25 YEARS OF SPNHC: THE PRESENT IS THE KEY TO THE FUTURE

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When The Society for the Preservation of Natural History Collections (SPNHC) first emerged from the efforts of a number of dedicated collections professionals, the developments of the last 5 years were both not known and, in some cases, not even thought to be even remote possibilities. By looking at some of these advances, we can give an overview of where SPNHC has landed and what we hope to accomplish in the future.

Collections Stewardship

In the past 5 years there have been a number of significant advances and developments in the field of natural history collections management and conservation. In many ways, our community has never been stronger but, like many disciplines, we need to build on the success of the past 5 years and look to continue to grow and engage the community in the development of standards, best practices, and collaborative activities. SPNHC is in an excellent position to lead on these initiatives.

In 2004, Heritage Preservation launched a very ambitious project to assess the condition and preservation needs of all USA museum, library, and archive collections. With a series of focus groups, the Heritage Health Index was born, with the participation of SPNHC leading the way in the natural science focus group. A detailed questionnaire was sent to all types of collections, including the various types of natural history holdings including anthropology, botany, zoology, paleontology, and geology collections. In December 2005, *A Public Trust at Risk: The Heritage Health Index Report on the State of America's Collections*, was published, and concluded that immediate action is needed to prevent the loss of several million artifacts, specimens, and collections. The report made four very important recommendations:

- Institutions must give priority to providing safe conditions for the collections they hold in public trust.
- Every collecting institution must develop an emergency plan to protect its collections and train staff to carry it out.
- Every institution must assign responsibility for caring for collections to members of its staff.
- Individuals at all levels of government and in the private sector must assume responsibility for providing the support that will allow these collections to survive.

To meet these challenges, SPNHC and its membership has been progressive and has focused the attention of our annual meetings on such topics as: Emergency Response and Salvage (2004), Realising Standards (2005), The Road to Productive Partnerships (2006), Building for the Future (2007), Collections Stewardship in a Changing World (2008), Bridging Continents (2009), and Biodiversity (2010). In the next decade, our meetings will continue to focus on many of these challenges and we will look for innovative ways to communicate this information to the membership and the natural history community.

"Best Practices" is a phrase that is becoming synonymous with many SPNHC activities. The 2008 publication of *National Standards and Best Practices for U.S. Museums* by Elizabeth E. Merritt gave us a new standard reference work. In

collaboration with the National Science Foundation-sponsored Collections Web initiative, SPNHC has hosted Best Practice sessions at our annual meetings beginning in 2008, and recently cosponsored a day-long technical session on best practices for geological and paleobiological collections at the 2010 Annual Meeting of the Geological Society of America.

SPNHC, through the tireless efforts of Andy Bentley, has made a major contribution to simplifying shipping small, alcohol-preserved specimens with the inclusion of a special provision covering these specimens in the 52nd edition of the International Air Transport Association rules. We currently are involved in a similar effort that we hope will simplify the permitting process for shipping dried plant specimens both into and within the USA.

Cyberinfrastructure

In 2006, at our joint annual meeting with the Natural Science Collections Alliance in Albuquerque, New Mexico, our hosts Cindy Ramotnik (U.S. Geological Survey) and Terry Yates (University of New Mexico) challenged our community to look for sustainable partnerships. One area that has received considerable attention in recent years is the development of the cyberinfrastructure of natural history collections management. Although there seems to be less interest in what species of database application museums or collections are using to capture and manage collection-related information, there has been considerable interest in how to mobilize and publish this information on the internet.

Guala (2007) described the massive investment in cyberinfrastucture across the globe in government and nongovernment communities and points to two very successful projects: SYNTHESIS in the European Union, and Distributed Generic Information Retrieval (DiGIR) network-based communities in the USA as examples of successful enterprises. Although the vertebrate communities have bonded together and developed several successful DiGIR networks (e.g., VerteNet), other communities are lagging behind. The paleontological community has partially invested in the Paleontology Portal, and the US Virtual Herbarium still is in discussion. One of the many best practices that have been developed, in association with the vertebrate communities DiGIR efforts, is the standardization of geospatial coordinate data and the best practices for rapidly capturing that information. The Museum of Vertebrate Zoology at UC Berkeley and the Natural History Museum at Tulane have led the charge in developing methodologies for rapid georefencing of collection data and the standardization of coordinate data (Biogeomancer and Geolocate, respectively).

The Global Biodiversity Information Facility (GBIF) is an important collaborative effort focused on making biodiversity data, from both specimens and observations, available freely on-line. A truly multinational effort with participation from 55 countries and 46 organizations (including SPNHC) as Associate Participants, GBIF now makes available over 323 million data records. Operating under a series of work plans and memoranda of understanding, GBIF seeks to improve the quality and quantity of available data as well as working to develop new methodologies to make data exposure easier.

Collection Initiatives

Participation in US initiatives has also increased in the past 5 years. In 2008, SPNHC joined the efforts to work on behalf of the museum community with the National Park Service on matters concerning specimen deposition and repository agreements. Several SPNHC members were "at the table" in the meetings that lead to the foundations of the new National Science Foundation Advancing Digitization of Biological Collections (ADBC),

and many of our US members likely are awaiting the outcome of the second round of funding from that program. SPNHC members also work on the various collection networking initiatives, including the US Virtual Herbarium, Herpnet, and Vertnet, to name just three.

An increasing important aspect of the SPNHC is participation in international initiatives. With the increased interest in mobilizing the data housed with natural history collections, it is imperative that we become cognizant of these efforts and participate wherever possible. Besides GBIF, we have also been involved in the activities of the Consortium for the Barcode of Life (CBOL), Biodiversity Information Standards (TDWG), and the recently-announced Scientific Collections International (SciColl).

Meetings and Workshops

The SPNHC annual meeting continues to be an important and highly visible activity of the Society. The themes of recent meetings have covered the gamut of current topics: professional development, building for the future, collections stewardship, cryocollections, collections digitization, and international cooperation.

An important aspect of the last decade is holding the SPNHC annual meeting in venues outside of North America. After the successful meeting at the Natural History Museum in London in 2005, we visited the European continent for the first time in 2009 when our colleagues at Naturalis in Leiden served as our gracious hosts. These meetings were very well received – I (RKR) recall a delegate from Estonia coming to me at the end of the Leiden meeting and personally thanking me for bringing the meeting to Europe. We are actively seeking additional international venues and hope to announce our next international destination within a year.

Where do we go from here?

Although we can't predict the future, we think that SPNHC has established itself as a group of professionals that both cares for collections and works on many fronts to help foster their preservation and wider accessibility. The best way to maintain this position is to continue developing our connections to the many groups and initiatives throughout the world that intersect our interests. In order to do this, we need our members to help by thinking "outside the box"—outside of the local issues that easily can consume much of one's daily activities.

Partnering with the collections committees of our traditional discipline societies and cohosting sessions on best practices or any of the many hot topics that are affecting our communities is a great way to expand our network of influence. Allied organizations, such as the American Institute for Conservation of Historic and Artistic Works and the Taxonomic Database Working Group, are two such groups with whom we could begin to build bridges on standards and best practices as they relate to preservation and access to digital collection data.

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ENHANCING THE BEAR GULCH PALEONTOLOGICAL RESEARCH COLLECTION AT THE UNIVERSITY OF MONTANA

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Abstract.—The Mississippian Bear Gulch collection (BGC) is one of the most extensive and important components of the University of Montana Paleontology Center (UMPC), largely because of the unique preservation of the marine fossils and the extraordinary diversity of life that is represented by it. A 3-year grant from the National Science Foundation (NSF), focused on the BGC, assisted in the enhancement of the collections facility and improved the accessibility of the collection for research. This was accomplished by upgrading the lighting, renovating the storage room (paint and air conditioning system), purchasing new collection cases and other equipment, installing a compactor system, completing an inventory of the collection, and developing a database to automate the collection data. The UMPC developed an interactive database that is accessible to anyone with an internet connection (http://www.cas.umt.edu/paleontology). This database provides innovative features such as a "shopping cart"-style loan request system and the ability to view a specimen locality through Yahoo! Maps. During the inventory, specimens were digitized and the images were uploaded to the database. A large-scale reorganization of the BGC was completed after the inventory. The UMPC collections were further enhanced by the installation of a space-saving compactor system and other upgrades to the storage facility. This compactor system greatly increased storage capacity and decreased the storage footprint. These renovations greatly improved the ability of the UMPC to support specimen-based research.

INTRODUCTION

The University of Montana Paleontology Center's (UMPC) research collection was established in the 1890s through the work of Earl Douglass, the first recipient of a graduate degree at the University of Montana in 1899. The full collection has an estimated 40,000 specimen-lots (an estimated 100,000 specimen elements), with 20,000 currently inventoried and 1,050 of these are type specimens. Much of the current collection focuses on fossils from the northwestern USA, but the collection also houses specimens from more than 18 countries. The holding includes an extensive Triassic invertebrate fossil collection, a Cenozoic mammal collection, a Cambrian trilobite collection, a Burgess Shale collection, and a Mississippian Bear Gulch collection (BGC).

The BGC collection totals 4,100 specimens, including 620 type specimens and a recently repatriated orphaned collection. This orphaned collection from Indiana University contained 966 fossils and 233 lithological samples. It was received in 2004 as uncurated material. Once the specimens were inventoried and added to the original BGC, the enlarged collection needed more space. To better manage the collection and make it available for research, a more efficient database was required. Many different database programs (Microsoft Access, MUSE, and Specify) have been used to manage the UMPC collections in the past. Although these programs are excellent for entering collection data, many were missing one key component—internet accessibility (in 2007). An inaccessible database, lack of secure space for specimens, and a poor storage facility became the catalysts in seeking funding for a major upgrade.

A 3-year grant (2008–2011) was awarded from the NSF, Collections in Support of Biological Research Program (Stanley, Principal Investigator [PI]). The grant allowed for a general upgrade of the UMPC collections facilities with a specific focus on the BGC. This

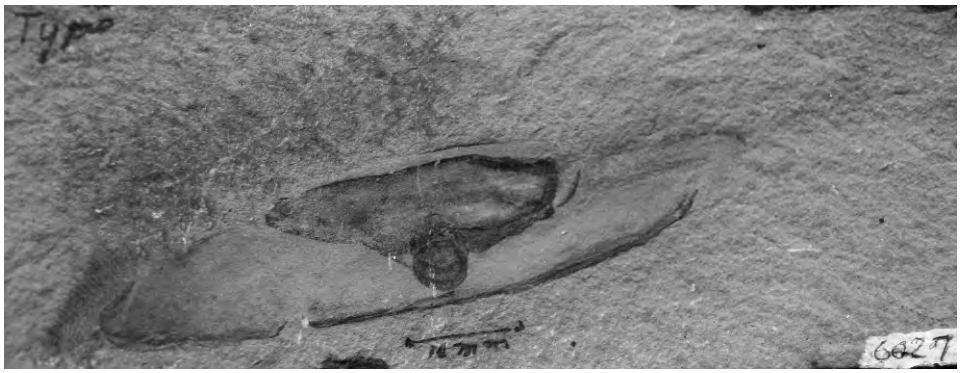

Figure 1. Example of a Bear Gulch fossil. This specimen is of the conodontophage (MI 6027), *Typhloesus wellsi*, which was one of the most controversial specimens from the Bear Gulch. It was first described as the elusive conodont animal, but later it was shown that the conodont apparatus was actually in the midgut, illustrating that this animal fed on the conodonts.

enhancement project has five main work elements: 1) Renovation of the lighting and air system in the storage facility; 2) purchase of equipment, including computers, scanners, additional storage cases, and ladders; 3) installation of a storage compactor system; 4) development of an interactive website/database; and 5) inventory and digitization of the collections with the help of students who were trained in the management of fossil collections. Stanley, the PI on the grant, was successful in securing additional funds from the University Research Administration to cover all costs of the room construction in preparation for the project. This included the lighting and air conditioning, because NSF considers such facilities costs to be the obligation of the institution. As a result, the project has made the collection more accessible to the paleontological research community and has greatly improved the overall condition of specimen storage, curation, and management.

The Bear Gulch Limestone

The Bear Gulch Beds contain over 150 different species of fossils, including large fish assemblages, highly diverse invertebrate faunas, aquatic and possibly terrestrial plants. These fossils from central Montana are ranked as one of the few lagerstätten, or exceptional fossil deposits, in the world. Fossils of the Bear Gulch are preserved in a fine-grained, platy limestone and display a wide array of unusual preservation (Fig. 1). These include soft tissues and organic films, phosphatic shells, cartilage, and molds of carbonate skeletal elements (Hagadorn 2002). The Bear Gulch Limestone was deposited during the Late Mississippian period (Serpukhovian, 328.39 to 318.1 Ma; Ogg et al. 2008), in a shallow basin or estuary-like environment (Williams 1983), paleogeographically located near the equator at approximately 10° to 12° N paleolatitude and characterized by a cyclic semiarid to arid, tropical paleoclimate (Grogan and Lund 2002). The rare examples of preservation may have resulted from climate shift from a dry to a monsoonal environment, causing rapid carbonate redeposition. During a geologically short period of time, approximately 30 m of carbonate rock accumulated (Grogan and Lund 2002). The Bear Gulch Limestone is a member of the Heath Formation and includes three beds: Surenough Beds, Bear Gulch Beds, and the Becket Beds. All three beds contain preserved specimens. Exposures of the Bear Gulch Beds can be seen over 70 km^2, and the largest exposure located in Fergus County, north of the Snowy Mountains, measures about 14 km east to west by 9 km north to south (Lund and Grogan 2005).

The first mention of the Bear Gulch in the peer-reviewed literature was in 1956. However, in-depth collection and study did not occur until the 1960s, when a local rancher contacted William Melton (University of Montana paleontology Curator) about fossils he found. Melton's first description of the Bear Gulch was in 1969 (see also Melton 1971, 1979, 1985). Collecting continued throughout the 1980s and into the 1990s with Dr. Richard Lund and Dr. Eileen Grogan. These individuals, plus researchers from other institutions and interested students, continue to publish and work on the Bear Gulch (Grogan and Lund, 2002). Despite these investigations, many questions concerning the fossils and their deposition have yet to be answered, and research on the Bear Gulch continues today.

The Project

Renovation

The UMPC research collection is housed in a 1,135 ft^2 (105.4 m^2), key-coded lock, basement storage room of the C. H. Clapp building on the University of Montana campus in Missoula. Before the renovation, room temperatures stayed at a detrimental 85°F (29.4°C) with changing humidity levels because of the proximity to the main boiler room, and the collections' room also lacked air conditioning. The heat and humidity, and the fact that many specimens were housed in oak cabinets due to the shortage of metal cases, created an environment that promoted Byne's Disease—a reaction with acid vapors in the air, resulting in a white powdery residue on the fossils (Shelton 2008). Pyrite Disease also occurred as the result of the oxidation of iron sulfide in the specimens to sulfuric acid, a corrosive substance. Fortunately, only a few specimens were afflicted. The maze-like arrangement of the cases created small, awkward working areas with poor lighting. Because the cases were only partially systematically organized and the old database did not have a case location field, finding a specimen required extensive and time-consuming searches. After the Bear Gulch orphan material was added to the collection, there was no more room for future collections growth.

Prior to installing the compactor system, the thickness of the floors was tested. The floors proved to be 7 in (17.78 cm) thick and reinforcement wasn't needed. A large number of cases had to be moved out of the collection room during the renovation. The fire marshal had to be notified and precautions had to be taken not to block fire exits or fire extinguishers. During the move, drawers were taken from the original cases and put into a transfer case with wheels. The empty shell of the original case was hand-carried into the hallway and the drawers in the transfer case were put back into the original case. This system allowed for a monitoring of the specimens' welfare, with special attention given to fragile or unstable specimens. Cases were locked and checked daily for tampering during the 5-day move. Once the collection area was emptied (Fig. 2A), the walls and ceiling were painted white to increase light reflection, and energy-efficient lights were installed in the entire room, effectively doubling the previous illumination. Two Carrier® air conditioning systems were installed to control the temperature and humidity in the collections room. Both air conditioners are on a separate air system because the room is isolated from the rest of the building air system. The collection now stays at a constant 72°F (22.22°C), with stable humidity levels (Johnson 1999) and the updated arrangement of the room creates an efficient work area (Fig. 2B).

Compactor System

In August 2008, the Spacesaver® Eclipse Powered Mobile System (Spacesaver, 1450 Janesville Ave., Fort Atkinson, WI, 53538) installation began. The installation of this compactor system involved: 1) laying down the tracks for the carriage system, 2) building

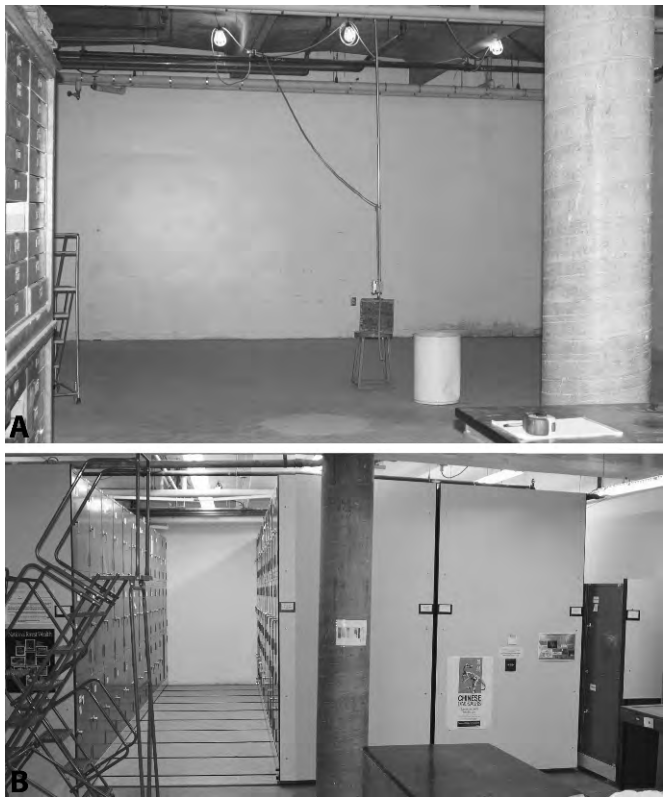

Figure 2. (A) The University of Montana Paleontology Center (UMPC) collection room during the renovation. (B) After the renovation (repainting, new lighting) with the compactor system installed.

a floor around the tracks so they were flush, 3) placing the carriage system on the tracks, 4) stacking the metal cases onto the carriages in a systematic order, and 5) bolting the cases together for earthquake safety. This high-density mobile storage system has increased storage space by 30% and decreased the storage footprint by about 40%. In total, this system holds 192 33 in × 29 in × 37 in (83.82 cm × 73.66 cm × 93.98 cm) specimen cases versus 147 cases prior to renovation (Fig. 3). Most rows are stacked three cases high, except for one, which is stacked only two cases high due to sprinkler pipes. Preventative measures have been taken to mitigate water leakage: 1) all pipes that descend from the ceiling were applied with foam sealant, 2) the floors are checked daily for water, and 3) there also is a plan to make a water damage preparedness kit following the recommendation of Harris (2005).

Other Equipment

Along with the compactor system, energy efficient lights, and the air conditioning units, the UMPC purchased additional equipment including two new Dell Inspiron 530S® computers to work on the database, two Epson Perfection V500® flat-bed photo scanners for scanning specimens and publications, and two new Ballymore Fold-N-Store® ladders (a 5-step and a 7-step). These ladders have large rolling wheels to assist in maneuvering over the tracks of the compactor system. To accommodate future growth, 45 new cases were purchased from Delta Designs Ltd® (PO Box 1733 Topeka, KS, 66601) and added to the

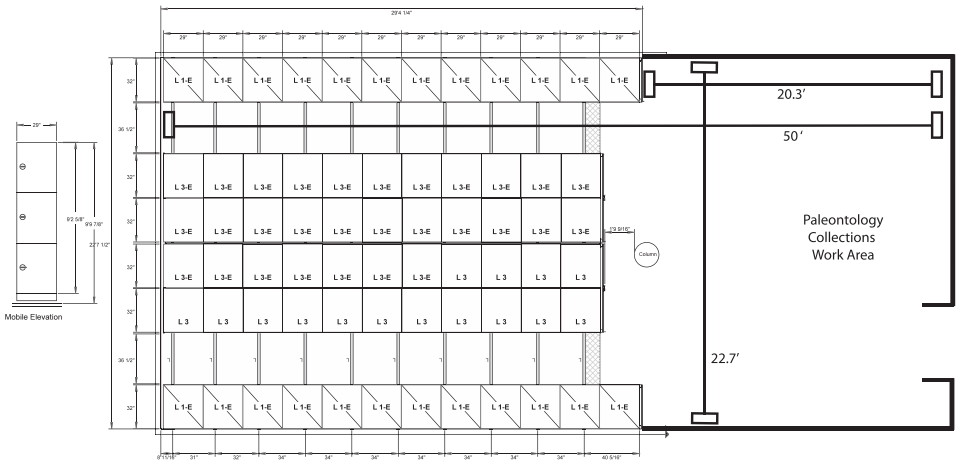

Figure 3. Space Saver System layout in the UMPC collections room, view from above. All rows are three cases high, except for one, which is only stacked two high. L3 E represents existing Lane cases and L3 represents newly purchased Delta cases. The middle double stacks can move independently of one another and the two outside rows are stationary. (Modified from the original design by the Spacesaver Corporation.)

older, more expensive Lane Scientific Equipment Corporation® cases. Colors for the inside, outside, and drawers of the Delta cases can be customized. The UMPC chose a light gray color for the outside and a white for the inside of the cases and drawers. Delta worked with DuPont to formulate a slip-type powder coat where the pigment of the white paint allows drawers to slide more easily, whereas other colors tend to drag. A large shelving unit was purchased to hold oversized specimens that do not fit in the normal specimen cases.

