plants collected by former colonial powers reside in these nations, while their former colonies have only a fraction of the documentation of their botanical wealth. It's ironic that many of the nations with the most diverse flora have the greatest difficulty in maintaining collections of this richness.

To address this problem in the most needy area, the African Plants Initiative was established in 2003 with the aim of digitizing type specimens of African plants and making these images available on the web (Patmore, 2010). Four years later the Latin American Plants Initiative grew out of this effort and has since become the Global Plants Initiative, now focusing on Asian plants. The Andrew W. Mellon Foundation funds this project, providing scanning and photography equipment to institutions. This initiative led to the digitization not only of herbarium specimens but of the botanical literature needed to support research in systematics. All these resources are presented through JSTOR Plant Science (JPS) which is much more than a database linking to specimens and journal articles. It provides a suite of search and social media tools that greatly enhance the value of the database itself. However, this doesn't deal with access to the technology needed to use these resources which often remains a challenge.

Within JPS, the specimen images are of high quality with a zoom feature for examining details. When a species name is entered in the search box, what appears is not only a thumbnail image of the specimen (or specimens) but also links to articles and citations related to that species, including JPS and other JSTOR resources, as well as the Biodiversity Heritage Library (BHL), the Tropicos database, and GBIF. In addition, on the opening page of JPS, there are links to comments from users concerning specimens in the collection. This is one way mistaken species determinations are corrected. JPS is also active on Twitter and Facebook, has a number of videos on Vimeo, and ran a blog as well (JSTOR Plant Science, 2012). With tools like these, JPS is creating a virtual and global taxonomic community for scientists and for biology teachers and students. One page with all these resources available for a particular species is a goldmine and shows students how reference materials can be organized to make them more useable. It also gives them a sense of the literature available, ranging from articles aimed at experts to ones easily read and understood by non-

professionals. Other resources in JPS include manuscripts and letters by such botanists as Asa Gray, Joseph Hooker, and Carolus Linnaeus; in addition, there are thousands of drawings and paintings of plants.

The JPS blog can be useful in teaching many topics, from evolution and genetics to biodiversity and economic botany. Some posts describe resources available through JPS. Others deal with the project's accomplishments and its outreach to the global plant community; posts included videos made at partner institutions around the world. They are reminders that our instant access to information is hardly the case globally. The majority of posts concern items in the specimen collection and often focus on history: everything from William Dampier, a pirate-botanist, to figs and how their leaves came to have a strategic place in art.

JSTOR is a widely-available database, but even without this access, the blog is open to all web users. One or more blog posts could be used as assigned readings in themselves, and many of the links are to freely available resources outside of JSTOR, so these too, can be explored by students. The posts are essentially curated guides to a topic. If students can access JSTOR, then the posts become more than just interesting reading and can develop into lessons in information literacy and the use of social media in research. This might be the best way to use the JPS blog: as a model for students to use in creating their own. Also, students can carry the social media connection further; groups involved in creating posts can share ideas, information, and resources via Twitter or Facebook, and they can embed the videos in their blogs. Such assignments combine writing, visual presentation, and evaluation of information in a way that standard PowerPoint presentations that students often create cannot.

Teaching with Digital Herbaria

There are many different ways to incorporate digital herbaria into biology classes. I'll describe three approaches here to suggest how these resources can encourage active learning about plants. For those who stress history, there are sites like the one presenting plants Charles Darwin gathered on his *Beagle* voyage and sent to his mentor, John Stevens Henslow, professor of botany at Cambridge University (Darwin's Plants from the Beagle Voyage, 2012). The site links to a video describing the importance of the collection to Darwin's work (Parker, 2009). The American plant systematist and historian of botany, James Reveal, has created a rich website on Lewis and Clark's botanical collection (Reveal, 2008). On the Linnean Society's website are scans not only of Linnaeus's plant specimens, but of insects, fish, and shells (The Linnean Collections, 2012).