Website/Database

Our previous collections database used Microsoft Access®. Although useful for automating the collections and supporting activities, this database did not suit all of our needs, especially for user interaction. Currently, there are database programs that incorporate many of the features that were needed for the UMPC database. Unfortunately, none of them served our needs completely. In addition, as of 2007, when Spectral Fusion, Inc., supporting the College of Arts and Sciences, started building a site, no other database programs could be accessed online. Spectral Fusion designed our current website and associated database to the UMPC's exact specifications. The website is hosted on a Windows operating system running an Internet Information Server that provides a reliable and manageable web application infrastructure. The MS SQL database can be accessed and queried using the Cold Fusion programming. Spectral Fusion Inc. was able to input all of the data from the old MS_Access database. However, these data included many errors, nonexistent specimens, and other problems. These issues must be dealt with on a specimen-by-specimen basis and new fields that were not in the MS_Access database had to have data inserted (e.g., case number, land ownership).

The new website promotes the activities of the UMPC (e.g., programs, classes) and the associated database allows the scientific community to access the collection for research. The site can be reached easily through the Department of Geosciences Web page (http://www.umt.edu/geosciences) or by going directly to the Web site itself (http://www.cas.umt.edu/paleontology). Available data includes, but is not limited to, taxonomic information

(from http://www.paleodb.org), collector contact information, site descriptions, age evaluations, and specimen images (Fig. 4). Features of the database include: downloadable search results (to an Excel file), the ability to view localities through Yahoo! Maps, an automatic specimen card constructor, and a ''shopping cart''-style loan system where users can remotely prepare their own loan requests. Because the database is publically accessible, only members (with a user name and password) have access to the restricted areas of the site, such as specimen locality details. Members also are the only individuals who can enter or change information in the database. This feature helps to keep paleontological localities safe from over-collecting and looting. Although this database was implemented in September 2008, many small changes to the database have occurred since, allowing the UMPC to continually improve and modify the system in order to maximize efficiency.

Digitization

As soon as the database was operating, a full specimen inventory began, starting with the BGC type/figured specimens, then continuing with the remaining nontype specimens, including the orphaned collection. Student assistants and volunteers entered all of the known information (e.g., taxon, locality) into the database. Some specimens had information that was transferred from the inaccurate MS_Access database and needed to be double-checked for errors, updated, or corrected. Once the specimen information had been checked and updated, the specimen was digitized. Because the BGC specimens are essentially flat slabs, they lend themselves well to scanning. Accordingly, a high resolution flat-bed scanner was used to scan the specimens and create 60 MB TIFF image of each specimen. A smaller version (typically around 110 K) of the scan also was made. This smaller image was uploaded to the database, whereas the larger image was saved for later use by researchers. When a specimen was too concave or convex for adequate scanning, it was photographed using a Canon EOS 10D digital camera. Type publications also were converted to PDFs and the citation added to the publication list on the database (in progress). Remote users now are able to conduct searches through the collection to view thumb-nail sized images of specimens. Since 2008, 35 students and volunteers have worked approximately 4,300 hours, processed roughly 3,400 specimens of BGC, and scanned 65 BGC type publications.

Conclusions

This project has immensely increased the research potential of the BGC by making the collection more physically and electronically accessible and by making the loan process simpler with the ''shopping cart''-style loan system. It has improved the overall status of the entire collection by reducing risks of damaging diseases due to heat and humidity, locating specimens more quickly from the large-scale reorganizing, and increasing space for additional specimens. This project also has benefited paleontological research by enhancing preservation and conservation of specimens, assisting in the training of graduate and undergraduate students, and supporting public outreach through K–12 educational activities. During the inventory, students and volunteers learned how to handle specimens, the importance of using archival quality materials, and the correct way to enter information into the database. The UMPC also hopes to build better relationships with other institutions, allowing increased flow of specimen information to make our collection data more complete and useful. The new cases and compactor system will allow our collections to grow for an additional 10 years. Although the project

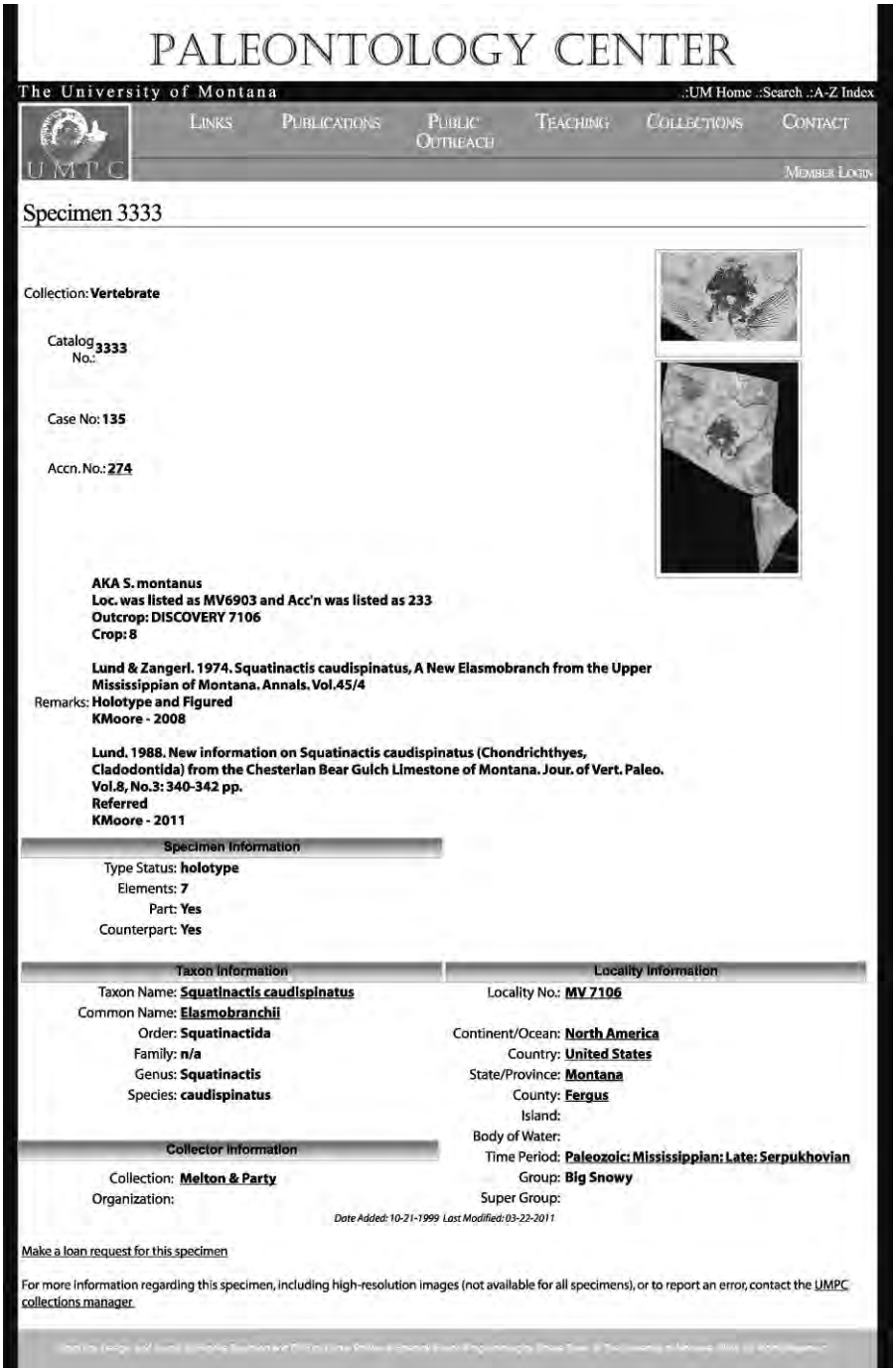

Figure 4. Screen shot of a UMPC specimen information page. This is an example of what a nonmember would see after clicking on a specimen's catalogue number from the search results page.

is essentially completed, we expect that the overall enhancement will better serve the paleontological community for research as well as to education and outreach. We invite interested readers to explore and utilize our new database or contact the authors for more information.

Acknowledgments

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DEVELOPING A TECHNICAL AND CONDITION DATABASE FOR CALIFORNIA NATIVE AMERICAN FEATHERWORK

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Abstract.—A conservation survey instrument designed to provide a searchable resource for information about indigenous featherwork has been successfully developed and piloted, focusing on material from California. Feathers and their colors have cultural significance to regalia makers and basket weavers in California, and different colorant systems found in undyed feathers account for differences in their susceptibility to fading. The survey form uses controlled vocabularies and visual glossaries to assist stewards in recording feather descriptions, cultural modifications, attachment methods, and conditions, including evidence of color change. In developing the survey as a tool for searchable reference information, rather than as a device for comparing items within a single collection, a large user pool is both possible and desirable. The collections reviewed thus far include California native featherwork selected from eight major collections. This paper describes the survey design and preliminary results gained from a review of 124 feathered regalia and baskets.

INTRODUCTION

Among the noteworthy indigenous cultural expressions found in California, basketry and feathered regalia stand out as especially significant. Although the history of native California is characterized by interrupted cultural traditions, both baskets and featherwork are well-represented in early collections and have been revitalized in traditional and contemporary forms. In the cultural expression of basketry, organizational efforts have flourished to prevent plant gathering sites from pesticide applications in order to protect both weavers and materials; for example, in California since 1993 (California Indian Basketweavers Association n.d.). Sustenance of featherwork in California has no such organizational authority, and working with feathers has been impacted by increased distance between artists and bird habitations, the extinction of traditionally important bird species (Bates et al. 1994), and state and federal migratory and endangered bird acts that present challenges for regalia makers and weavers seeking to obtain feathers (McCoy 1991, US Fish and Wildlife Service, n.d.). Political and cultural influences affected the types of items fashioned by regalia makers and basket weavers in California beginning ca. 1900, with specific feather forms emblemizing a pan-Indian during the early 20th century (Cothran 2010). The present emphases on repatriation of ceremonial feather regalia by California tribes, as well as the creation of specific tribal guidelines for feather preservation, illustrate a sustained interest in traditional featherwork and in the ceremonies they represent (Barnard 2009, Repatriation and Collections Management of the Yurok Tribe n.d.).

This sustained community interest in native featherwork has been accompanied by changes in feathered regalia and baskets. Reports from contemporary featherworkers, evidence of the physical replacement of feathers with dyed yarn on baskets, and publications of books describing how to replicate feathers of protected species (such as eagle) using chicken feathers (Forsythe 2008)—and vendors who provide such replicas (Crazy Crow n.d.)—indicate the evolution of traditional practices. Because cultural

meaning and preservation measures, including sensitivity to light and ultraviolet radiation, vary for different feathers depending on their natural coloration and structure, it is critical for stewards of feather collections to be able to discriminate between feather types (Horie 1990, Solajic et. al. 2002, Pearlstein and Keene 2010). The current project includes the development of an item-by-item survey to assist stewards in the development of: 1) a technically accepted vocabulary for feather structures; 2) descriptive language about locations of color within the feather, useful to ornithologists for species identification (Dove and Koch 2010); 3) condition descriptions that draw on ornithological research about lifecycle damage and distinguish these from collections conditions; and 4) standardized terminology about the ways feathers are culturally modified (i.e., split, blunt cut, serrated). The planned transfer of this resource to the Web to provide increased access by collections' stewards also will allow for regalia makers, weavers, and ornithologists to exchange information about feather identification, usage, modifications, and observed damage.

Survey

During 2009–2010, a detailed survey form for recording aspects of indigenous featherwork was developed and piloted through use in museum collections, mainly in southern and central California. The survey is part of a larger research project on feather preservation which, until a recent publication (Brunn and Burns 2005) and course (SPNHC and CBA n.d.), saw little attention from conservators, and still sees little research benefitting from interactions between indigenous cultural experts, ornithologists, and conservators. The survey format was designed to prompt users to enter information adapted from accompanying glossaries, which in an online format can be accessed through links to other websites referenced in this article. The survey was conceived as a pilot that can ultimately serve as a research resource for the exchange of cultural, technical, and condition information about California feathered regalia.

The objects surveyed fall into three large cultural groups: northwestern traditions of the Klamath River, including the Yurok, Karuk, Hupa and Wintu; central California Sierra traditions, which include the Pomo, Patwin, Miwok and Maidu; and southern California ''Mission'' tribes including Cahuilla (Fig. 1: Map of California tribes). Collections surveyed and numbers of items examined at each location are included in Table 1. California native collections at many of these museums are larger in number than what could be physically viewed; therefore, criteria were developed for selecting objects for study. Feather regalia from northern and central California were selected in preference to feathered baskets, and items for which feathers were specifically identified in the respective museum catalog were given preference.

The types of feathers found in American Indian California featherwork in North American collections vary based on the object type and purpose, creation date, location, and circumstances surrounding creation. The extent to which feathers are accurately identified has depended on the scholarly interests of the original collectors and subsequent review by native specialists, ornithologists, and ethnologists who informed the object record (Bates 1993). In the case of collections from California, those who assembled and later cataloged collections are well-known and include Stewart Culin, Roland Dixon, John Peabody Harrington, John Hudson, Charles Wilcomb, and more recently Craig Bates, Brian Bibby, and Sally McLendon (Dixon 1905, Walsh 1976, Fry 1979, Bates and Bibby 1980, Fane 1991, Bates 1993, McLendon 1993). California collections include feathers generally readily identified due to their distinct visual

Figure 1. Map of California Indian pre-contact tribal territories, redrawn from http://www.kstrom.net/ isk/ maps/ca/california.html.

appearance, such as Red- and Yellow-shafted Subspecies of the Northern Flicker tail and wing, Pileated Woodpecker scalps, Acorn Woodpecker crests, Red-tailed Hawk tail, Mallard duck scalps, and California and Mountain Quail topknots. However, creators of regalia and baskets also make use of less readily identified feathers, especially those used

Table 1. Collections and number of objects reviewed.

Collection title	Number of objects
California State Indian Museum, Sacramento, California	18
Field Museum, Chicago, Illinois	25
Oakland Museum of California, Oakland, California	9
Phoebe A. Hearst Museum, Berkeley, California	24
Point Reyes National Seashore Museum, Pt. Reyes National Seashore, California	1
San Diego Museum of Man, San Diego, California.	15
Southwest Museum at the Autry National Center, Los Angeles, California	12
Yosemite Museum, Yosemite National Park, California	20

as small fragments or to imitate others, (i.e., chicken or goose in place of Flicker feather shafts; B. Bibby, California Indian Ethnologist pers. comm. 2010).

Survey Development

The design of the current survey draws on both traditional conservation survey strategies and online sources with thesauri and metadata prepared by the authors for shared sites of documentation, with the intention to create a ''data exchange standard'' for featherwork (Elings 2007). The idea of standardized and searchable language in conservation documentation is not embedded in conservation practice, and survey data typically are not designed to be shared among institutions. Comparable initiatives to create online repositories for conservation documentation have focused predominantly on paintings. Web sites designed to permit technical comparisons have been developed for hosting technical data and images provided by conservators about geographically dispersed but technically related paintings (for example by assembling images of brushstrokes, pigment dispersion samples, and paint cross-sections), (Lahanier et al. 2002, Master of the Fogg Pieta n.d., National Gallery of London n.d.).

Within the field of conservation, collections surveys most often are performed within a single collection or institution to assess conditions of objects or environmental conditions, with a goal toward assessing and managing risk (Keene 1992, Taylor 2005). For example, recent surveys within natural history collections are designed to evaluate massive diverse collections according to discrete categories which then are scored to provide rankings for mitigation (Favret et. al. 2007). In the case of the current survey, it is designed to include conservation, technological, historical, and indigenous information about feathers. The survey expands upon ongoing research into the fading behavior of biological colorants and structural colors in featherwork, in that it asks surveyors to estimate degree of fading perceptible on each type of feather used. It also responds to conservation research needs articulated in a 10-year-old study in which natural history stewards identified preservation of color in biological specimens, effects of light and radiation, and accurately assessing condition as three priorities for future study (Cato et al. 2001). Therefore, instead of surveying diverse subcollections within a single institution for comparative evaluations of condition, the California Feather Reference Resource seeks to probe deeply into a discrete group of related objects found in various institutions.

The survey has been developed as a pilot and was used to record data about 124 objects from eight collections. The survey form was developed using FileMaker Pro 10, a relational database with options to create customized layouts and the possibility for web publishing. The most important survey data fields and search capabilities are outlined in Table 2. The user creates a unique record for each cultural object.

Other data that are considered equally significant, including feather-collecting practices and traditional use and storage of feathered regalia and baskets, are being gathered through consultation, and will be invited through the web format. The ability to connect fading or insect-deterioration data collected through the survey to native use and preservation methods is a significant anticipated outcome.

Feather Identification

The survey process encourages users to visually distinguish between different feather types, and to then record details about color, structure, and size, as well as modification and condition, for each feather type. Such details, which normally might not be

Table 2. Survey data fields and searchable data.

Information recorded in FileMaker Pro database	Searchable relational data
Description of feathers	Identification of unidentified feathers
Description of feather modification practices	Catalog of technology
Description of attachment methods	Catalog of technology
Specific associations of feather types with certain regalia and baskets	Relationship of feather type/color to type of regalia
Condition of each type of feather found	Relationship of feather type/color to condition
Evidence of fading	Relationship of color chemistry to fading
Evidence of lack of fading	Relationship of color chemistry to fading
Evidence of attraction to insects	Relationship of color chemistry/feather type/regalia type/collection data to insect damage
Ability to connect fading or insect deterioration to museum display, storage or treatment conditions	Condition trends

documented in conservation records, are essential for feather identification. Examples from the survey include PAHMA 1-2343, a Hupa, Yurok, or Karok headdress for which "feather 2" was recorded as measuring 15–17cm × 2.5–3cm, and as a probable wing or tail feather with a pennaceous barb structure. These feathers were described as having alternating brown and tan to white stripes of equal width on the ventral and dorsal vanes. In most cases, the shaft also is striped on both sides; in some cases, the shaft is solid brown on the ventral side and striped on the dorsal side. A record of feather dimension and the striped patterning within the shaft permits nondestructive identification of this feather as a gamebird, i.e., likely turkey, rather than hawk, on a headdress that includes feathers of both types (Fig. 2: Hupa, Yurok, or Karok headdress, PAHMA 1-2343). This

Figure 2. Hupa, Yurok, or Karok headdress (Phoebe A. Hearst Museum 1-2343).

Table 3. Bird feathers identified in original study.

Common name	Scientific name	Color chemistry	Native California use
American Goldfinch	(*Spinus tristis*)	Carotenoid[a]	Yellow feathers on head, chest and back, golden yellow feathers used in basketry and in deer skin belts, made by covering belt in pine pitch to adhere feathers
Mallard	(*Anas platyrhynchos*)	Structural colors resulting from melanin[b]	Scalp and neck feathers used in blankets, robes, belts, and basketry
Northern Flicker	(*Colaptes auratus*)	Carotenoid[c]	Whole wing and tail feathers and shafts used; dominant in headdresses but also in baskets
Red-tailed Hawk	(*Buteo jamaicensis*)	Not characterized	Arrow fletching, and for dance regalia and fire fans
Great Horned Owl	(*Bubo virginianus*)	Melanin, porphyrins[d]	Down, breast, wing, and tail feathers
Western Scrub-Jay and Steller's Jay	(*Aphelocoma californica*) and *Cyanocitta stelleri*)	Structural[e]	Wing and tail feathers used in ceremonial dress

[a] McGraw et al. (2001).
[b] Watanabe et al. (2005).
[c] Stradi et al. (1998).
[d] With (1978).
[e] Bancroft and Woolfenden (1982).

conclusion can be drawn by connecting survey data with information provided in a web-accessible wildlife identification guide (Trail 2003).

The identification of feather types is important for understanding their preservation, because feathers vary in their biochemistry and structure, and photochemical and mechanical damage patterns, as well as possible biodeterioration patterns, are species-specific (Hudon 2005). As the authors surveyed collections, an increased familiarity with feather morphology and color developed, enabling more precise identifications for readily identified feathers. For half of the material reviewed, the surveyors indicated that all of the feather species were identified either by the museum documentation or through observation. Although museum documentation sometimes can record erroneous information and often omits data, and the authors selected items with identified feathers for review, it is noteworthy that the feathers were fully unidentifiable in only four of 124 instances.

At the outset of the project, the authors were particularly interested in examining items made using feathers from seven bird species identified as significant in California regalia of the Central region by ethnographer Craig Bates (1982), but also with unique color chemistry, which are simultaneously being studied by the authors for stability to light aging. These seven species appear in Table 3. As the survey progressed, 41 different species were identified by the authors with information derived from observation, catalog records, or consultants with whom the authors discussed the collections. The feather types which occurred most frequently (not surprisingly for the group initially identified for study) are: Red-shafted subspecies of the Northern Flicker (*Colaptes auratus cafer*), Pileated Woodpecker (*Dryocopus pileatus*), Acorn Woodpecker (*Melanerpes formicivorus*), Mallard (*Anas platyrhynchos*), Red-tailed Hawk (*Buteo jamaicensis*), Steller's Jay (*Cyanocitta stelleri*), owl (possibly Great Horned Owl or *Bubo virginianus*), Wild Turkey (*Meleagris gallopavo*), and California

Quail (*Callipepla californica*, found predominantly on Pomo baskets). A variety of yellow to orange feathers noted in museum records as oriole, meadowlark, goldfinch, or canary, which based on species available in California are likely to be Bullock's Oriole (*Icterus bullockii*) or Hooded Oriole (*Icterus cucullatus*), Western Meadowlark (*Sturnella neglecta*), American Goldfinch (*Spinus tristis*), or Common Canary (*Serinus canaria*), require a record of further discriminating features to be accurately distinguished on collection materials (American Ornithologist's Union 2011, Poole 2005, Scott and McFarland 2010).

Of equal importance to the written documentation in recording feathers are images that serve as an important resource to aid in feather identification. Such images exist on freely accessible databases that permit researchers to search by scientific or common names. The advent of high-resolution scanning followed by color correction has spawned various websites with searchable images. Excellent examples described in their order of creation date are: Feather Atlas for Birds of the Western Palearctic, part of The Featherguide Organisation (n.d.), the Wing Image Collection of the University of Puget Sound, Washington (University of Puget Sound 2010), and The Feather Atlas website sponsored by the US Fish and Wildlife Service Forensics Laboratory (2010). The first site originated in 1994 with a goal of mapping the feathers of all bird species of Europe, North Africa, and the Middle East. Each record includes detailed data, with a stated goal of attaching chromaticity and luminosity data to each feather, which permits more precise color recordation. The creators of The Feather Atlas for Birds of the Western Palearctic (n.d.) describe their process in the following quote.

> A set of parameters will be applied to each species, describing the structure and colour of its feathers, including differences of sex, age, and subspecies. Structural parameters include absolute and relative lengths of feathers, proportions of vanes, emarginations, tip shapes, curvature of shaft, etc. A second database for statistical evaluation of measurements was programmed in FileMaker Pro, and more than 30,000 measurements were already entered. Colour parameters include a classification of colour patterns and numeric colour coordinates. Colour names used in the literature to describe bird plumage are often very subjective and imprecise. With the colour model used and the standardized method by which the feathers were scanned, it is possible to give precise coordinates of chromacity and luminosity for each tone of colour, thus making it possible to distinguish similar species from each other by numeric colour criteria—called ''colour fingerprinting''—rather than by subjective colour names.

At the present time, users can access a sample PDF describing the curlew (*Numenius arquata*), which includes images of wing and tail coverts, as well as body feathers (for example from the throat, rump, scalp, and chest), with a measurement scale and descriptions of plumage structure and coloration (Anonymous n.d.). North American species of cultural importance are included in the species list, but searchable high resolution images are not yet available.

The second site was created between 1997–2005 using collections owned by the Slater Museum of Natural History at the University of Puget Sound, and wing specimens loaned from the Burke Museum, University of Washington, and does not include uniform scales or color correction to the images (University of Puget Sound 2010). The Wing Image Collection includes both dorsal and ventral views of wing feathers from many culturally significant birds in California; for example, the Northern Flicker and Pileated Woodpecker. However, because scalp, throat, and chest feathers from different woodpecker species are found on regalia and baskets, further reference material is needed to assist with feather identification on regalia.

The Feather Atlas website sponsored by the United States Fish and Wildlife Service Forensics Laboratory (2010), a resource designed to aid in the federal enforcement of bird protection, became available in 2010 and continues to be expanded. At the time of this writing, the site included high-resolution scans of the flight feathers from 172 North American birds. Scans typically include the dorsal side of 12 wing feathers and six tail feathers, with flight feathers from both male and female birds in cases of sexual dimorphism. The authors of this paper currently are producing a searchable image database of feathers from species valued for California regalia to complement many that are found in The Feather Atlas produced by the United States Fish and Wildlife Service Forensics Laboratory. In a digital environment, the survey developed here will allow linkage to scanned images to aid in identification of feathers found in regalia. A printed resource recently authored by Scott and McFarland (2010), which includes color images and measurements of feathers from the whole body of 379 species of North American birds, serves as another reference for collections' stewards.

Survey Results

Objects surveyed by the authors included 25 baskets and 99 items of regalia. Sources for objects as recorded in collection catalogs were divided by the authors according to originating regions within California, including northern (north of the Sacramento River Valley including the Shasta region, central (Sacramento and San Joaquin Valleys and foothills), and southern (Southern desert region) (see Fig. 1). Regional attribution achieved greater accuracy than tribal attribution because in numerous cases, multiple tribes were acknowledged as the possible source by the museum. Authors sought to emphasize central and northern California materials; consequently, 74 central and 39 northern objects were reviewed, but only 15 southern California items were reviewed.

Attachment and Modification Methods

Standardized vocabularies for describing cultural modifications occur in some collections databases to permit researchers to study regional and individual methods of fabrication. An excellent example for American Indian collections is the National Museum of American Indian Techniques Reference List (n.d.), where specific terminology includes, for example, basketry and quillwork methods. Although there are numerous modification and attachment methods employed when feathers are used, these methods are not part of any currently available vocabulary known to the authors. Feathers are attached to their support using varying methods, and the feathers themselves are modified in a variety of ways, each of which contributes to the complexity of the appearance and influences the flexibility of the feather in movement. Feathers of some of the same birds are found used on regalia either attached to the skin or separated from the skin. Of the 41 feather types observed on the regalia and basketry, only six species were observed as used with the feathers attached to the skin. These species are Pileated Woodpecker, Mallard, Acorn Woodpecker, and an unidentified hummingbird, with rare instances of Red-tailed Hawk and California Quail. The last two types of feathers are more often found plucked from the skin.

Attachment methods used to secure feathers to supports such as semitanned skins, textiles, and basketry are remarkably universal, evidenced by comparisons between regalia throughout the USA and methods applied, for example, to Amazonian featherwork (Torrecilla and Varela 1993). In order to permit attachment methods to be compared between different featherworking traditions, the following terms were developed for describing attachments:

Figure 3. Feather attached by folding the calamus and wrapping with sinew (San Diego Museum of Man 1961.30.2).

- Tied: fastened with a string, cord, thread, etc. by knotting around the feather
- Adhered: attached with an adhesive
- Couched: vane or shaft secured with multiple visible stitches
- Folded: feather calamus or shaft folded around other element(s)
- Inserted: captured in a gap or between woven, coiled, or netted elements, contributing to surface but not the structure
- Feather wrapped: feathers used for wrapping around another element
- Feather woven: feather used as an element in twining or coiling, which contributes to structure

California regalia surveyed showed widespread use of the attachment method where the calamus is folded onto itself and around another element, typically sinew, processed plant fiber, or commercial thread, which is stitched to the support. The folded calamus is sometimes wrapped with sinew or thread to maintain the fold (Fig. 3). Thirty-five of the regalia items examined had this type of attachment for at least one of the feather types. This form of attachment is associated with skin supports for headdresses, and it results in the feathers being held in a specific orientation (dorsal or ventral) and gives the feather restricted movement (Fig. 4). Thirty-seven items had tying as the only method of support, i.e., with a straight calamus, and this was restricted to tremblers and head plumes, where feather movement is critical to function (Fig. 5). Fourteen items had feathers couched to the support, which is coupled with adhesive joining; these methods typified feather application to Hupa Jump Dance headdresses (Fig. 6).

The methods for incorporating feathers into Pomo coiled basketry was consistent throughout and is described by master weaver Elsie Allen (1972) in *Pomo Basketmaking* as placing the scraped calamus at a 45-degree angle to the basket foundation rods, and then catching the feather tightly in the stitches. Pomo weaver Susan Billy described

Figure 4. Hupa headdress with top feathers secured in specific positions (California State Indian Museum S1194.52).

Figure 5. Pomo tremblers with feathers tied so each calamus is straight (Oakland Museum of California Art H16-520E).

feather baskets as being made by twisting the prepared feather calamus within the basket stitching material while weaving (Billy 2010). In the survey, the phrase ''inserted'' was designed to refer to these methods as distinct from feathers used as elements in wrapping or weaving. However, surveyors were inconsistent in describing feather attachments in

Figure 6. Hupa Jump Dance headdress with feathers attached with a combination of adhesive and couching (California State Indian Museum 309-2-4357).

Figure 7. Northern Miwok dance stick with feathers with split shafts (Yosemite Museum 26055).

baskets as being inserted versus woven. Also wrapping was used even when the feather wasn't doing the wrapping. These inconsistencies support a current initiative to provide visual details taken from objects that illustrate these methods. The proposed revised terminology is to refer to the method as "captured in weaving stitches."

Feathers not only are used whole but as fragments; for example, as tufts of barbs. Whole feathers often are modified with techniques such as trimming barbs, removing barbs, shaping sections of the vane to influence feather shape, and splitting the shaft partially or completely to create a more flexible structure (Fig. 7). Many feathers have colored wrappings near the base, which can be culturally significant in California regalia, or feather extensions applied near the tips (Fig. 8). Modifications made to whole feathers were described using the following terminology in the survey (more than one of these modifications is possible per feather):

- Folded: part of feather bent over onto itself, unrelated to attachment
- Cut: reduced or trimmed with a sharp instrument
- Blunt cut: trimmed to a straight edge
- Serrated: vane cut or altered to create zig-zag
- Shaft notched
- Curled: formed into a curved shape
- Split: divided or separated from end to end into distinct parts
- Stripped: parts of feather removed (one or both of the vanes separated from the rachis)
- Shaft extension: feather shaft wrapped with or adhered to another element, such as thread or secondary feathers
- Spliced: two or more feathers combined to make one feather

Interestingly all of the examples surveyed with serrated feathers are from northern California (Fig. 9), and half of the examples surveyed with split feather shafts include owl

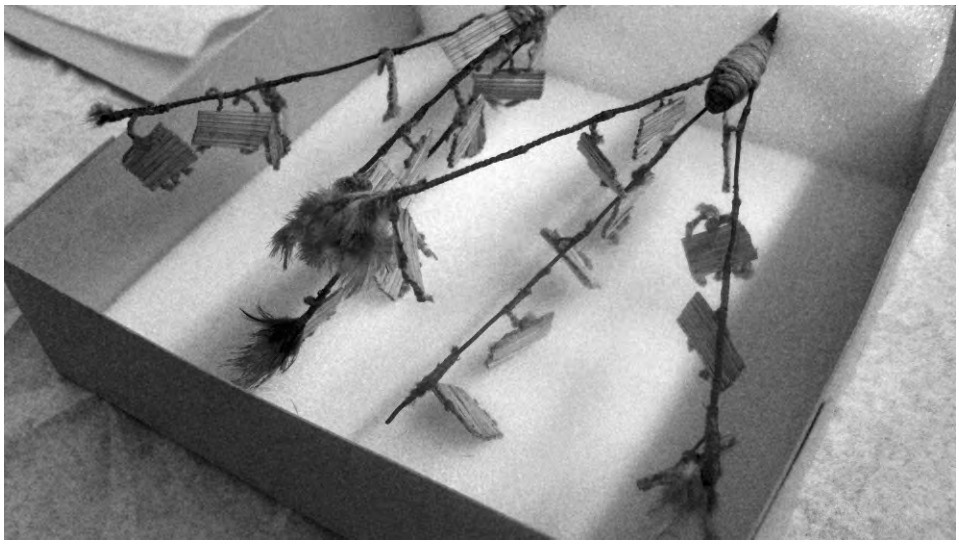

Figure 8. Maidu tremblers with feathers secured by wrapping (Oakland Museum of California Art H16-2322B).

feathers and are from southern California. Not surprisingly, the central California tradition of stripping the vane off Northern flicker feathers and using the shafts for headdresses dominated this type of modification (Fig. 10). Blunt cutting and uneven cutting were found on both regalia and baskets from all regions. The category of shaft extension was added after the pilot phase after examples were noted (Fig. 11).

Damage

As previously mentioned, the survey was developed as part of a larger study about the preservation of color in undyed feathers of cultural value (Pearlstein and Keene 2010). The survey showed that the visual detection of fading of feathers used in regalia and basketry is unreliable. The survey allowed conservator reviewers to rank the degree of fading detectable between one (least fading) and five (most fading), and to describe the basis for the detection, i.e., concealed or reverse surfaces with contrasting color retention. All feathers ranked as two or three are those with yellow or red biopigment coloration. Although it could be the case that these colorants, largely carotenoids, are the most fugitive, surveyors were unable to provide an objective basis for making this determination. For example, museum stewards were generally unable to report on cumulative lighting or ultraviolet radiation exposure received by feathers, and, not surprisingly given the specificity of fastness, only certain feathers found on single objects showed evidence of color loss or change while others did not.

Much more widespread deterioration is attributed to insects. Of the 124 items evaluated, 84 items showed some evidence of insect damage, with narrow, elongated losses of barbs being the most prevalent detectable result. Each of the institutions whose collections were surveyed reported an historical application of insecticides to feathered material during their stewardship. It is difficult to map damage against applications of insecticides, and it is clear that items in all of the museums surveyed showed evidence of insect damage to feathered collections. Likely due to the current small population of items surveyed, no one particular feather type was recorded as more susceptible to

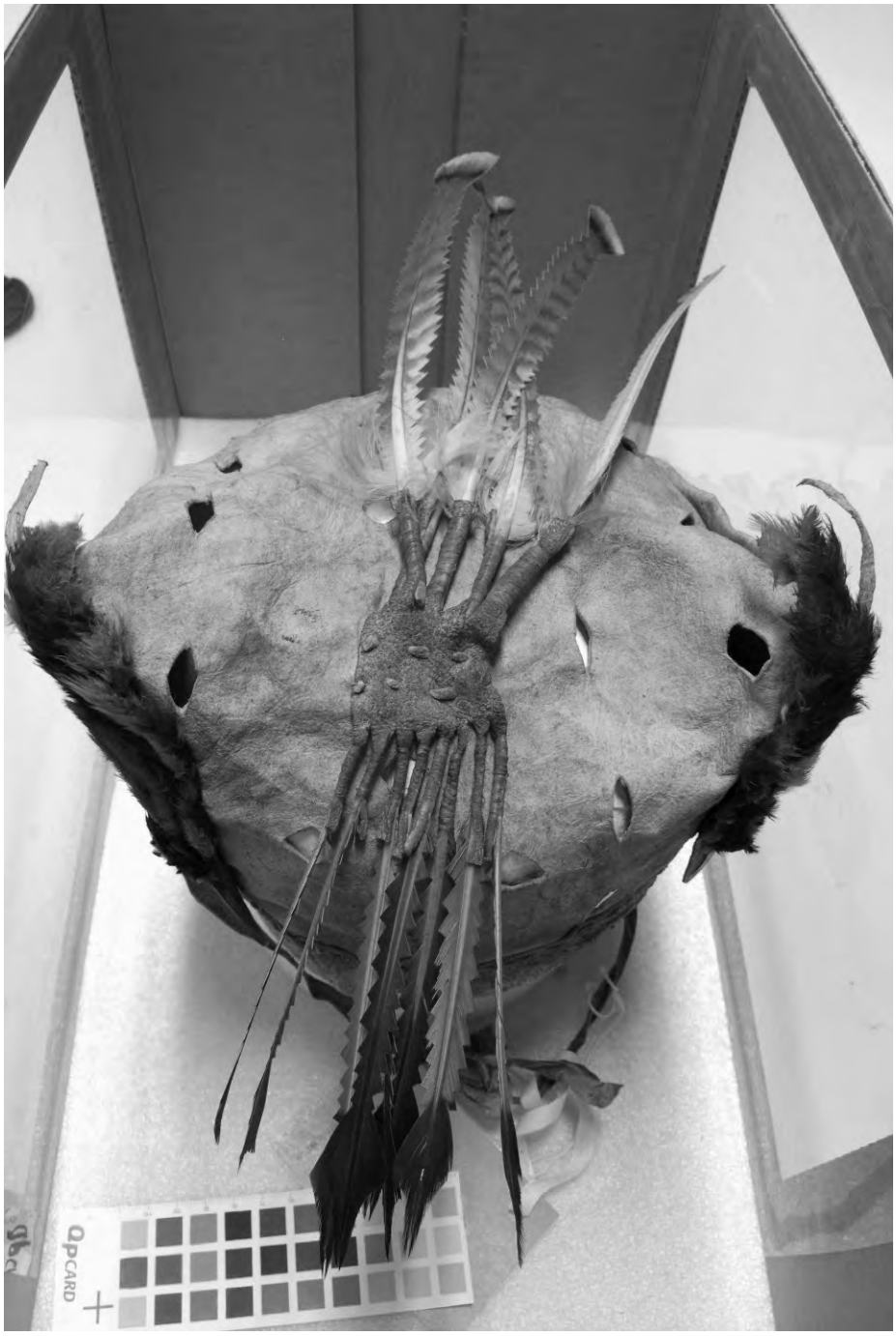

Figure 9. Achumawi headdress with serrated feathers (Field Museum 58942).

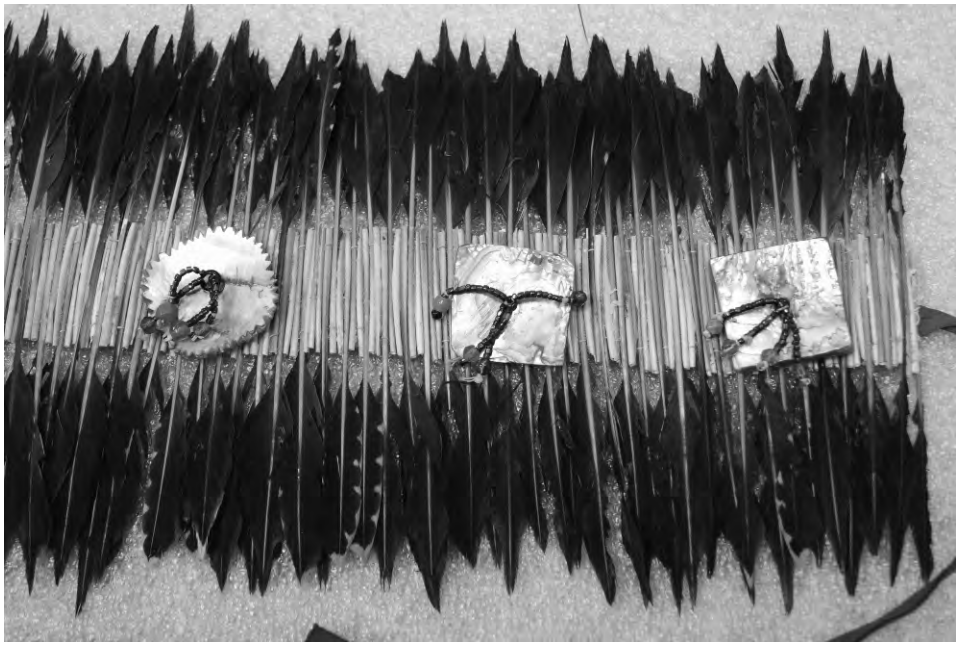

Figure 10. Southern Miwok headband with stripped feather shafts (Yosemite Museum 26818).

biodeterioration, although one-third to one-half of the items with Northern Flicker, Mallard, and Great Horned Owl showed evidence of insect damage. Steller's Jay wing feathers, which are readily identified in California materials because of their banded patterning and color, demonstrated uniform deterioration wherever found.

A form of lifecycle damage found in feathers when birds have suffered dietary or other stress has been described as "fault bars." First described by O. Riddle in 1908, fault bars refer to a variety of growth interruptions in feathers that result in less dense linear areas—generally due to a lack of barbules—occurring in a pattern perpendicular to the barbs. Riddle's early work indicated that fault bars occur in all bird species; however, occurrence increased among domesticated and caged birds versus those found in the wild (Riddle 1908). Subsequent research has indicated that fault bars are most prevalent on wing and tail feathers, and within the wing, they are likelier to be found on proximal rather than distal flight feathers, because the distal or outer flight feathers are more essential to flight (Jovani et al. 2010). Eight of the items surveyed had feathers that displayed fault bars; the majority of these were flight feathers from medium to large birds such as condor, eagle, hawk, grouse, goose, and turkey (Fig. 12). Also noted were fault bars on Steller's Jay feathers. Compilation of further data could assist collections' stewards in accurately designating damage.

Conclusions

The design of a survey tool that links collections stewards to ornithological feather identification tools, to visual glossaries for describing modifications and attachment methods, and to cultural sources identifying feather preferences has been demonstrated to be effective for analyzing feather types, deterioration, and cultural decision-making. Results from the preliminary survey of California featherwork indicate that museum

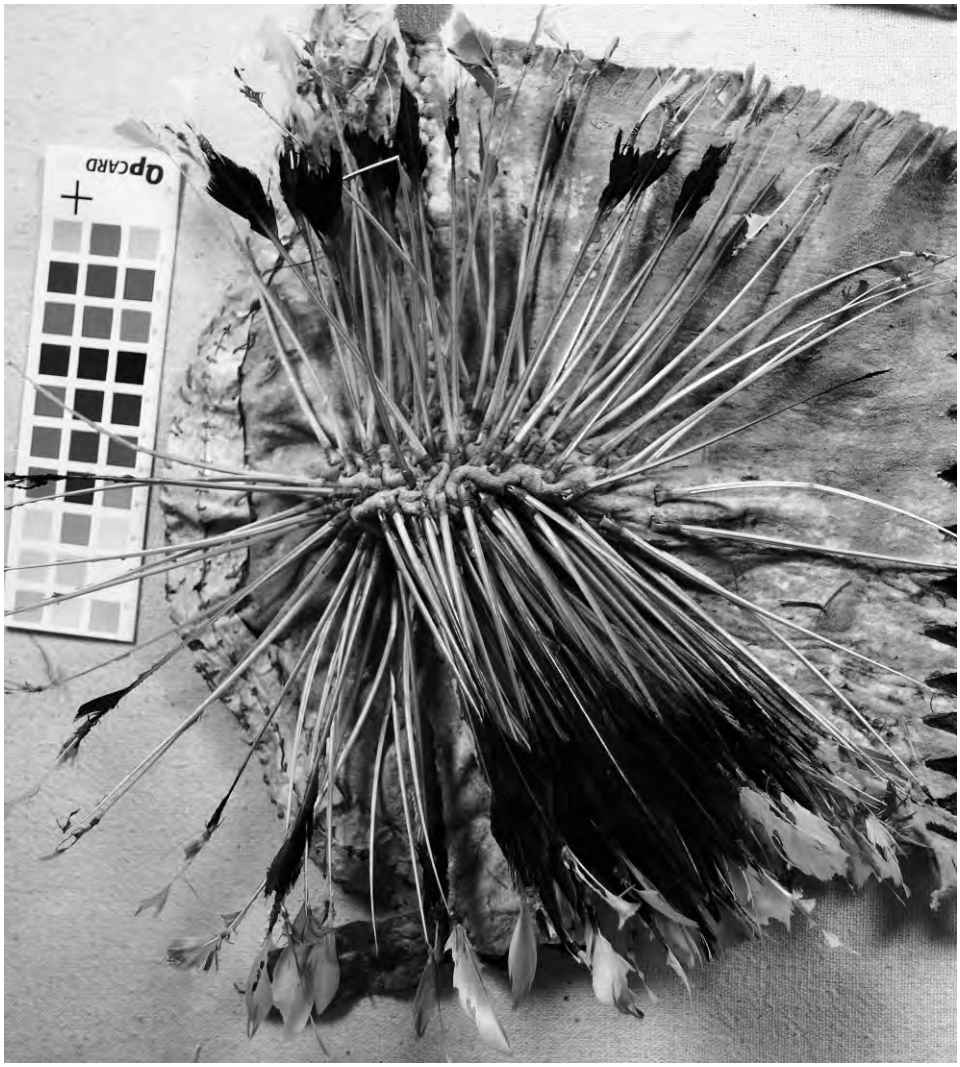

Figure 11. Yurok headdress with feather shaft extensions (Phoebe A. Hearst Museum 1-1230).