Depending on what's being taught, students could explore one of these sites. On the Darwin site, there's a page on reading a herbarium sheet that might be a good place to begin. Then students could look out for specimens labeled "Type" and investigate what this means. They could also compare historical specimens with recently collected ones of the same species. This might lead to issues of name changes and synonyms; the Plant List (2010) is a comprehensive entry point for this research. Also, students could examine how labels have become more information-rich, especially in terms of location data with GIS coordinates. As an exercise in biological information literacy, they could compare the sites for two or more of these historical herbaria to see how they differ in terms of information, accessibility, etc.

For ecology courses, digital herbaria are useful in investigating biodiversity, environmental change, and phenology. LifeMapper (2013) is a website which provides georeferencing data for many species worldwide. As with most of these global sites, some of the information is sketchy, but that in itself is a good lesson for students that ecology, biodiversity studies, and biodiversity informatics are all developing enterprises. As an exercise, students can collect plants, identify them, create specimen sheets, and geo-reference them using Google Earth (2013). They can then compare their specimens with online examples of the same species. There are also two national digital projects, examples of Citizen Science, in which they can participate. Part of the National Environmental Observatory Network (NEON), Project Budburst (2013) involves plant budding, flowering, and fruiting times. The data input will document climate change in the future and can also be compared to historical data. An activity like this doesn't just fulfill the requirement for a grade but also makes a valuable contribution to environmental studies. The same is true of another national program, Nature's Notebook (2013), one element in the National Phenology Network. Participants sign up to take notes on a particular area, looking for specific organisms. This is a great way for students to begin to appreciate the nature that surrounds them. It also helps them to realize that even though they may live in a very human-altered environment, there are still habitats and organisms to study. They could, for example, take notes on the spread of an invasive species just moving into an area or be on the lookout for rare plants. Searching for these species in digital herbaria might be the next step. Students can also learn to use one of the many online plant checklists or local floras. Learning about these resources may help to make them lifelong students of nature.

Because biology is the most visual of the sciences, I stress visual literacy when I teach. Observation is frequently taken for granted as an obvious skill, but it needs to be nurtured. Collecting plants in the field and identifying them are ways of developing this skill, as are exercises in comparing

specimens of the same species collected at different times or in different locations. Large digitized plant collections available to students include those at the Smithsonian Institution (2013), New York Botanical Garden (2003), Royal Botanic Gardens, Kew (2013), and the Muséum National d'Histoire Naturelle (2013). Most digitized specimens are of high quality and can be magnified, so students can inspect texture and fine structures. It is also valuable for them to compare specimens with photographs of the same plant, and with illustrations. Each approach has advantages and disadvantages in communicating information about a plant; it's useful for students to investigate these differences and describe them. And as an ultimate exercise in visual literacy, they could draw plants from life and from herbarium specimens.

While this paper has focused on plants, there are superb zoological and fossil collections online as well. NSF is heavily funding digitization of all types of natural history collections, so more and more of these resources will become available on the web. The related literature is also being digitized through the BHL (2013), and field notebooks for American naturalists are coming online through a Smithsonian Institution project (Field Book Project, 2012). The material available is so rich that it's open to a variety of approaches that can attract different types of learners and also renew a sense of discovery in faculty as well.

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REFERENCES

ANDREASEN, K., MANKTELOW, M., AND S.G. RAZAFIMANDIMBISON. 2009. Successful DNA amplification of a more than 200-year-old herbarium specimen: recovering genetic material from the Linnaean era. *Taxon*, 58: 959–962.

BIODIVERSITY HERITAGE LIBRARY. 2013. Accessed from http://www.biodiversitylibrary.org/ on 5 Mar 2013.

BRIDSON, D., AND L. FORMAN. 1998. *The Herbarium Handbook* (3rd ed.). Kew, UK: Royal Botanic Gardens.

CLIFFORD, H. T., ROGERS, R. W., AND M.E. DETTMANN. 1990. Where now for taxonomy? *Nature*, 346: 602.

CRAWFORD, D. J. 2001. Plant macromolecular systematics in the past 50 years: One view. In T.F. Stuessy, E. Hörandi, and V. Mayer. *Plant Systematics* (pp. 81–103). Vienna, Austria: International Association for Plant Taxonomy.

DANDY, J. E. 1958. *The Sloane Herbarium.* London, UK: British Museum.