Figure 12. Detail of Luiseño skirt feathers showing fault bars (San Diego Museum of Man 1965.054.0001).

conservation specialists, with support from contemporary cultural experts and ornithological and ethnographic resources, are able to enrich the record of feather types, technologies, and meanings. Creating detailed records from various collections of California featherwork has allowed the authors to make preliminary observations about feather usage, regional modifications, and universal attachment methods. Similarly, questions about condition trends, such as tendencies toward fading based on colorant system, nonspecies-specific appearance of insect deterioration, and correlations between bird size and presence of fault bars, can begin to be addressed.

Interpretation and preservation of featherwork in collections ultimately relies on identifying the feathers in order to understand their color chemistry and distinguish between lifecycle and collections damage. The current survey not only has demonstrated promotion of the conservation research needs articulated by natural history stewards (i.e., preservation of color in biological specimens, effects of light and radiation, and accurately assessing condition; Cato et al. 2001), but has identified a method for specifying this research by collecting broad comparative data using controlled vocabularies and educating stewards through interdisciplinary sources. Resources identified in this paper are available to support discovery and dissemination of these data, and their linkage to a shared survey instrument is proposed to provide a valuable contribution to feather research.

The information gathered about local color selection and feather manipulation is significant to indigenous communities, because regalia and baskets are created from feathers and birds that reflect cultural and ceremonial associations, tribal aesthetics, and performance, as well as feather availability. The repatriation of ceremonial feather regalia by California tribes and the development of tribal guidelines for feather preservation indicate significant developments in stewardship. A shared resource that provides a forum as well as a survey repository would permit access to information about diverse collections and would permit consultations to take place over great distances.

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A GRAND SCALE: REHOUSING THE MOLLUSK COLLECTION AT THE ACADEMY OF NATURAL SCIENCES OF PHILADELPHIA

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Abstract.—The rehousing of the vast dry mollusk collection at the Academy of Natural Sciences of Philadelphia is described. Considerations regarding the existing building, the choice and design of new equipment, and the logistics of the project are discussed, together with evidence for its necessity.

Introduction

The Academy of Natural Sciences of Philadelphia (hereafter "The Academy") is the oldest natural history museum in the USA. Among its myriad treasures, it boasts the third-largest mollusk shell collection in the world by volume, with roughly ten million dry specimens in 450,000 lots and an extensive fluid-preserved collection. Shells have been a mainstay of the institution's holdings since its founding in 1812, and the collection has enjoyed an unbroken succession of curators and managers since the establishment of its Conchological Section (now the Department of Malacology) in 1866. The many great names in the field who have worked in the department include Thomas Say, Timothy A. Conrad, Isaac Lea, George W. Tryon, Henry A. Pilsbry, and R. Tucker Abbott.

In 1975, George Davis, then chairman of the department, initiated computerization of the collection, one of the first such efforts among world natural history museums. From that year onward, each new lot was recorded in a database with details of its collection and provenance. In 1999, work commenced on digitizing data from the ledger books that recorded all the lots prior to 1976; following the completion of that project, the two bodies of data were amalgamated.

The first comprehensive rehousing of the dry shell collection took place in the 1950s, under the supervision of curator R. Tucker Abbott. The shells and their labels were placed in standard-sized cardboard trays in new cabinets. Many specimens had until then remained glued to display boards that dated from the 19th century. These boards were retained, because they often provided the only collection data, but they often were cut up or trimmed to fit into a smaller space. The catalog numbers were written onto the detached specimens.

The trays were placed in drawers constructed with a pine frame and a Masonite base that in turn occupied steel stationery cabinets sourced from a local office equipment manufacturer and fitted at the Academy with custom interiors made of pine, plywood, and galvanized steel sheet (Fig. 1). A total of 228 cabinets and 11,700 drawers were required to house the dry shell collection, and these were distributed throughout the top floor of the 1908 building.

This history is pertinent to the rehousing project described here in that it demonstrates the importance of a broad range of knowledge and abilities in curatorial staff. R. Tucker Abbott himself helped design and fabricate the cabinet interiors, and raised the funds to buy many of them by offering sponsors the chance to name individual units. Significant further savings were made by adapting existing office cabinets rather than purchasing specialist museum equipment, and through the considerable contributions made by volunteers to the physical work.

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Figure 1. A row of the 1950s cabinets.

Reasons for a Second Rehousing

By 2002, the Academy's mollusk collection ranked among the world's largest in terms of the number of specimens. Nearly two centuries of collecting on expeditions and acquiring whole collections meant that many of the existing drawers were full, but aside from this, there were two specific conservation issues that made rehousing the collection a priority.

"Byne's Disease"

Compared to many natural objects, mollusk shells are relatively durable. Most of them tolerate fluctuations of temperature and humidity that would damage a botanical or entomological collection, but they are not indestructible. Their colors fade with continuous exposure to light, and some split and crack if humidity levels fall too low. Insects pose problems too, though they tend to attack labels and tissue dried inside the shells rather than the shells themselves. From a long-term collections management view, however, the most important issue is damage from acid vapors.

"Byne's Disease" is a well-documented phenomenon (e.g., Tennent and Baird 1985, Shelton 1996) that most frequently is recorded in shell collections. Acetic and formic acids are given off as a product of the natural decay of cellulose, the basic material of wooden drawers, paper trays, and cotton stoppers (Tétreault and Stamatopoulou 1997).

In the presence of even minute quantities of water vapor, the volatile acids react with the calcium carbonate of the shells. A simple reaction produces calcium acetate/formate compound salts and water, eroding the shells in the following processes:

$$CaCO_3 + 2\ CH_3COOH \rightarrow Ca(CH_3COO)_2 + H_2O + CO_2$$

(calcium carbonate + acetic acid → calcium acetate + water + carbon dioxide)

and

$$CaCO_3 + 2\ CH_2O_2 \rightarrow Ca(HCOO)_2 + H_2O + CO_2$$

(calcium carbonate + formic acid → calcium formate + water + carbon dioxide).

Left unchecked, this process can entirely destroy specimens, especially very small ones (Fig. 2), and like all such reactions it is accelerated by heat and humidity. As the salts themselves are hygroscopic, individual specimens can deteriorate very rapidly while those around them remain relatively unscathed. The reaction can be stopped by soaking and washing shells in clean water and then moving them to a dry, acid-free environment, but the damage cannot be repaired. Byne's Disease is quite common in private and museum collections worldwide, and the authors have seen many cases over the years.

''Glass Disease''

Many of the Academy's shell specimens are sufficiently small to require keeping them in glass vials, of which there are over 200,000 in the collection. The majority of these were older items made of soda glass, which long has been the most common kind for commercial and scientific use because it is cheap and easily worked. Many of the older vials were made of relatively poor quality glass that has proven chemically unstable over very long periods.

Soda glass is mostly sodium metasilicate ($Na_2O{\cdot}SiO_2$). Given the presence of water and sufficient time, sodium compounds are leached out of the silicate matrix and then themselves react with atmospheric moisture to form a hygroscopic alkaline compound as follows:

$$Na_2O{\cdot}SiO_2 + H_2O = SiO(OH)_2 + Na_2O$$

(sodium metasilicate + water → dihydroxy silicone + sodium oxide), then

$$Na_2O + H_2O = 2\ NaOH$$

(sodium oxide + water = sodium hydroxide), then

$$2\ NaOH + CO_2 = Na_2CO_3$$

(sodium hydroxide + carbon dioxide = sodium carbonate, then

$$Na_2CO_3 + 10\ H_2O = Na_2CO_3{\cdot}10\ H_2O$$

(sodium carbonate + water = sodium carbonate decahydrate).

As the reaction progresses, the glass gradually weakens and becomes opaque. The solution forming in droplets on its surface stains both specimens and labels and can remove periostracum from shells. Although not strongly basic in these concentrations, the

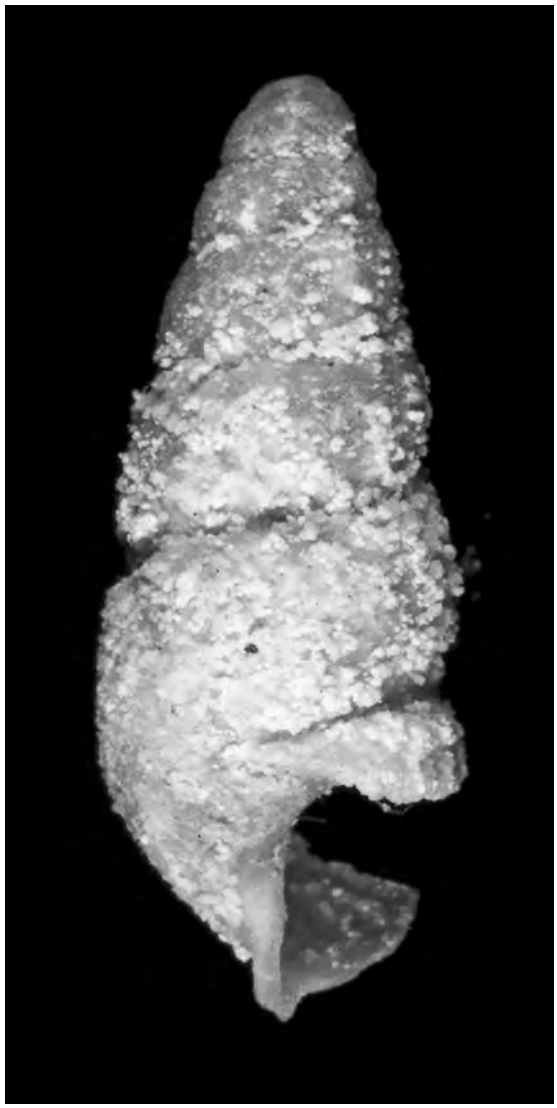

Figure 2. A gastropod snail shell almost consumed by Byne's Disease.

substance involved is lye, and thus is not to be ignored. This process is known informally as ''glass disease,'' and is well known to museum conservators and curators (Figs. 3, 4).

It is quite possible that the presence of large amounts of decaying glass in the Academy's cabinets acted as a buffer to the acid fumes and thus prevented far worse damage from occurring. Although this could not be conclusively proven, it was clearly sensible from a conservation perspective to replace both decaying materials at once.

The Collection Environment

The design of the 1908 building (Fig. 5) represented the state of the art in its day. Its floors needed no pillars for support, because they were made of concrete poured over a framework of parallel steel I-beams laced together with steel hammock straps. Rainwater

Figure 3. An old soda-glass vial showing the characteristic opacity and fracturing associated with glass disease.

drains were encased within the masonry walls, and the building featured a fireproof stairwell from ground level to the top floor. Large windows on all four sides let in plentiful light, and an infill section was later joined to one side that linked the floors to those of the adjacent museum on all levels.

As a collections space, however, the 1908 building had at least one serious flaw. Heating was by high-pressure steam conducted through iron radiators and a series of valves. In later years, a single thermostat for the entire building was located in the third-floor library. This tended to shut off the steam before the temperature throughout the fourth floor had risen to an acceptable level for a working space, but not before the radiators themselves had become extremely hot and raised temperatures to dangerous levels in cabinets several feet away. The cold, dry northeastern winter and Philadelphia's famously hot and humid summers combined to create massive fluctuations in temperature and humidity over a year, even within the cabinets. The original wooden sash windows were replaced with sealed, double-glazed units during the 1990s, which isolated the space fairly well against direct encroachment by outside air, but the lack of a controlled ventilation system meant that internal humidity still built up to unacceptably high levels during the hot months. Year-round, relative humidity (RH) ranged from as little as 12% in February to over 75% for long periods in summer. In periods of low humidity, the familiar coupling of steam heat cycles and RH was detectable through monitoring of the collections space with a combination of Thermo-hygrographs and

Figure 4. An old soda-glass vial, showing the formation of liquid droplets on the inner surface.

Onset® HOBO electronic loggers. During the summer, however, both humidity and temperature remained constantly above acceptable levels.

Alternately sweltering and freezing within their cabinets, bathed by acid vapors and nestling in decaying glass, the shells were in dire need of a new home. The most efficient approach would be a combined effort to fix all the problems at once, and in 2002 a proposal to do this was made to the National Science Foundation (NSF) under its Biological Research Collections program. The proposal was funded (NSF grant DEB 0237511), providing $465,000 toward the project. The Academy's endowed Hattersley Family Foundation Collections Care Upgrade Fund, which is dedicated to the care of the institution's collections, has provided an addition $634,000 to date. The Academy invested about $150,000 beyond this from its operating budget to refit the collection gallery, including wall repair and asbestos abatement, new lighting, and a new heating and ventilation system.

The Design Process

Floor Loading

One of the first steps was to determine whether it would make sense to mount new cabinets on compacters. This widely adopted measure allows the storage of more material in a given space than is possible with open aisles. Against that advantage, however, must be weighed the expense of the equipment and the cost of installing it, particularly in older buildings, and the restrictions it places on rapid access to individual sections.

Figure 5. The 1908 building, with the library on the second and third floors and Malacology on the top floor.

In the Academy's case, the issue was easily settled. Compactors can only be installed on floors that are strong enough to bear the concentrated weight of the collection, and the 1908 building definitely did not qualify. Designed as an open exhibit room, the fourth floor measures 89.5 × 50.6 ft (27.3 × 15.4 m) but, as mentioned above, features no supporting pillars. The original architects' drawings could not be found at the Academy, but a search of the priceless archives at the Athenaeum of Philadelphia yielded two partial diagrams of the structural steelwork. These, together with some measurements and analysis of concrete samples, allowed the calculation of a reasonably accurate floor-loading rate. Not surprisingly, given the unsupported design, the conservative maximum safe loading was a mere 125 lbs/ft^2 (5.27 kg/m^2). The underside of the floor forms the

high, decorated ceiling of the main library's reading room, and the reinforcement necessary for a compactor would have entailed prohibitive cost and disruption. The new cabinets thus could be no heavier than the existing ones.

Another complication was that part of the collection was housed in an adjacent wing with older construction, having iron instead of steel support beams. It was rated at only 75 lbs/ft^2 (3.16 kg/m^2), so it was decided to swap office space with collection space, consolidating the collection in a single systematic sequence on the stronger floor.

The New Cabinet Design

Early in the planning process, a review of standard cabinet designs offered by the major US manufacturers was conducted. Some were already installed in other parts of the Academy, whereas others were inspected at sister institutions. All were of good quality, but none of the designs was felt to be optimal for a shell collection. Most of the specimens in a dry mollusk collection are small and rounded or cylindrical in form, and thus require a retentive housing such as a vial, box, or tray. The average height of the specimens is less than 1 in (25 mm), and many drawers thus do not require more headroom than that. The system of drawer organization developed by Abbott and his associates in the 1950s was found still to be better than anything currently on offer, and thus it was decided to create a custom design that built further on its advantages. The authors employed their long experience with the collection and enthusiasm for lateral thinking to envisage ways in which the new design could further optimize usability while reconciling the optimal specification with the known limitations of the building and strict budgetary constraints.

A brief was drawn up for a new cabinet of identical size to the existing ones, with improved rigidity and door sealing, and a distributed top loading capacity of at least 100 lbs (45 kg). The latter requirement was made to allow the cabinet roofs to be used as storage space and as walkways for servicing the lighting and air conditioning.

In order to accommodate 50 years of projected growth in the collection and the immediate integration of some sections that were being held elsewhere, the new cabinets would need to hold more content than their predecessors. Two aspects of the eventual design made this possible. It was decided to retain the existing layout of 3-in-wide (76 mm) transverse lanes within each drawer, and thus to rehouse the specimens in trays whose widths were multiples of 3 in (76 mm) (Figs. 6, 7).

The lane dividers in the existing cabinets were made of wood, and each drawer could hold a maximum of seven lanes. If all six dividers were deployed, their cumulative thickness, together with those of the front and back of the drawer, came to almost 2.5 in (63.5 mm). Replacing the wooden dividers with thin aluminum ones and remaking the drawers in sheet metal added roughly an extra 2 in (51 mm) of usable internal length. Careful design of the cabinet doors and backs gained another 0.5 in (12.7 mm) in drawer length, and the cabinet was then made 0.5 in (12.7 mm) deeper to gain the last bit of room needed to add an eighth lane. The innermost lane in each drawer generally is left empty, to guard against pulling a drawer out too far, so the increase from six to seven usable lanes increased available space by 16.7%. To gain the 0.5 in (12.7 mm) depth per cabinet, aisle width was reduced from 40 to 39 in (1016 to 990 cm).

The second method for increasing capacity was the adoption of more closely spaced drawer glides. Previously, if one specimen was taller than the height of the drawer rim—even by a tiny margin—a whole drawer's height had to be skipped, plus its headroom (2 in: 51 mm). With the more closely-spaced glides, however, the maximum headroom

Figure 6. A drawer from the 1950s cabinets, showing the organization in lanes and the thick wooden dividers.

allowed over the tallest specimen in a drawer would never need to exceed 7/8 in (21 mm). This meant that the glides overhung the drawer base, but this could be done without loss of internal space because the metal edge of the drawer was thinner than the old wooden edge. A third trick was to lower the height of the base-plinth of the cabinet from 6 in (15.2 mm) to 2.5 in (63.5 mm), which allowed four more drawers per cabinet. The old cabinets held between 68 and 72 drawers, but the new ones could hold 100 if no slots needed to be skipped, an increase of between 39 and 47%. In practice, the increase in the usable number of drawer slots per cabinet is at least 20%. Coupled with the 16.7% increase in capacity of the drawers, available space for collection storage was increased by at least 40% in the same footprint.

Following a competitive bidding process among three major vendors, Biblio Design of New York was chosen as the supplier. A prototype cabinet was ordered and delivered from the manufacturer, Steel Fixture Mfg. Co. in Topeka, Kansas. In addition to holding 40% more specimens than an existing unit, internally accessible screw adjusters allowed the cabinet to be leveled and straightened once in position, and air-filled D-section Neoprene door gaskets sealed far more efficiently than the existing felt items. The gaskets are retained by riveted flanges rather than glue, and thus easily can be replaced on site.

With all the advantages of the new design, one problem remained. The all-steel prototype, while extremely strong and rigid, was too heavy. The authors worked closely with Biblio Design and the manufacturers over several weeks to bring the weight down. First, the solid internal walls that bore the glides on each side and in the center each were replaced with a box-section post at the back and front. The guides themselves were formed as channels and spot-welded to the posts, which restored some of the lost rigidity. The false floor was removed, with a thick transverse box section retained at the front and back to act as a sill and to bear the door lock plate. Finally, it was decided to fabricate the drawers from aluminum, reducing the unit weight to 3.5 lbs (1.6 kg) versus 6.8 lbs (3.1 kg) in steel. This combination of measures did the trick; even fully loaded, the new cabinets would not exceed the floor loading limit.

Figure 7. View of a new cabinet, showing the fine degree of drawer height adjustment and the amount of space gained with the new design. The same content filled the previous unit.

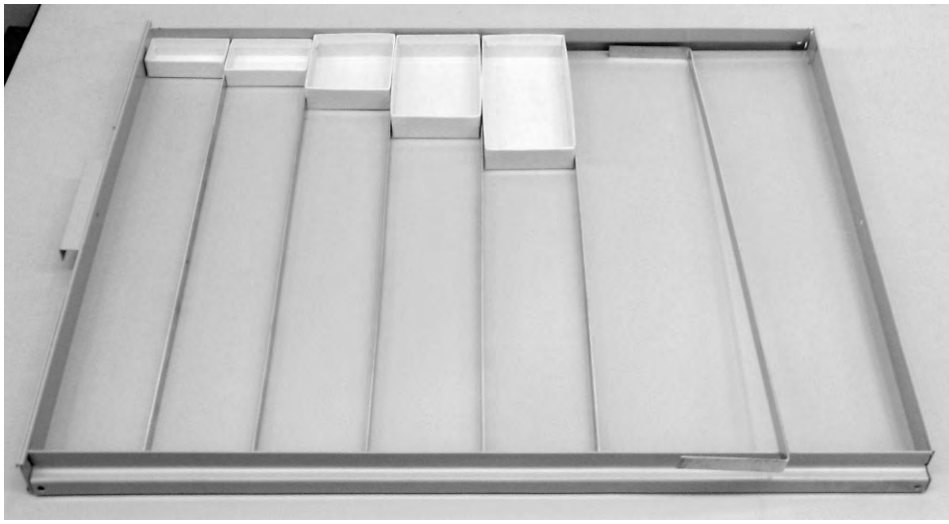

Figure 8. The new drawer, with dividers and trays.

Since installation, it has been periodically necessary to inspect the cabinets for accurate door closure, and to relevel them as necessary to account for varying degrees of settling. The cabinets initially were leveled in empty condition, but most now hold over 100 lbs (45.5 kg) of material, which is not always distributed evenly. Additionally, the floor itself can be expected to have bowed slightly as 40 cabinets' worth of content was returned to each area. Keeping the cabinets level and square is the single most important maintenance procedure, because eliminating torsion ensures even vertical loading and smooth door operation.

An epoxy powder-coat finish was applied to the prototype, and because the drawers would be running in plain glides, the durability of the coating had to be tested. A drawer was loaded with 50 lbs (22.7 kg) of material – twice the recommended maximum—and inserted and withdrawn 100 times, simulating decades of average use. The coating remained intact and only superficially scratched. This test also is important because the drawers and glides are made of dissimilar metals, and direct contact between bare steel and aluminum is best avoided in principle, because there always is the potential for corrosion.

The new drawers featured an everted square-section runner at the base of each side that slotted into or between the guides. A special drawer divider was designed that could take advantage of the two resulting channels within the drawer. A strip of aluminum was cut to a width exactly matching that of the channel and a length 6 in (152 mm) greater than the width of the drawer. A 3-in (76 mm) section at each end was then bent at right angles. The finished divider (Figs. 8, 9) had a slight torsion, and when the bent sections were slotted into the drawer channels, this created enough friction to hold the divider firmly in place. The problem of stabilizing the contents of partly-filled drawers was thereby solved without the need for back-filling with empty trays. To avoid the cost of shipping the awkwardly shaped dividers, they were delivered as plain aluminum strips and the two bends were performed in-house using a specially designed jig (Fig. 10).

A small number of drawers carry especially large and heavy specimens (e.g., Fig. 11). In these cases, a plain mat made of 2 mm powder-coated aluminum sheet is inserted first. This spans the entire drawer and roughly doubles its load-carrying capacity.

Figure 9. Detail of a new drawer.

Regular use over several years has revealed unforeseen benefits to making the drawers as light as possible. Compared with steel units in other collections, it is easy to feel how much more control the user has in removing drawers from the cabinet and handling them. This is particularly noticeable with the higher drawers in a cabinet, which some users must withdraw and insert almost at arm's length. Many proprietary steel drawers weigh considerably more than their eventual contents, and are far stronger than necessary for many collections. The lightweight version of the Academy's cabinet design are well suited for collections in other areas that have lighter specimens, such as Ornithology or Entomology, but if made in steel throughout it could handle a Geology or Paleontology collection.

Trays and Vials

For Byne's Disease and Glass Disease both to be banished from the collection, it was necessary to replace all of the approximately 400,000 cardboard trays and over 200,000 glass vials. Replacements for the trays were considered and tested in several alternative materials, including polystyrene and acrylic sheet, but the most economical and practical material for the job remained paper-wrapped cardboard. Several paper box manufacturers were invited to bid on a specification for trays made from archival buffered card and paper. The insistence on archival materials could have rendered a small production run prohibitively expensive, but the sheer scale of this order allowed the manufacturer to purchase a full drum of the card stock in advance and to provide the boxes in the eight different specified sizes at an average price of under 10 cents apiece. Space limitations at the Academy and the need to spread the budget over 3 years resulted in an agreement

Figure 10. The bending jig (left) with raw and finished dividers.

Figure 11. A drawer of heavy giant clams, with the reinforcing mat in place.

with the chosen supplier, Allstate Paper Box of Newark, New Jersey, that the trays would be manufactured and delivered in three separate installments over the same period.

Finally, replacements for the old glass vials were sought. Samples of clear polystyrene and polythene vials were obtained from several vendors and tested. They scored highly for weight, clarity, and price, but questions concerning their long-term durability proved impossible to answer with sufficient confidence. Rigid polystyrene boxes have been used

in the collection since the 1960s, and most have performed well, but crazing, yellowing, and distortion have been observed in certain places with no clear connection to the age of the box. Research revealed that manufacturers adjust the proportion of plasticizers and flow agents that are added to the clear styrene resin in order to maintain uniform molding characteristics in varying climatic conditions. This variation in the formula potentially leads to differences in durability, even between consecutive batches of the same product that would, however, become apparent only over the very long term. Given the labor involved in revialing 200,000 lots and a projected period before the next rehousing of at least 100 years, it was decided not to risk using plastic for the vial bodies. Borosilicate glass vials with polythene stoppers eventually were chosen in 1-, 2-, 4-, and 7-dram (3.7, 7.4, 14.8 and 25.9 ml) sizes, all of which fit within a 3-in (76 mm) box, and these were supplied by Fisher Scientific Co. (Waltham, MA). (The 4-dram (14.8 ml) size has since been discontinued by its manufacturer, and a substitute is being sought).

Logistics

With funding approved and a satisfactory cabinet design in hand, the first stage of the project was scheduled to commence in spring of 2003. In order to make space for the first 40 cabinets without moving any of the existing ones, the work room at one end of the 1908 building was removed, together with the fireproof walls around the now-defunct stairwell (a new external fire tower had been added with the construction of the adjacent library stack building in 1992). The floor was cleaned and repaired, the new cabinet layout was set out with masking tape, and on September 15, 2003, the first of six shipments scheduled over 3 years arrived from Kansas in a 53-foot truck.

The route from the Academy's loading dock to the fourth floor of the 1908 building passes through two passenger elevators and several narrow entrances. Careful surveying had revealed just sufficient clearances for the new cabinets to pass through all the narrow points while lying on their backs. It was vital that this be possible because they could not be moved upright, due to headroom limitations, or on their sides, because the center divider was not be strong enough to bear the weight of the 50 drawers with which each cabinet was loaded at the factory. At almost 300 lbs (136 kg), the cabinets could not be carried or laid on conventional dollies. To move them, therefore, three custom-built super-dollies (nicknamed ''Dolly Partons'') were created in-house (Fig. 12). Each had a deck of shuttering plywood screwed to a perimeter chassis of 4 in $\times$ 2 in (10.2 cm $\times$ 5.1 cm) pine with two cross members at one-thirds and two-thirds of the dolly's length. Four 6-in (15.2 mm) composite casters were bolted to the cross members, giving a clearance between the underside of the chassis and the ground of 9 in (23 cm). This height was necessary because the dolly was going to have to ''kneel'' to an angle of about 30 degrees. The chassis at one end was chamfered on its underside to allow the dolly to be tipped up until the end of the deck rested on the ground. Finally, a twin-size bed mattress was placed on the deck.

At the loading dock, each cabinet was slid up to the end of the truck, where a dolly was held in the ''kneeling'' position. The cabinet was turned so that its doors faced into the truck and then carefully tipped backwards onto the dolly, which was allowed to fall slowly back onto all four wheels as the cabinet came to rest in the horizontal position. A little shoving sufficed to square it all up, and the loaded dolly was then rolled into the first elevator, through a dining hall, onto a second elevator, and into the collections area. Two people were needed to move each unit, and an assistant was posted on the

Figure 12. The "Dolly Parton" moving dolly. The strip of carpet at the sharp end was intended to be trapped by the cabinet and thus help hold the end steady, but proved unnecessary.

fourth floor throughout to assist with tipping the cabinet back upright in its final position (Figs. 13, 14). In this manner, a team of seven people using three dollies were able to safely unload and set up 40 cabinets in 3 hours. The large-diameter casters with their rubber tires ensured a smooth ride over floor joints, and the bed mattresses absorbed the shocks.

With the new cabinets in place and leveled, the contents of the first 40 existing ones were transferred into them, drawer-for-drawer, over about 2 weeks. This was a unique chance to carry out a major task that had been contemplated for years. Abbott had arranged the collection in systematic order, as is normal, but for an unknown reason had made it run from right to left. This was confusing, especially to visitors, but its reversal had up to that point been seen as too large a physical job to warrant doing. Now it could be accomplished with no extra effort, together with large-scale updates of the systematic sequence, which in places still dated from the 1930s.

In order to ensure that preparation for the next shipment would be complete, the rehousing of individual lots was not commenced until all 40 existing units were empty. The old cabinets were subsequently removed to a storage area and many were eventually sold. As soon as the contents were transferred, work began on replacing the boxes and vials simultaneously. As anticipated, this task did not keep pace with the arrival of cabinets, and by the arrival of the last unit no more than about 50% of the total had been replaced.

It was known that in certain places, large amounts of new material were due to be incorporated into the collection as a result of field work and the acquisition of collections. The increased capacity of the new cabinets allowed blocks of space to be created at appropriate points to accommodate this.

Figure 13. Maneuvering a new cabinet through the collection area.

The last new cabinet arrived with the sixth shipment in November 2007. Following this, new lighting was installed throughout the collection. For reasons of cost and ease of maintenance, 48-in (122 cm) double fluorescent tube units with UV sleeves were chosen. These were linked to run the length of the aisles and the center corridor, with individual pull switches at the front of each aisle and a master switch at the entrance to the collection. A new forced-air heating and air conditioning system was installed simultaneously on the uppermost two floors of the 1908 building, and this has significantly improved temperature control in the collection. Finally, the whole collection was masked off and the walls and ceiling were sprayed with white acrylic paint. This was carried out last of all in order to seal the painted plaster surfaces after all electrical work and modifications to the ducting were complete.

Rehousing individual lots requires careful attention, because many shells are tiny and can adhere to the inside of the vials. In addition, some of the original labels are over 150 years old, and must be handled carefully. This has proven a long process, and it continues today. It was estimated to be 80% complete as of the end of 2010, and will probably last 3 more years. The job currently is being carried out entirely by volunteers, because the collections staff must now turn their attention to another mammoth task: the first-ever full inventory of the collection, which will be described in a future article.

Figure 14. Tipping the new cabinet upright into place.

Conclusions

The revitalized collection has drawn praise from visiting researchers and museum professionals alike. Accessibility, both physically and on line, is the key to a large collection's continuing relevance and usefulness, and a major rehousing is a perfect opportunity to make improvements in both of these aspects. Preliminary testing has shown a reduction in the levels of volatile organic compounds within the new cabinets of over 90%, compared to the previous units, and the switching out of all the housing materials simultaneously also has removed a vast amount of dirt, wood dust, and other debris. The new lighting and clear new vials allow many specimens to be examined *in situ*, resulting in greater efficiency and reduced handling risks.

In 2006, the US Department of Agriculture adopted the Academy's cabinet design for its main mollusk reference collection, and satellite collections in some US ports, such as Miami, also now use the design.

There were several keys to the success of this project:

1. The bulk of the planning, design, and logistical work was carried out by the department's curator and collection manager, in consultation with equipment manufacturers. It was not assumed that an existing product would be the optimal solution, nor that custom-made equipment would necessarily be more expensive than off-the-shelf equipment. Careful budgeting consistently ensured the most cost-efficient use of grant funds. Familiarity with the properties of materials and buildings once again was shown to be essential in planning this kind of project, together with practical experience in simple logistics.

2. Despite the scale of the project, the holistic approach taken allowed more actual renovation to be achieved per person-hour than would have been the case with a partial rehousing.
3. The various efficiencies outlined above made the project as a whole remarkable value for money. In particular, purchasing replacements for all the vials and trays simultaneously yielded significant savings, compared with an incremental approach. However, gaining these advantages meant bringing the equipment budget up to a larger part of the total than usual, and then relying on highly productive curatorial assistants and volunteers to complete the work.
4. When extra hands were needed, mostly when shipments of cabinets arrived, collections staff from other areas were happy to help. The Academy has a strong tradition of such cooperation among departments, stemming in large part from the high degree of autonomy accorded to individual collections managers and the institution's laudably minimal bureaucracy.

Acknowledgments

Certain key people were responsible for the success of this project. At the Academy, they include curatorial assistants Judy-Lynn Goldberg and Tim Hayes; volunteers Jane Heintz, Happy Robertson, Betty and Nick Ruggeri; collection managers Nate Rice (Ornithology), James Macklin (Botany, retired), Ned Gilmore (Herpetology), and Mark Sabaj-Perez (Ichthyology); and other Academy staff, Jennifer Sontchi (Exhibits) and Anthony Geneva (Molecular Lab).

Elaine Brown and Peter Diemand of Biblio Design in New York provided invaluable liaison with the team at Steel Fixtures, which was headed by the late Stan Hubbard and Roger Emperley.

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Note added in proof:

Since this paper was sent to press, it has been announced that the Carnegie Museum of Natural History in Pittsburgh has adopted the Academy′s cabinet design for the rehousing of its mollusk collection.

THE RESTORATION OF COLOR TO AVIAN TAXIDERMY MOUNTS

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Abstract.—Although literature exists covering the causes and consequences of feather deterioration, in general, very few studies have been published concerning techniques for the restoration of color to feathers. Light is a major cause of color fading and structural degradation within avian taxidermy collections. This paper discusses the experimental restoration of a 20th century Common Wood Pigeon specimen (*Columba palumbus*) donated to the University of Lincoln by the Bournemouth Natural Science Society (BNSS) in Dorset, UK. The ethical implications of restoring color to avian taxidermy specimens are addressed first, because replacing color generally is an irreversible process. However, depending on the purpose and status of the taxidermy mount, be it for public or private use, such a process might be justified under certain circumstances. When preventive conservation has failed, restoring color with such methods provides natural history institutions with the opportunity to save both economic and environmental resources and potentially increase the durability and longevity of their collections. An experimental technique developed using fiber-reactive dyes and acrylic inks to create accurate color and iridescence is discussed, and applied. Using this type of dye in this application created both desired and undesired results, depending on the chemical formulation of the dye: an alkaline dye solution works successfully whereas an acidic dye solution has detrimental effects on the integrity of feathers.

Ethical Considerations

Before initiating any restoration process, conservators must consider the ethical implications of potential conservation or restoration treatment. It is important to ensure that procedures are in line with international ethical conduct; however, these ''rules'' can be amended depending on the purpose of the object and the wishes of the client. For the purpose of this paper, the opinions of professionals—conservators, collections managers, and taxidermists—were sought through personal correspondence. Below I present a summary of that exchange in order to frame the ethical debate. Although many arguments exist around this particular question, my research only intended to touch the surface to generate ideas and gain a general perspective.

First, the argument most often cited against recoloring advocates that restorations be avoided if it is irreversible. The American Institute for Conservation of Historical and Artistic Works (AIC 2010) code suggests that restoration is acceptable, provided that it is fully recorded, reversible, and detectable. It also states that the restoration must not falsify the aesthetic, conceptual, or physical characteristics of the object nor remove or obscure the original material. Feathers are among the most delicate structures within natural history collections; the keratin-based structure of fine barbs and barbules is susceptible to damage caused by environmental factors such as light (Horie 1990) and temperature, as well as atmospheric pollution (Thomson 1978).

A feather consists of a shaft (or quill), which transitions into the vane (Hudon 2005). The vane of a contour feather varies in texture from base to tip, but generally barbs extend from the vane, the barbs support smaller, interlocking barbules, which create the insulating and waterproof qualities of the feather (Fig. 1). They are especially hard to clean because the arrangement of the barbules is prone to adsorbing particulate pollutants. As a result, even dry methods of color restoration, such as the application of powdered pigments, are not 100% reversible. Feathers are notoriously hard to dye and

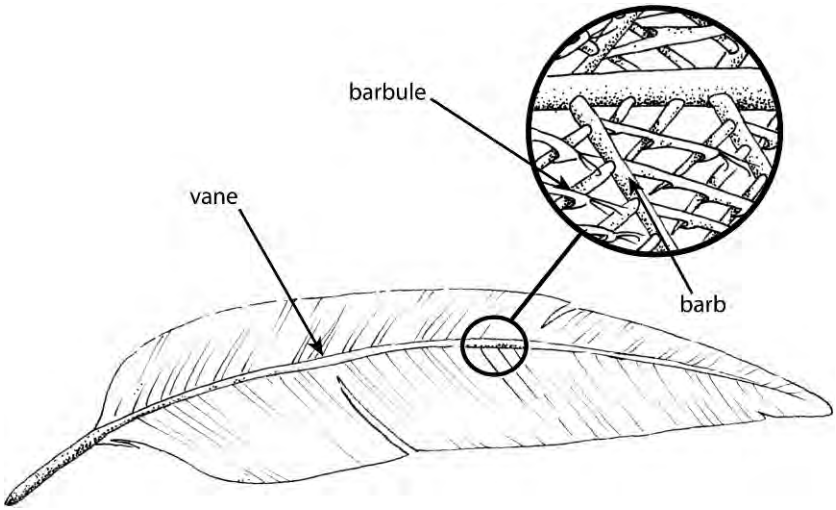

Figure 1. The structure of feathers.

attempts to do so are accompanied by serious risk of damage to the mount. Excessive water penetration to a mount or skin can cause a loss of feathers, distortion of the skin, and can trigger fungal or mold attack.

Many mounted specimens are irreplaceable and have a high value, such as those prepared by noted taxidermists or those with significant scientific importance. These often are seen as historical works of art containing valuable details about the scientific, aesthetic, and historical context from which they came. Type specimens and study skins are key examples for the classification of families, genera, or species. These original samples should never be tampered with because they are of major scientific importance. Feathers document the genetic make-up of birds of a particular era and area, as well as the environment in which they were produced (e.g., isotopic analysis; Hobson and Wassenaar 1997).

It also can be difficult for the inexperienced conservator to create a color accurate for the mount and to know the bird's color with life in respect to age, gender, and time of year (because seasonal color changes take place in many species). Finally, there also is the potential for the loss of scientific information (such as environmental residues) when feathers are treated with materials such as synthetic dyes (J. Hudon pers. comm. 15 April 2010).

The question of whether or not permanent restoration of an avian mount is appropriate depends on the actual purpose of the mount. In this case, the pigeon in question serves as an educational object and lacks historical and scientific significance. It was donated by the Bournemouth Natural Science Society for this research. The purpose of all ornithological collections is to improve the quality of existing scientific information and further the understanding of the species. In the museum environment such as that of the BNSS, this purpose is public education and instruction of species identification for schoolchildren, amateur bird watchers, naturalists and wildlife artists. A restored appearance can provide the observer with a clear visual impression of the object's natural form (Caple 2000). Consent to restore the mount was acquired from the BNSS prior to restoration. The Bournemouth Natural Science Society donated the mount because the faded appearance made it a poor depiction of the bird it was representing and with the

knowledge that the Common Wood Pigeon is not a rare or endangered species; thus, it was ideal for this experiment. They also preferred to save funds by restoring instead of purchasing a new mount. In interviews, many expressed that often institutions find that it is simply easier to replace an old mount with a new one. However, this does not take into account the difficulty of obtaining certain avian specimens or the expense of taxidermy itself. Many museums and collections simply cannot afford to buy new mounts. In heavily urbanised countries such as England where wildlife preservation is a significant concern (Case study: Royal Society for the Protection of Birds 2008), obtaining new specimens is not an easy process. Restoring avian mounts can provide a longer display life for the specimen and save resources.

The taxidermy mount is not always perceived as an object of historic importance and is often considered as a "disposable" museum object. The removal of degraded varnish from oil paintings, a process that is not reversible, often is used in conservation and is accepted because it allows the original colors of the painting to be visually appreciated. It is hard to find reasons why taxidermy should not be preserved in an analogous way as long as there is sufficient research to find suitable and ideally reversible materials and as long as the restoration is performed in a respectful way to create a naturalistic result.

Existing Techniques of Color Restoration

Three materials commonly are used for the restoration of color to taxidermy: commercial hair dye, direct dyes, and wood stain. In the opinion of those consulted, hair dye seemed to be the most suitable colorant for feathers because it is used on human hair, which also is made of keratins, although the keratins vary greatly (Spearman 1966). However, hair dye also contains high levels of hydrogen peroxide, a powerful bleaching agent that is unsuitable for damaged feathers. Direct dyes are a class of hot water dyes recommended for use on cellulose fibers. Because feathers are composed of proteins rather than cellulose, this dye type is not ideal. Direct dyes also must be applied with heat in a dye bath, neither of which is suitable for a taxidermy specimen. The final recommendation was wood stain. Wood stain usually is composed of pigment, a solvent (alcohol or water), and a binder. Although the solvent evaporates during the drying time, the binder (usually petroleum, shellac, or lacquer) remains on the surface potentially leaving an damaged finish.

Alternative Media and Techniques

The aim of this research was to determine a new effective, stable, and lightfast dye formula for use on taxidermy mounts. Fiber-reactive dyes offer a promising alternative to these old methods due to their light-fast properties, a result of covalent bonds formed between the dye molecules and amino acids within the keratin (Burch 1998a). The fiber-reactive synthetic dye (Procion MX, Fred Aldous Ltd., 37 Lever Street, Manchester, M1 1LW UK) was selected because it can be used at room temperature, unlike "natural" dyes that need to be heated, thoroughly rinsed, and often involve the use of a heavy metal mordant. The fiber-reactive dyes also come in a wide range of colors. The reactive portion of a fiber-reactive synthetic dye molecule is circled in Figure 2.

Chemical similarities between feather (Hudon 2005) and silk keratins (Dobb 1967) suggested that techniques for dyeing silk might suggest a better method of dyeing feathers. Although it is recommended to dye feathers with acid dyes (V. Jensen, Lab Manager, PRO Chemical and Dye, 126 Shove Street, Fall River, Massachusetts, 02724, pers. comm. 2010), silk can deteriorate rapidly in an acidic environment (Landi 1985).

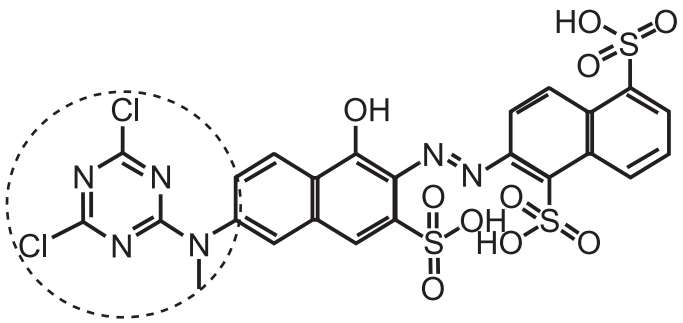

Figure 2. Procion MX dye; color index name reactive orange 4 (based on Burch 1998b).

For this reason, both acidic and alkaline fiber-reactive dye formulas were developed for this experiment. The process of dying feathers on avian mounts differs significantly from dying traditional materials in that the dye, once applied, cannot be rinsed for risk of saturating the mount. Thus this experiment tested not only the dye type and the formulae used, but also the consequences of leaving excess dye on the mount.

Iridescence

The other aim of this investigation was to research methods of recreating iridescence. Iridescence is defined as a surface interference color (Brush 1978) and is created by structural features within the feather keratin. Visible light is reflected in an array of colors that change with the angle of viewing. Silicate mica flakes have been added to various artists' materials to replicate this effect and are promising for recoloring avian mounts. These tiny flakes are coated with metal oxides to create an array of colors. They remain inert and stable due to the resilient qualities of the mica.

Factors to Consider Prior to the Restoration Process

Before restoration begins, conservators must consider potential unwanted side effects that could cause damage to, or influence the future display life of the object. Dust and other particulate matter present on the mount can have a negative effect because it affects the adherence and even distribution the dye molecules to the feather. There also is the risk that dust particles will be carried into the shaft of the feather and potentially cause structural damage. To prevent this, the mount was cleaned with a vacuum and soft brush prior to restoration. Aqueous cleaning methods were not employed due to the risk that water penetration could cause the stiffening, distortion, or discoloration of the skin. Restoration cannot be justified if the barbs tear or curl, as occasionally occurs with the use of solvents and chemicals, or if the result is uneven or unnatural in color. Rather than compromising the scientific qualities of the entire mount, only the outer surface of the mount should be dyed, allowing the feathers underneath to remain in a natural state. This also prevents excessive water penetration onto the skin of the mount.