DARWIN'S PLANTS FROM THE BEAGLE VOYAGE. 2013. Accessed from http://www.darwinsbeagleplants.org/Darwin/Home.aspx on 5 Mar 2013.

FIELD BOOK PROJECT. 2013. Accessed from http://nmnh.typepad.com/fieldbooks/ on 5 Mar 2013.

GBIF. 2013. Accessed from http://www.gbif.org/ on 5 Mar 2013.

GOOGLE EARTH. 2013. Accessed from http://www.google.com/earth/index.html on 5 Mar 2013.

HARLEY, R. M. 1990. In defence of taxonomy. *Nature*, 347: 223–224.

IDIGBIO HOME. 2013. Accessed from https://www.idigbio.org/ on 6 Mar 2013.

JOPPA, L. N., ROBERTS, D. L., AND S.L. PIMM. 2011. How many species of flowering plants are there? *Proceedings of the Royal Society B: Biological Sciences*, 278: 554 –559.

JSTOR PLANT SCIENCE. 2012. Accessed from http://jstorplants.org/ on 5 Mar 2013.

KOHLER, R. 2006. *All Creatures: Naturalists, Collectors, and Biodiversity, 1850-1950*. Princeton, NJ: Princeton University Press.

LIFEMAPPER. 2013. Accessed from http://lifemapper.org/ on 5 Mar 2013.

MACGREGOR, A. (Ed.). 1994. *Sir Hans Sloane*. London: British Museum Press.

MUSÉUM NATIONAL D'HISTOIRE NATURELLE. 2013. Accessed from http://www.mnhn.fr/le-museum/ on 5 Mar 2013.

NATURE'S NOTEBOOK. 2013. Accessed from https://www.usanpn.org/natures_notebook on 2 Mar 2013.

NEW YORK BOTANICAL GARDEN: STEERE HERBARIUM. 2003. Accessed from http://sciweb.nybg.org/science2/SteereHerbarium.asp on 5 Mar 2013.

PARKER, J. 2009. The Roots of a Theory: How Plants Specimens Led a Young Darwin to Discovery. Accessed from http://www.youtube.com/watch?v=9jTcG-WV7Y4 on 5 Mar 2013.

PATMORE, K. 2010. All Vascular Types On-line. *Global Plants Initiative*. Accessed from http://gpi.myspecies.info/content/all-vascular-types-line-global-plants-initiative on 5 Mar 2013.

PLANT LIST. 2010. Accessed from http://www.theplantlist.org/ on 2 Mar 2013.

PRIMACK, D., IMBRES, C., PRIMACK, R. B., MILLER-RUSHING, A. J., AND P.D. TREDICI. 2004. Herbarium specimens demonstrate earlier flowering times in response to warming in Boston. *American Journal of Botany*, 91: 1260–1264.

PROJECT BUDBURST. 2013. Accessed from http://budburst.org/ on 2 Mar 2013.

REVEAL, J. L. 2008. Lewis and Clark Herbarium—Plants collected by Lewis and Clark. Accessed from http://www.plantsystematics.org/reveal/pbio/LnC/LnCherbindex.html on 5 Mar 2013.

ROYAL BOTANIC GARDENS, KEW: COLLECTIONS: HERBARIUM. 2013. Accessed http://www.kew.org/collections/herbcol.html on 5 Mar 2013.

SIEMENS, G. 2008. *Learning and knowing in networks*. Presented at the ITFORUM. Accessed from http://www.ingedewaard.net/papers/connectivism/2008_siemens_Learning_Knowing_in_Networks_changingRolesForEducatorsAndDesigners.pdf on 8 Mar 2013.

SMITHSONIAN INSTITUTION HERBARIUM. 2013. Accessed from http://botany.si.edu/colls/collections_overview.htm on 5 Mar 2013.

THE LINNEAN COLLECTIONS. 2012. Accessed from http://www.linnean-online.org/ on 5 Mar 2013.

ZANGERL, A., & M. BERENBAUM. 2005. Increase in toxicity of an invasive weed after reassociation with its coevolved herbivore. *Proceedings of the National Academy of Sciences*, 102: 15529–15532.