In the specimen studied, ultraviolet radiation had caused the dorsal contour and cervical tract feathers of this sample mount to fade and become brittle (Fig. 3F). This damage to the feather keratin could affect dye absorption and color saturation. Excessive physical contact also can cause the barbules to fracture. To minimize these risks, preliminary testing was conducted with various dye formulas and inks to understand the color and textural results that could be expected on the Common Wood Pigeon feathers. Finally, as with all 20th century taxidermy, there are risks associated with the presence of

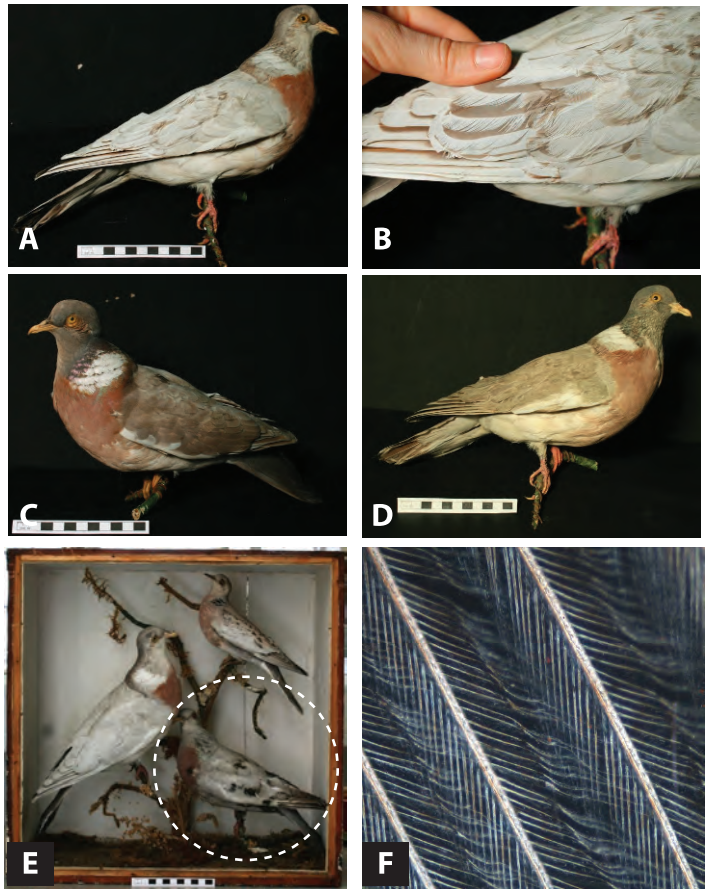

Figure 3. (A) Common Wood Pigeon (removed from the case with the exposed side visible). (B) The original colors are visible when flight feathers are shifted (C) Common Wood Pigeon (removed from case with the unexposed side visible). (D) Common Wood Pigeon (exposed side) after restoration treatment. (E) The taxidermy case with Stock Pigeon used in the experimental phase circled. (F) Photomicrograph 100× magnification shows the deterioration and embrittlement of the barbs and barbules on the feathers of this specimen.

undocumented pesticides or preservatives. To minimize potential health hazards, both the preliminary experimentation and actual restoration was conducted in a controlled environment and with suitable protective garments.

Preliminary Testing

Figures 3A and 3B show the extent of fading on the dorsal contour feathers of the Common Wood Pigeon. The aim of this project was to restore color to the faded side of the mount, matching it with the unexposed side (Fig. 3C) as requested by the owner (the restored mount is shown in Fig. 3D for comparison). Because only the exterior surface had faded, the color appeared irregular and uneven when the feathers were moved, further complicating this challenge. Due to the age of the artefact and that it is exhibited in a case with two other birds from the Columbidae family, the client requested that it be restored in an appropriate way and not be obviously retouched. For preliminary testing of the selected dye, feathers were collected from a discrete area on a Stock Pigeon

(*Columba oenas*) exhibited in the same case with the Wood Pigeon (bottom right in Fig. 3E). Feathers from the two specimens had received an identical amount of exposure, which meant the final color could be accurately predicted.

Fiber-reactive dye colors used in the preliminary testing included Procion MX ''Ecru'' and ''Pearl Grey.'' Both were selected for their similarity to the natural feather color needed. The standard dye formula were modifications of one recommended by Niall O'Meara (Fred Aldous Ltd., 37 Lever Street, Manchester, M1 1LW UK, pers. comm. 2010). The base mixture consisted of dye powder, water, and sodium chloride (NaCl). To make the acidic formula, acetic acid (CH_3COOH) in the form of distilled vinegar was added. To make the alkaline formula, sodium carbonate (Na_2CO_3) was added. The pH levels of the dye formulae were measured prior to application; the alkaline formula measured at pH 10 and the acid dye measured a pH level of 3.5. The dye formula was applied to the samples using an airbrush because it initially was thought this would provide even coverage. However, this was later dismissed for the actual restoration in favour of a paintbrush. The trial feathers were then left to dry for 24 hours and then examined with the naked eye and inspected under the microscope.

Visual and Microscopic Analysis of Results

Visual comparison of the tips of the dyed feathers to the unexposed side of the Common Wood Pigeon demonstrated that the alkaline dye created an accurate and natural color. The acid dye created a finish that was softer to the touch, whereas the alkaline dye left the barbules slightly brittle with the occasional presence of small sodium chloride crystals. Because these mounts are displayed in a case, the visual result was of more importance than the texture.

Microscopic analysis ensured that the dye formula selected for use has not caused deterioration to the feather keratin. Small sections of the dyed feathers were mounted onto glass slides and the images were captured using a Leica DMLM microscope at the University of Lincoln, UK. Figures 4A and 4B show alkaline dye molecules bonded to the keratinaceous cells. Dyed areas form brown dots spaced equally along the length of the barbules. The dye bonded to the barbules successfully, producing a satisfactory color without visible damage to the keratin.

The acid dye (Fig. 4C), however, caused intense structural deterioration revealed by the scattering of light caused by the fractured keratin. No dye is visible on the barbules—they have simply deteriorated in response to the low pH level. The amine (NH_2) group is provided by the amino acids glycine and alanine, two common constituents of keratins. When these amino acids bond with the reactive dichlorotriazine ($C_3H_2Cl_2N_4$) of the Procion MX (as circled in Fig. 2) it created hydrochloric acid (HCl) and therefore enhanced the already acidic environment (Fig. 5). It can be concluded that once the dye had reacted with the feather, the pH levels of both formulae would have dropped to a lower pH. The alkaline dye, when measured on the feather after application, was pH 3.45. No sample for the acid dye was tested, although it can be assumed that the pH level would have been low. This proves the importance of microscopy in this type of conservation work. This result also demonstrates that the pH level of any dye can change rapidly once it has been applied, and emphasizes the need for preliminary testing when working with new materials. Without these tests, the success of the dye would have been measured by the color and texture only, when in fact the soft finish of the feathers dyed with the acidic formula was only due to the deterioration of the keratin cells.

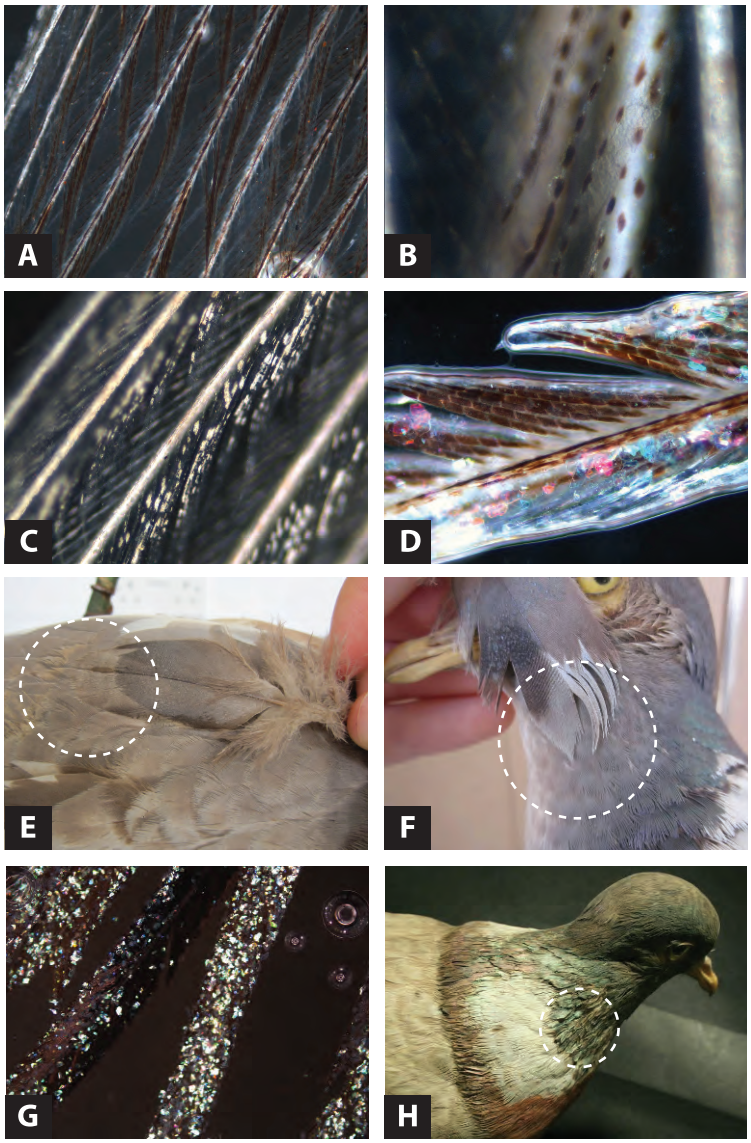

Figure 4. (A) Photomicrograph 100× magnification of alkaline dye formula on the feather barbs and barbules. (B) Photomicrograph 500× magnification of alkaline dye formula. (C) Photomicrograph 100× magnification of acid dye formula. (D) Photomicrograph 200× magnification of alkaline dye formula after 9 months, showing a stabilised and identical color to Figure A. (E) A color match between experimental feather and unexposed side of mount (circled for clarity). (F) ''Ecru'' and ''Jet Black'' combined created a darker shade of gray that matched the cervical tract on the unexposed side of mount (circled for clarity). (G) Photomicrograph 50× magnification showing iridescent particles after use of acrylic ink. (H) Exposed side of the mount after restoration showing artificial iridescence used on cervical tract (circled for clarity).

The mica-based iridescent pigment also underwent preliminary testing to analyze the color and texture created. When applied to the feather, the dry pigment produced an unnatural sparkly surface. In order to obtain a smoother metallic finish, a mixture containing a binder was sought. Art material supplier Daler-Rowney produces

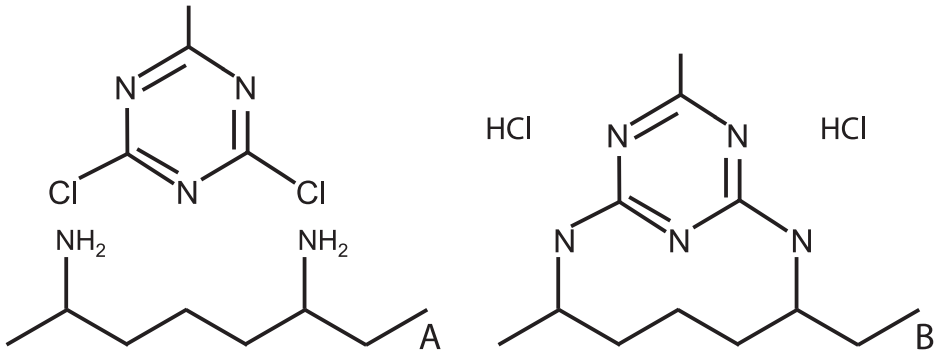

Figure 5. Dye molecule (A) prior to and (B) after reaction (showing production of HCl).

semitransparent acrylic inks with mica flakes. These contain a water-based, acrylic copolymer emulsion (Daler-Rowney, Peacock Lane, Bracknell, RG12 8SS, UK, pers. comm. 2011). Although research into acrylic mediums has shown that emulsions eventually deteriorate, limited resources available during this research meant that this ink was selected for use.

Although the color result with the alkaline Ecru formula was ideal for the dorsal contour feathers (Fig. 4E), it was too light for the ventral cervical tract where the color value is much darker. Very small amounts of Procion MX ''Jet Black'' dye were added to the Ecru formula to obtain a darker shade of blue/gray (Fig. 4F). The ink ''Shimmering Green'' was applied with the airbrush to sample feathers removed from the Stock Pigeon. When compared to the natural iridescence, the color was a slightly lighter shade of green; however, the iridescent effect was satisfactory. The ink was convincing to the human eyes but when seen under the microscope, the large iridescent particles clumped the barbules together (Fig. 4G), creating a rigid texture. However, if used in minimal amounts, the ink provided sufficient and realistic iridescence and was therefore selected for use. Because pigeons naturally have a ''two-tone'' iridescence, a color that changes with the angle of viewing, another ink, ''Shimmering Red,'' was applied on both sides of the cervical tract, creating a tone more natural for the Common Wood pigeon (Fig. 4H).

Application and Evaluation of Method and Materials

The restoration was completed in April 2010 within the Conservation Department of the University of Lincoln in the UK. Before restoration could begin, the dyeing process was thoroughly planned to understand how the various areas on the specimen varied in color. Several problems were encountered in the course of this experiment. First, due to their damaged state, some feathers acquired an unexpected or unnatural color when airbrushed. A better result was obtained using a concentrated dye formula applied in a localised manner, using a fine paintbrush. This also prevented tide lines caused by pooling of excess solvent.

Achieving the correct level of application was important. If applied too heavily, the dye caused a slight curling of the contour feathers. Areas of over-application also had small sodium chloride crystals present on the feathers, matting the barbs and barbules. In addition, even when the dye was applied directly, the vanes of the feathers did not take the color. The vane, barbs, and barbules of a feather all contain the same cell structures in different sizes, indicating that the thicker surface of the vane prevented penetration with

this method of application. The barbs on feathers in the cervical tract became intertwined, further exposing the skin. Attempts to "brush out" these sections resulted in fracture because the barbules were very weak from ultraviolet exposure. The acrylic ink provided a high reflectance and good color although the textural finish was poor due to the barbules sticking together. The airbrush was successful for applying a thin layer of ink, but too dense an application resulted in a thick residue on the feathers. The force of the airbrush also occasionally caused the feathers to shift and fracture.

Evaluation of Research

This paper examines new methods for restoring color to avian taxidermy. It provides a basic method that uses easily attainable materials. The color-restored specimen is shown in Figure 2D. In this process, the alkaline dye formula produced an accurate color match and did not visibly damage the feather keratin. The acidic dye created an accurate color match that was texturally softer; however, it caused a deterioration of the feather keratin. Therefore, the most substantive outcome of this research was the knowledge that fiber-reactive dyes react with feather keratin, creating a dangerous drop in pH levels that can exacerbate deterioration. For this type of dye, the acidic dye formulas usually recommended for use on feathers are inappropriate. Even if the specimen was rinsed, the damage already would have taken place. The importance of preliminary testing is clearly demonstrated, especially when working with new and untested materials.

Nine months after the initial restoration, the feathers were examined again using microscopy. Figure 4D shows that the dye formula has dispersed within the barbules, but has not changed color or caused any visible structural deterioration (the interference colors are caused by the acrylic inks). Although this information is valuable in the short term, it still is important to study the long-term effects of this dye. Future studies also will include examining accelerated aging of the dyed feathers to understand how light, temperature, and humidity affect the color or pH level. Another interesting avenue for future research is the potential to strengthen feather barbs by adding consolidants to the dye formula. If applied using a device with less force, such as an ultrasonic mister (modified from an ultrasonic humidifier) the feathers potentially could be structurally reinforced and colored simultaneously.

Acknowledgments

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GIS, THE KEY TO COLLECTIONS MANAGEMENT OF A LARGE RESEARCH ARCHIVE

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Abstract.—Management of a large nonvertebrate paleontology collection with limited full-time staff is addressed by integrating the digital database of the specimens with a Geographic Information System (GIS) of the collection storage facilities (repository). Digital maps of the repository, linked to digital records of specimens within each cabinet, enable rapid location of specific items required for research, exhibit, loan, or for conservation treatment.

An accurate map of the collection accelerates assimilation of students and volunteers on whom the repository must rely for assistance. It also increases the efficiency of research visits because the bulk of the collection is stratigraphically organized, thereby requiring a wider browsing footprint for those interested in taxonomy. By mapping individual specimen locations within the repository, those environmentally susceptible and critically important specimens can be pinpointed and relocated to the less climatically hostile or a more secure area. Additional data layers specific to aspects of collection management allow for efficient tracking and observation of multivariable interrelationships.

Similar mapping techniques are being applied to specimen collection field sites. This is a standard option for new research but it also is used to focus on historic collection localities that no longer exist because of urban development, lakes, or other changes to the original landscape. Those data add research value to specimens originating from such lost localities and support monitoring them in the repository.

INTRODUCTION

The Texas Natural Science Center (TNSC) includes the exhibit halls of the Texas Memorial Museum (TMM) and several research and collection units. One of those units, the Nonvertebrate Paleontology Laboratory (NPL), is the guardian of geological collections derived from research completed during the last 150 years. Many of these specimens are irreplaceable; their collection sites are covered with water, buried beneath the footprint of development, or merely eroded away.

This repository is not a singular entity. It has accrued over the years often by embracing specimens from formerly distinct units or entirely different institutions that did not have the facilities for long-term curation of their research collections. The outcome has been a multitude of numbering systems, catalogue systems, storage systems and housing units, and collection policies. In addition to these curatorial vagaries, the specimens themselves have been subjected to many physical moves. Some specimens are at risk of loss as a result of this history, especially where sensitive specimens are placed, unintentionally, in environmentally unsuitable locations.

The total collection has now grown to about 4 million specimens, exclusive of microfossils. To curate and conserve these specimens in an appropriate manner, and make them accessible for research and education, requires physical and human resources whose need exceeds their availability. It is imperative that any resources are used in the most efficient manner. One of the most important steps to achieve that goal is the

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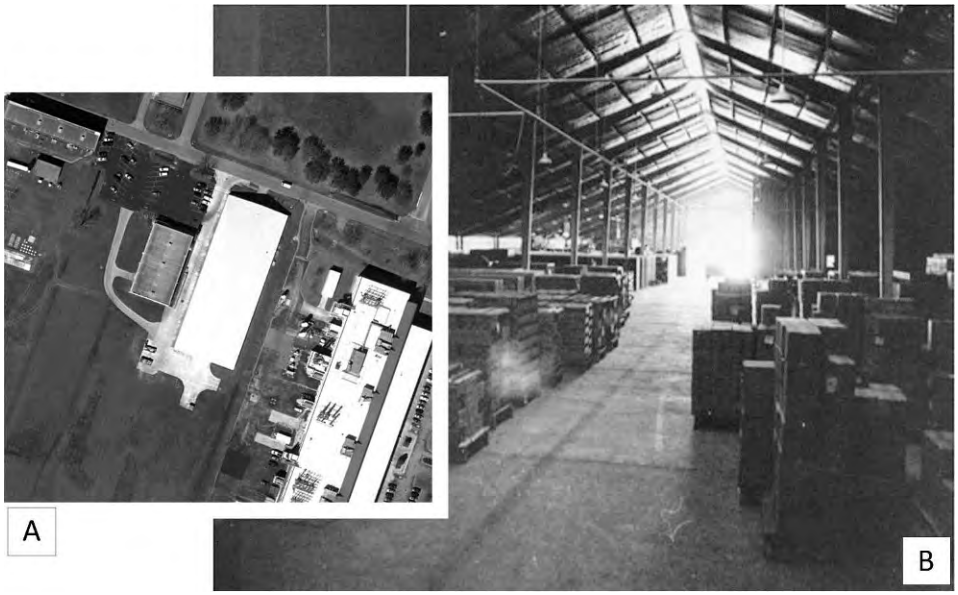

Figure 1. (A) The J. J. Pickle Research Campus building 33. (B) PRC33 (the ''cages'') in 1974, home to increasing numbers of specimens transferred to the Texas Natural Science Center (TNSC) from other departments (as space on the main campus diminished) and from orphaned collections from other institutions.

adoption of a geographic information system (GIS) for managing and integrating various curatorial tasks.

The bulk of the collections remain in an open warehouse (Fig.1), within three large caged areas amounting to about 11,250 ft^2 (1,045 m^2). Recent modifications to this warehouse have improved working conditions for research and for the welfare of the specimens themselves: insulated outer walls; inner walls containing plywood baffles, which lower the level of dust; improved lighting; a large wash sink with sand trap; health and safety supplies; and a mobile phone (Fig. 2A). In addition, all cages have a computer with 100 Mbps Ethernet connections to the main server on the University of Texas campus. Old wooden cabinets (Fig. 2B) are slowly being replaced with well-gasketed, metal cabinets (Figs. 2C, D).

Two blocks away from these ''cages,'' a second, smaller (3,000 ft^2 [279 m^2]) climate-controlled building houses the remainder of the collection, including the type and figured

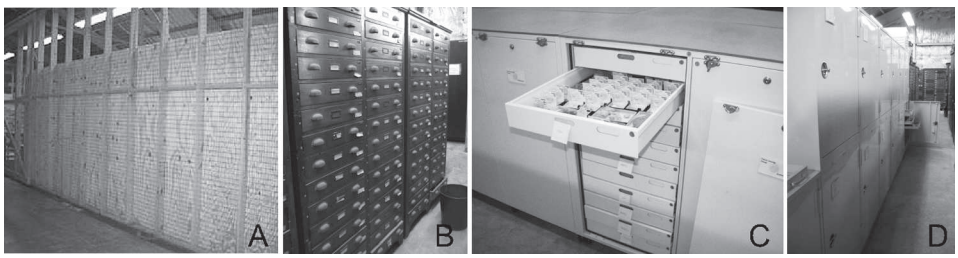

Figure 2. (A) Wire and plywood walls separate the original open cage into three areas. (B) Oak cabinets. (C and D) Archival quality metal cabinets.

collections. A university setting, coupled with a directed search for volunteers to help curate this collection have generated a good supply of affordable labor. This crew has to be trained with the inevitable caveat of student labor: constant turnover as they graduate. The continual training requirement falls on the shoulders of the very few permanent staff (1), semipermanent staff (0.5) and established, long-term volunteers. Numerous aids, general protocols and procedures, detailed procedures for individual projects, and specific tracking of training levels, plus work timetables and productivity records, all help to make the most of the crew labor.

Some aspects of the curatorial tasks can be more effectively handled by adopting existing technologies normally used in the planning sphere and applying them to the repository environment. One critical aspect for a new assistant is knowledge of the spatial layout or geography of the repository, and where a specimen is located within that space. This requires not only that the assistant know in which cabinet and drawer a specimen is located, but also where in the repository that cabinet is situated. As the current specimens are studied, exhibited, loaned, and conserved, their storage locations can change and these new locations need to be efficiently tracked. Ongoing visual and electronic monitoring of specimen drawers might indicate environmental problems with some particular area of the repository or a specific collection that should be moved. New specimens are added to the collection; improved cabinets replace the old ones. It was critical to find an effective mechanism to connect a specimen, its data and its repository location, as well as any other appropriate information relating to the condition of the specimen.

Our solution was "an interactive map" showing the cabinet layouts in the two buildings. This is digitally linked to the databases and contains such added elements as the location of safety equipment, pest traps, and areas of water seepage or roof leaks. This GIS tool needed to be easily updated and user-friendly. There were two major phases in the evolution of our GIS system; the first began in 2002 and the second in 2009, with ongoing refinements to the present. Both phases are described (Molineux et al., 2003, 2009; Criswell et al. 2010).

The Geographic Information System (GIS)

GIS is a digital version of a traditional paper map, combined with digital database technology (Bolstad 2005). The system enables the user to query and analyze features of the map, which consist of shapes (polygons, lines, and points). There is a base map layer providing the framework for the overlying details. Each feature on the GIS map can be related to relevant attributes or linked to specialized data sources. GIS is a basic tool used by geographers, planners, environmental researchers, hydrologists, and geologists (Comeaux et al. 2007, George et al. 2007). It is used as a tool in facilities management of all types but has seen only limited application within Museum collections, most notably within the sphere of Integrated Pest Management (IPM) (Monk et al. 2002). We have used the system since 2002 and now have incorporated it into field work whenever possible (Comeaux et al. 2007, George et al. 2007).

Methods

Phase1: Create Maps of the Larger Warehouse, the "Cages," and Link Them to the Main MS Access® Database (Fig. 3)

The outlines of the cabinets were drawn by hand on a scaled building plan. The diagram was used as a template in Adobe Illustrator® and a digital map was created.

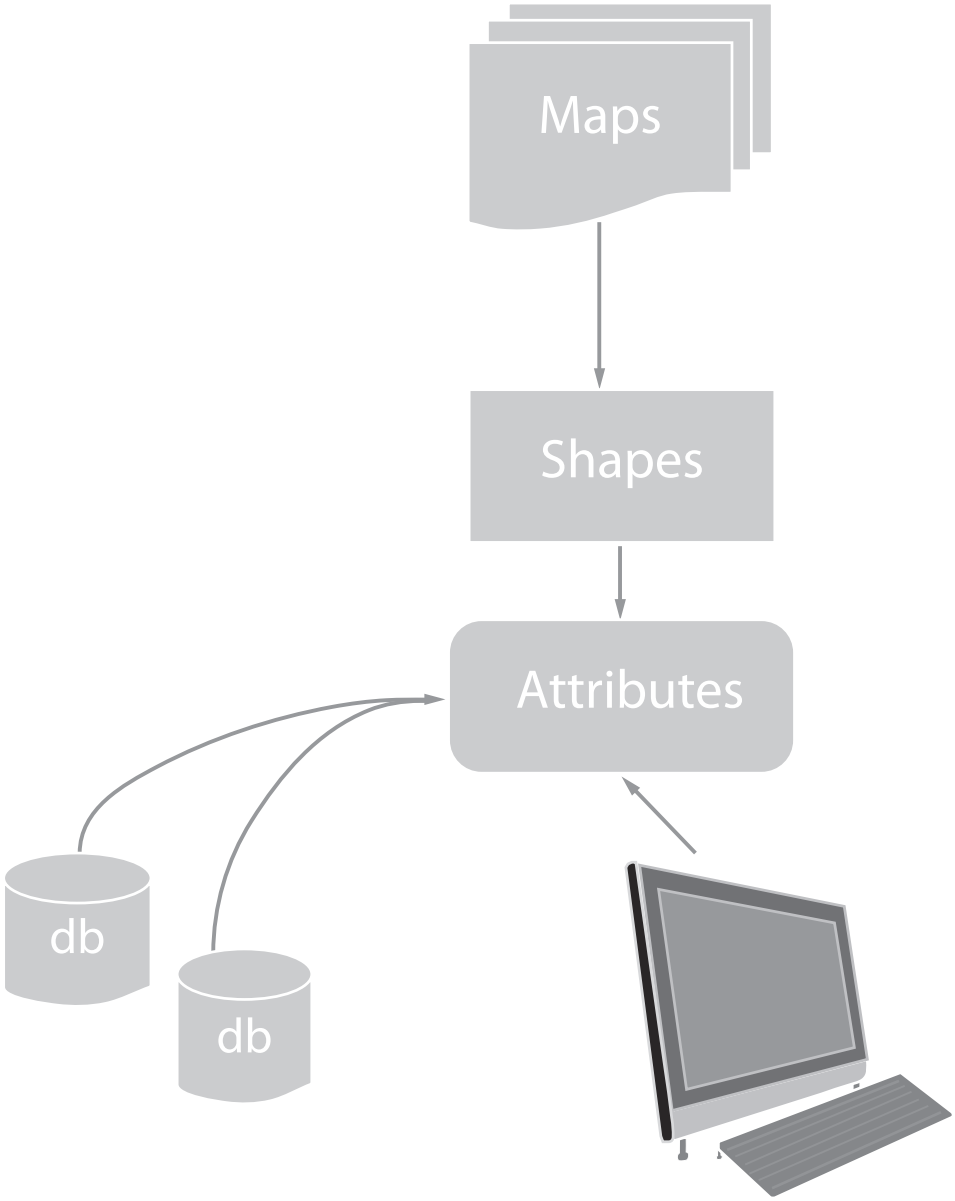

Figure 3. Simplified flowchart of the initial Phase 1 Geographic Information System (GIS) project.

The final digital map was imported into ArcView® GIS 3.2 as a series of shape (.shp) files. The shape files included the building and demarcation of major spaces within the separate caged areas, and each individual cabinet structure (Fig. 4A). An attribute table was generated for each cabinet or other specified feature, such as a table; details included the style of cabinet, whether wood or steel, and general contents. Cabinets could then be selected by these attributes, such as the geologic age of specimens (Fig. 4B). The Phase 1 project took one summer using one volunteer and one graduate student.

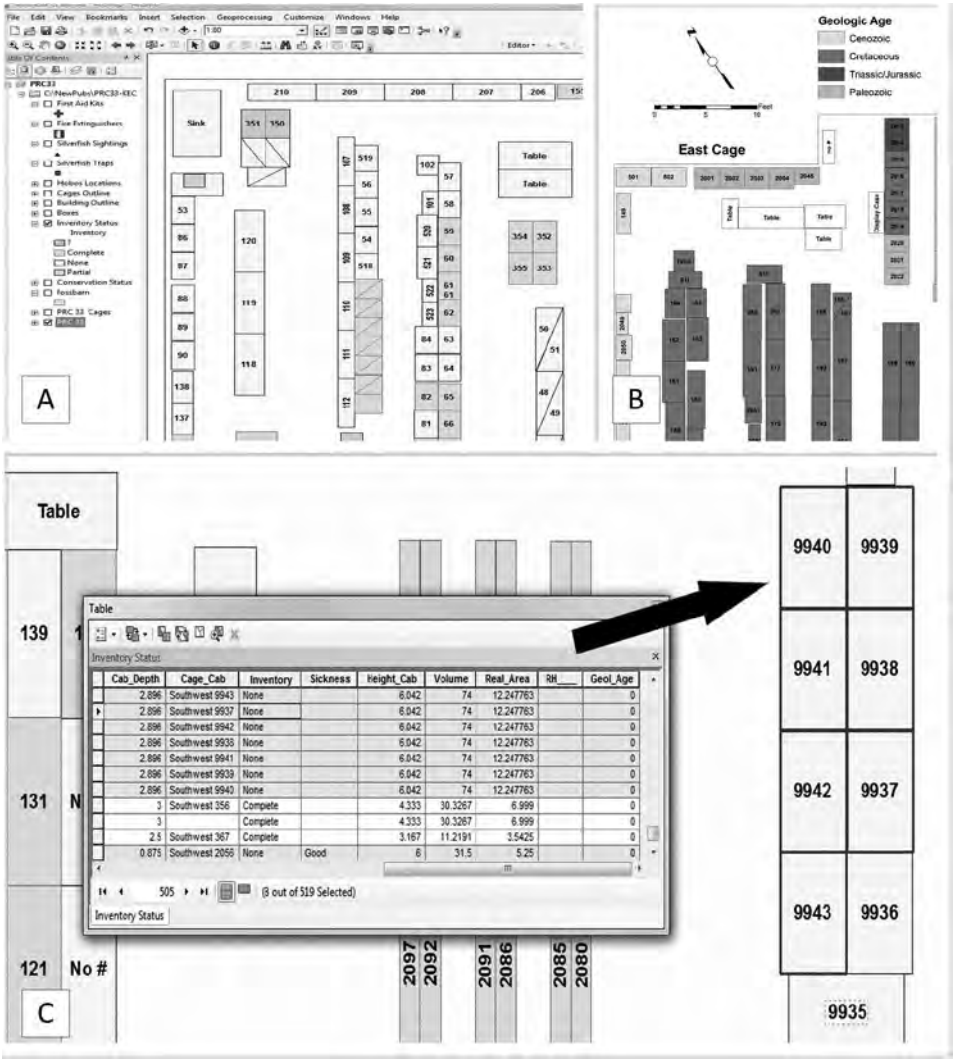

Figure 4. (A) Basic outline map (example from the northwest cage). (B) Cabinets mapped by the geologic age of the specimens (example from the east cage). (C) Selection of specific cabinets by inventory status.

Phase 2: Create Properly Scaled Maps for Both Storage Facilities; Develop Distinct Layers for Selected Variables, Linkable to Any of the Databases (Fig. 5)

This phase involved one graduate student for a summer and ongoing undergraduate volunteer input. The entire repository was updated and migrated into ArcGIS 9, ArcMap® 9.3. Vertical dimensions were added to the basic shape footprint, providing for analysis of the collection by volume of available storage space. This is not a trivial task where there are numerous cabinet styles and sizes, shelving units, and storage cupboards (Fig. 2 B–D). An adequate data frame and projection were created, and the updated data were projected onto the new framework. The attribute tables were extended to include the additional cabinet measurements. The second storage area was also mapped, as were storage boxes located on top of cabinets in both repository buildings.

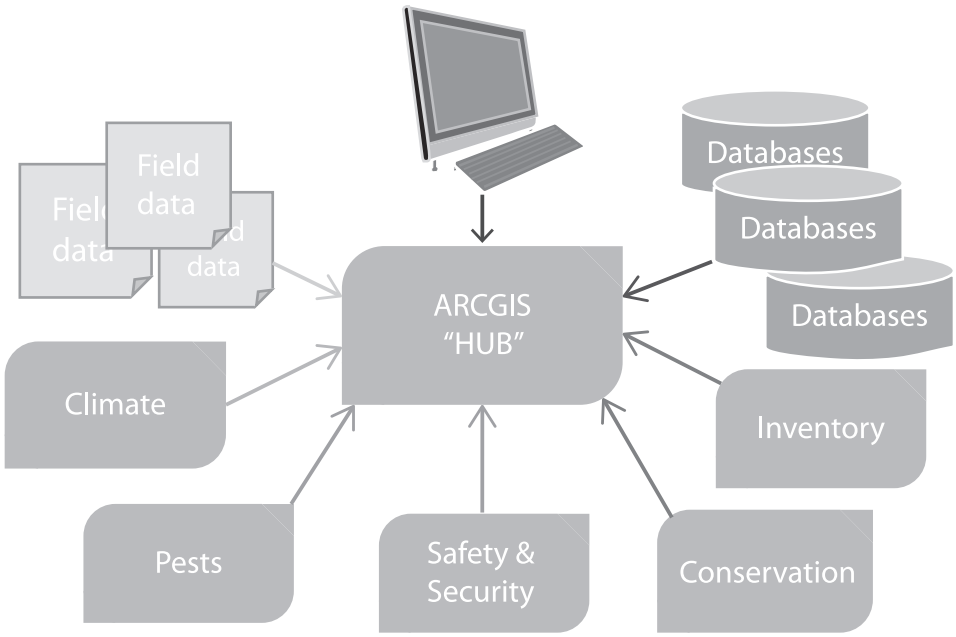

Figure 5. Simplified flowchart of the Phase 2 GIS project.

Additional layers were added to the basic cabinet shape layer. A safety layer carries locations of first aid kits and fire extinguishers; climate monitoring shows data-logger positions and any areas of water leaks or damp; pest management locates pest traps and sightings; conservation status demarcates zones with observed problems such as "Bynes disease," pyrite reactions, or mold, even if the affected specimens were relocated to the climate-controlled storage. An inventory status layer indicates the progress of the current inventory (Fig. 4C).

Results

The system produced in Phase1 provided a very useful map of the collection. The simple map of the repository was a huge improvement and immediately removed one somewhat daunting learning curve for any new assistants. The map was digital and could be updated to reflect changes that were being made. Linking the maps to the database meant that searches for specific items were possible. An example was the search for foam-covered tables needed for specimen layout prior to selection for an exhibit (Fig. 6A–D). Each cabinet could be joined or related to several databases, allowing effective searching for specific specimens or specific relocations for returning loans.

Monitoring of environmental hazards is an important part of managing a collection. In this example (Fig. 7A), a recurring leak was a problem that could not be completely fixed. Our standard practice for new cabinets is to require they be raised off the concrete surface. Given the possibility of repeating leaks in the northwest area of the repository, we opted to raise all cabinets, old and new, off the ground (Fig. 7B). The next step was to check the contents of those cabinets closest to the leak and determine if they contained susceptible specimens that should be relocated. The system allowed us to pinpoint nearby cabinets and have some idea of their content without having to open all 200 drawers for visual inspection (Fig. 7C,D).

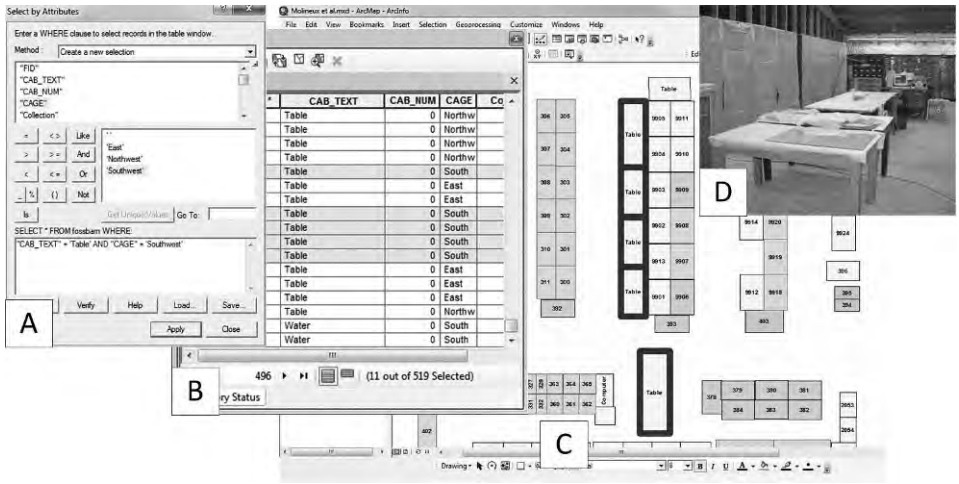

Figure 6. (A–B) Searching the database for foam covered tables for exhibit specimen layout. (C) Suitable tables are found in the southwest cage and are highlighted on the map. (D) Tables selected for exhibit layout.

However, the system did contain some obvious flaws. It needed to be updated; it was incomplete, did not take advantage of layers, and it was not adequately scaled. We had not based the map on any particular coordinate system and thus were not able to quickly measure areas, and we had not measured the third dimension of the cabinets, which prevented easy access to volume data. The latter is often requested by federal surveys and internal requests for future space allocation. The position of the cabinets and their areal extent was not precise, and as the repository was filling with new storage cabinets, space became a more serious issue. In addition, the second storage building was not yet part of the system, and we needed to have the entire repository covered.

Phase 2 addressed the coordinate issue and increased map coverage to include the second building and contents. More extensive use of layers for different aspects of

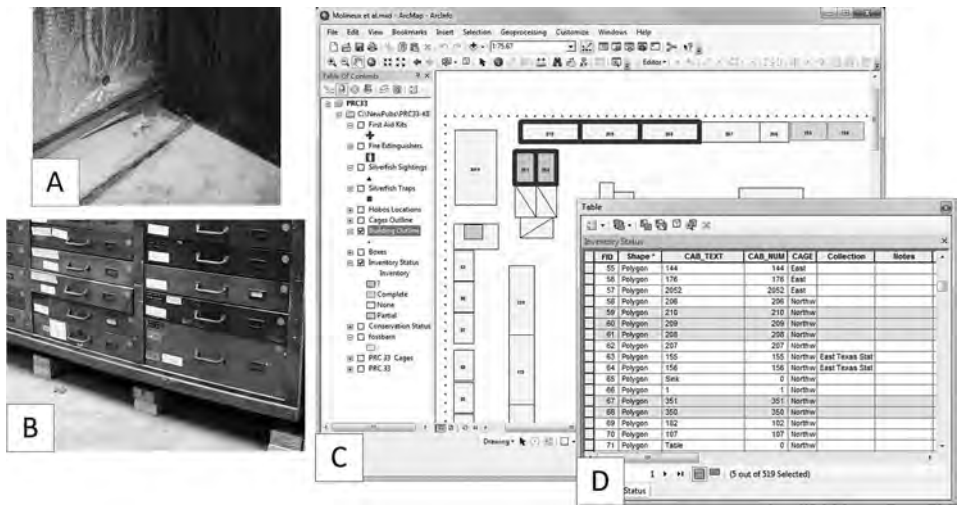

Figure 7. (A) Leak observed. (B) Cabinets are raised off the concrete ground surface. (C) The cabinets affected. (D) Cabinet contents.

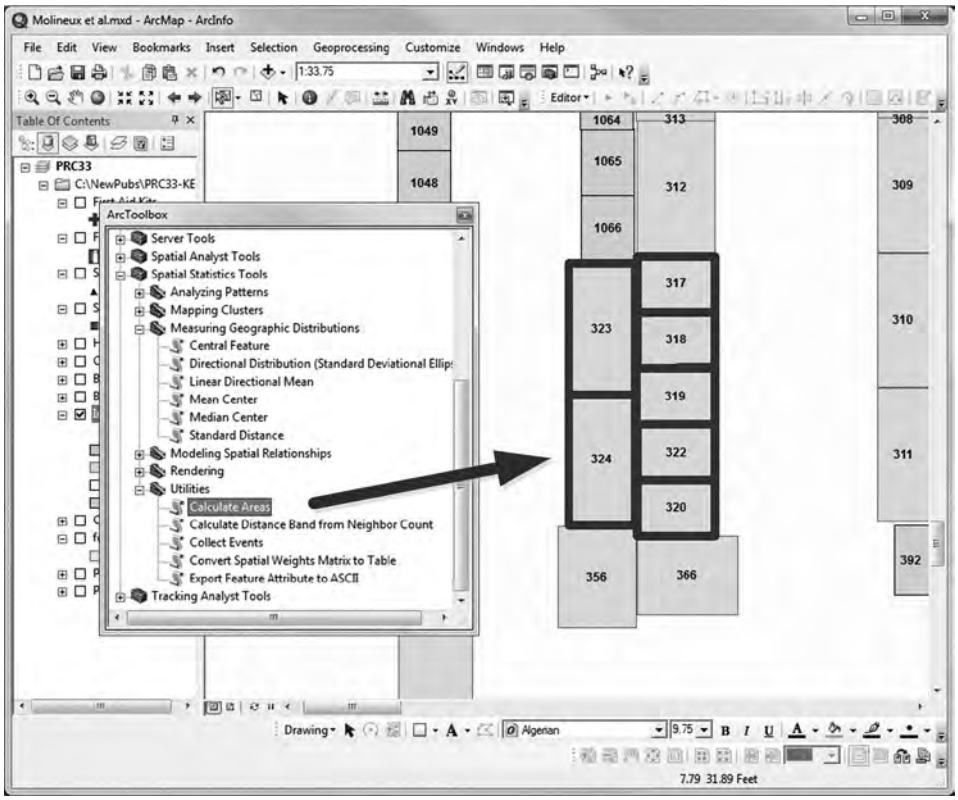

Figure 8. Analytical ability is much improved with more accurate data frame and polygons. This screenshot illustrates the tool to measure the areal extent of the highlighted cabinets.

collection management has made it easier to train other students and volunteers. It is considerably less daunting if the worker is only updating a single layer of the system and not risking the integrity of the entire map. For example, an assistant can open up the program and simply update the layer tracking inventory status, or select specific cabinets slated for moving and measure their areal extent to make sure they fit in their new space (Fig. 8).

Climate monitoring with Onset HOBO® data loggers records critical data for temperature and relative humidity. One data logger is fixed and the other eight rotate around the collection. It is important to track conditions, especially in the ''cages,'' where the microclimate near the door can be very different from that of a cabinet in the interior of the building. The locations of current and previous positions of the mobile data loggers are recorded in the system, and thus provide an indication of monitored areas and where we might have additional data relevant to a new problem (Fig. 9A–C).

Conclusions

Success of any system is linked to functionality. Both phases of this project produced products of great value to this collection. Phase 1 provided a much-needed map of the collection that we could easily link to the databases. Phase 2 has added to that basic system a greater level of positional accuracy, a much more flexible system, and one that encourages even more questions as we see the data in a spatial and temporal context.

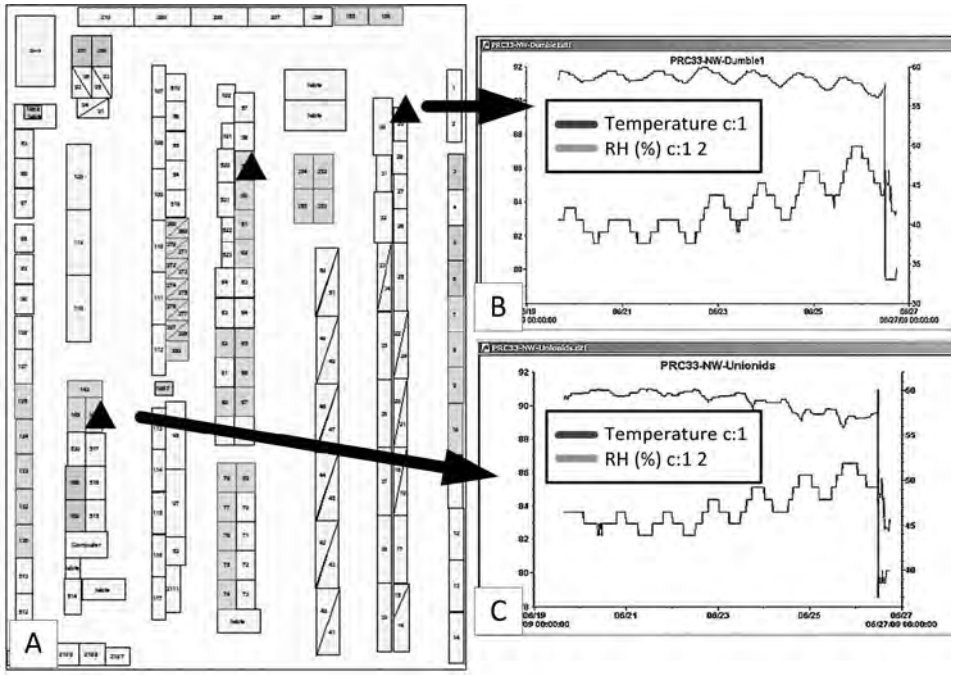

Figure 9. Tracking climate conditions for sensitive and irreplaceable collections. (A) Basic map of the cage closest to the warehouse door. (B) Sample chart from test of conditions in the historic Dumble Survey collections. (C) Sample chart for the same time span within the historic Recent mussel collection of the Singley and Askew collections housed in interior cabinets.

The learning curve for GIS is still quite steep, but with good protocols and simple instructions, we are reducing the time it takes new assistants to become adept users of the system, capable of updating specific aspects. The GIS system has reached a point at which those students and volunteers who are not experts in GIS mapping can contribute and help to keep the system viable and up to date. This consistent effort to keep it current means that this tool must be integrated into the routine of monitoring pests or recording climate conditions, or any other variable that we monitor and manage within the GIS system. We continue to experiment with the basic design of our system and shortly will migrate into ArcGIS® 10 where we shall be able to share our content via web browser, desktop, or mobile device, thereby providing a much more flexible interface to the data.

We are developing compatibility between our new relational database, Specify 6® and the current GIS system. This is more a matter of the creation of a flat file extract from the database structure similar to that needed for data portal access. When our Specify 6 data structure is fully populated, the GIS system will have more efficient access to the entire collection.

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EVALUATION OF A COLLECTIONS NETWORK AS A SOURCE OF INFORMATION ON ECONOMICALLY IMPORTANT PLANTS

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Abstract.—We compared a collections network with six other sources to provide quantitative evidence of its relative value in gathering essential information on economically important plants. The collection network included 30 Canadian herbaria. The other sources included: 1) eight Canadian Conservation Data Centers; 2) 12 provincial Invasive Species Councils; 3) 18 of the largest Canadian botanical gardens and arboreta; 4) 14 Canadian botanical clubs; 5) a Web search; and 6) a search of scientific journals. We used two major invasive plants as an example: sea buckthorn (*Hipppohae rhamnoides* L.) and scotch broom [*Cytisus scoparius* (L.) Link]. For each of the sources involving communication we asked five questions. For the Web and literature searches we provided word strings. The results were evaluated on the basis of five criteria: 1) amount of information gathered; 2) currency of information; 3) uniqueness of useful information; 4) response time; and 5) association with experts. Two aspects of the results are particularly important: 1) all sources provided some useful and unique information; and 2) a collection network can be the very best source of information to guide the management of economically important plants. In a world of ever-increasing information sources, collections often remain at the forefront.

Introduction

Value of and Support for Collections

The importance of collections and their contributions of information have increased in the recent years due to greater impacts of a changing environment. Collections play a vital role for society by contributing to management of environmental problems, public health and safety, monitoring environmental changes, and enhancing national security. Unfortunately, many herbaria and other biological collections throughout the world have experienced reduced financial support over the past few decades. The consequences of this include not only serious damage to irreplaceable national heritage, but also a diminished capability to deal with increasing environmental problems. The reasons for this reduced support are both economic and trend-related. An underappreciation of the value of collections has become widespread (Suarez and Tsutsui 2004). Collection managers and curators now need to spend substantial time explaining value that was much more generally accepted and understood only a few decades ago.

Explanations and Intentions

A large number of articles have acknowledged the value of biological collections (Holland 1965, Cohen and Cressy 1969, Genoways et al. 1976, Miller 1985, Nudds and Pettitt 1986, Catling et al. 1989, Danks 1991, Morin et al 1989, Cato 1991, Wiggins et al. 1991, Catling and Dang 1992, Catling 2001, Funk 2003a, 2003b; Prather et al. 2004a, 2004b; Suarez and Tsutsui 2004, Chapman 2005a, Funk et al. 2005). As recently as 1995, Canada's response to the Convention on Biological Diversity included strategic direction 2.7 "… maintain the capacity of museums and other institutions to … store collected specimens, as well as maintain their ability to effectively disseminate information" (Biodiversity Convention Office 1995). In the key actions of the Invasive Alien Species

Strategy for Canada (Environment Canada 2004) a priority key action is ''support existing diagnostic tools of biological collections and taxonomic libraries.''

These articulate explanations and well-conceived intentions are very useful, but there is a need for evidence to support them in the form of quantitative analysis that includes considerations of recent developments, such as the increases in information accessibility through the Web. Because new, quantitative evidence is an important part of the explanation of value, we designed an experiment to evaluate a collections network of 30 cooperating Canadian herbaria and their specimens (Fig. 1). This was done through comparison with other sources with respect to five questions regarding two invasive alien plants: sea buckthorn (*Hippophae rhamnoides* L.) and scotch broom [*Cytisus scoparius* (L.) Link], both of which have been rated as the top 100 most serious invasive plants of natural habitats in Canada (Catling 2005, Catling and Mitrow 2005). The economic importance of invasive plants, including those of natural habitats, is generally well-known, and management costs reach hundreds of millions of dollars in North America each year (Pimentel et al. 2005, Colautti et al. 2006).

Our hypothesis was that the herbarium collections network remains a superior source of information on invasive plants, despite a substantial recent increase in other sources of information on this subject.

Material and Methods

Subject Plants

Sea buckthorn (Fig. 2) is a remarkable plant that has huge economic potential (Small and Catling 2002). Its cultivation could expand into a new industry for Canada. It has turned into a significant fruit crop in North America only in the last decade (Li and McLoughlin 1997, Li and Shroeder 1999, Li and Beveridge 2003). The orange berries are produced in abundance and contain medicinal and nutritious substances. As well as being a very valuable plant, sea buckthorn can escape to threaten native biodiversity (Yaki 2007, 2010). Scotch broom (Fig. 3), has dominated rocky headlands and Garry Oak openings on Vancouver Island, and as a result, at least 100 native plant species are at risk and some have been lost at their only Canadian sites (Peterson and Prasad 1998). This plant is also a serious threat to agriculture, forestry, health, and to the general economy. (Catling and Mitrow 2011c). For both of these species there are questions about current status in Canada and the extent to which they can be expected to cause environmental damage in the future.

Specific Information Solicited

The queries used were the following:

1) We are studying occurrence of two plants cultivated in Canada. These are sea buckthorn (*Hipppohae rhamnoides*) and scotch broom (*Cytisus scoparius*). We would appreciate receiving any information on occurrence in Canada that you may have for these two species.
2) Are they grown in your area, and if so, for how long?
3) Are they cultivated in the general region?
4) Has either of them escaped from cultivation in your area?
5) Do you have any other related information which you think might be useful for our study?

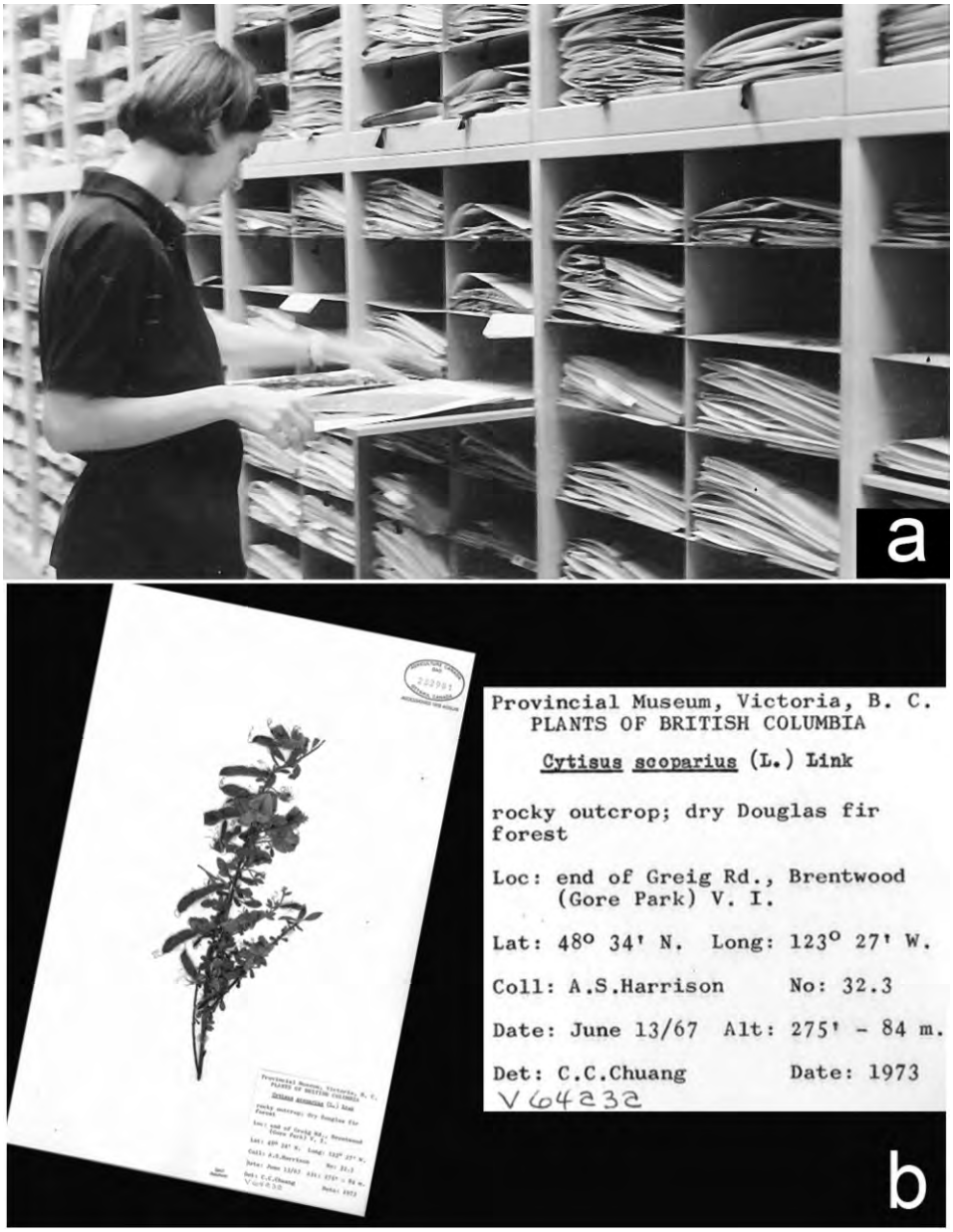

Figure 1. A herbarium is a collection of dried and pressed plant specimens with labels mounted on sheets of light cardboard. (a) Gathering information from the DAO herbarium. (b) Specimen of scotch broom with label enlarged.

Communicating Groups and Electronic Sources

The five communicating groups utilized are listed below; more information on the approach to each is available in Appendix 1. In addition, two electronic sources were used. All communications and data searches that were part of this study were conducted from January to April 2011.

Figure 2. Sea buckthorn (*Hippophae rhamonides*). (a) Branches with berries. (b) Habit of shrub. Photographs taken in Indian Head, Saskatchewan, Canada, in September 2009 by William (Bill) Schroeder.

1) The Canadian Herbarium Network included 30 herbarium collections across Canada. These are managed by universities, museums, provincial and federal governments, and support local floristic studies, identification, and systematic research worldwide. The term "Network" here refers to a directly interacting group of people and contact by individual phone calls and e-mails, rather than a query to a central portal. We could have, in addition, posted queries on a list serve such as "Herbaria" to obtain information from outside Canada, but did not because the questions here pertained only to Canada.
2) The Canadian Conservation Data Centers. There are eight across Canada, and their mandate mainly is to track and document populations of rare species. They also provide information on conservation issues.
3) The Provincial Invasive Species Councils. There are 12 across Canada and they work to minimize the negative ecological, social, and economic impacts of invasive species.
4) The Canadian Botanical Gardens and Arboreta. We selected the 18 larger ones from across Canada. They are living museums that provide information on cultivation and their key roles are in the area of horticulture, conservation, and education.
5) The Canadian Botanical Clubs. We selected 13 major clubs across Canada for this study. These botanical clubs were established for social activities, education, and to preserve biodiversity. Members of botanical clubs are devoted people ranging from professionals to amateurs.

Figure 3. Scotch broom (*Cytisus scoparius*). (a) Flowering branch. (b) Rocky headland where scotch broom dominates the landscape. The white-flowered shrub in the foreground, the Puget Sound Saskatoon (*Amelanchier florida* Lindl. var. *humptulipensis* G. N. Jones) is a relative of the Canadian crop called "Saskatoon." This crop relative might provide useful germplasm for crop improvement, but it is being overwhelmed by scotch broom. Photographs taken in Victoria, British Columbia, Canada on 26 April 2010 by P. M. Catling.

Table 1. Summary of ratings for seven sources using five criteria. CDC = Conservation Data Center. For details on all sources, see Appendix 1.

Criteria	30 Herbaria	8 CDCs	18 Botanical gardens/ arboreta	13 Invasive Species Councils	14 Botanical clubs	Web searches	Library literature searches
Amount of information gathered (% of total), max. = 10	9	5	6	9	5	7	5
Currency of information (−2 for each 5 years old), max. = 10	10	9	7	10	6	6	5
Uniqueness of useful Information (% unique to source), max. = 10	9	2	8	9	3	5	6
Response time (−2 for each week after 1), max. = 10	10	10	7	10	4	10	10
Association with experts (10 = high, 0 = low), max. = 10	10	10	10	10	7	6	10
Total	48	36	38	48	25	34	36

6) Web Searches. We did on-line searches using key words and phrases (See Appendix 1). For example, we used ''alien'' or ''invasive'' and ''Canada sea buckthorn,'' ''alien'' or ''invasive'' and ''British Columbia sea buckthorn'' when searching for each province, and we also exchanged the common names for the Latin plant names. We examined the first 25 to 50 hits because those after this point generally were much less relevant. Some sites with botanical information, such as Global Biodiversity Information Facility (GBIF), the Database of Vascular Plants of Canada (VASCAN), US Department of Agriculture Plant Database, and e-Flora of British Columbia, either did not appear among the early hits and their information was lost, or these sites had mostly general information and failed to provide answers to most of the study questions. As these and similar sites mature, they could become more useful and occupy positions among the early hits. Although the Web might be sold a little short by our method, we think that it still is a fair test of information that is readily available.
7) Library Literature Searches. The library searches were done from the Agriculture and Agri-Food Canada on-line system which allows searches on the Biosis System (including biological abstracts) for scientific journal articles. Words used were the similar to those used for the Web searches.

Scoring System

In order to evaluate the different sources, we decided on five criteria (Table 1). We used a simple rating scale of 1 to 10 points for each of these criteria (Table 1).

Results

Information acquired from different sources varied in depth, return time, and amount, and varied according to the nature of the question. The following are the results of the five selected criteria used for evaluating the information received from each of the sources.

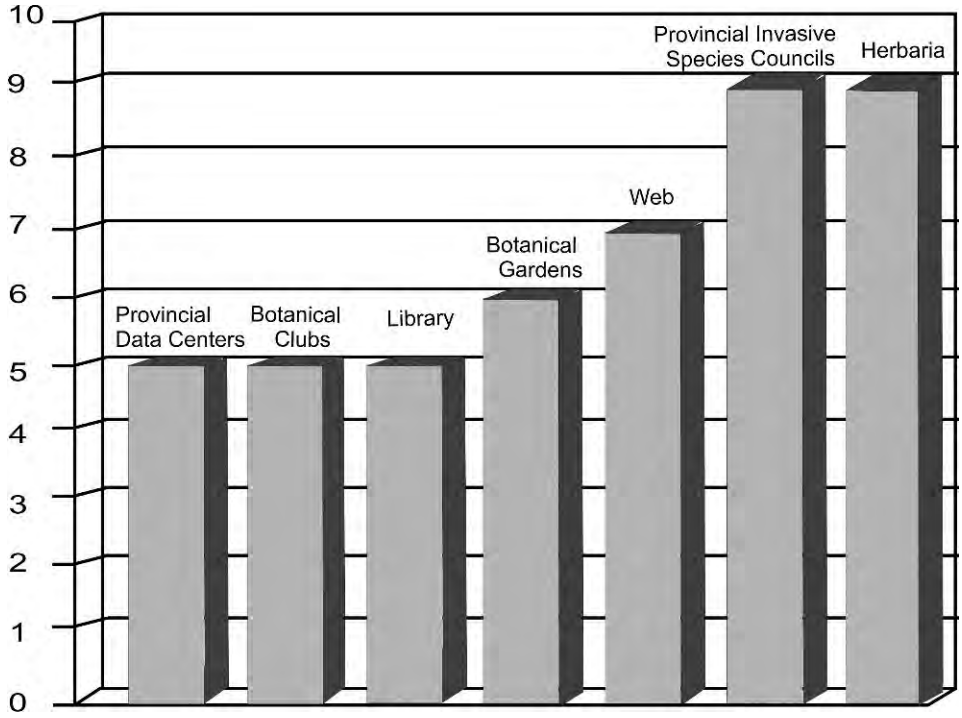

Figure 4. Histogram portraying the amount of information gathered from seven major information sources.

Amount of Information Gathered

First, we considered the amount of useful information. The fact that the herbarium network and invasive species councils did well (Fig. 4) can be attributed to the more specific invasive mandate of the latter and the broad mandate of the former. The others were able to send us useful information but provided less because their mandate was less focussed on the subject area. Provincial data centers, for example, are strongly focussed on rare species. It is notable that the Web, despite holding huge amounts of information, was not a major source for the subject areas used here.

Currency of Information

The Invasive Species Council and herbaria scored a 10 because of many recent plant records and current information (Fig. 5). The Conservation Data Center placed third because the information received was current due to ongoing communication and field work. The library rated the lowest in this category because there was very little relevant recent literature available.

Uniqueness of Useful Information

The Herbarium Collections Network and Provincial Invasive Species Councils rated the highest on uniqueness of useful information provided (Fig. 6). The information received mainly included records of specific occurrence for each of the species, which makes it possible to produce a distribution map and predict spread. The herbarium collections network provided a long historical record enabling certain kinds of analysis that could not be done without historical data. Botanical Gardens rated slightly lower than the two top sources because they provided fewer occurrences but

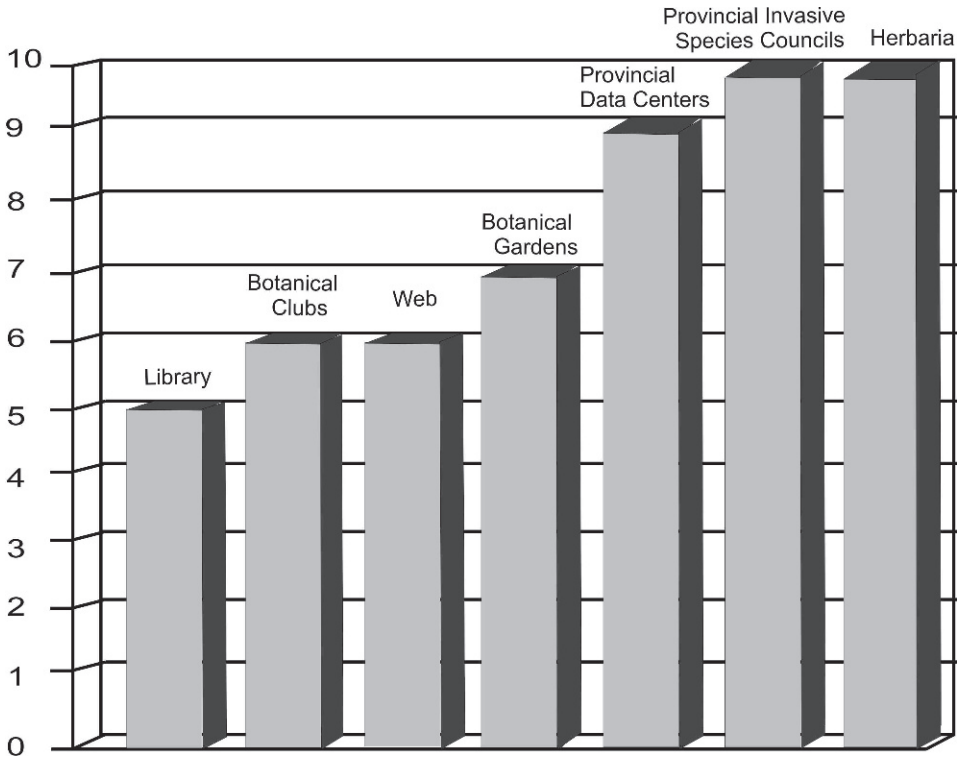

Figure 5. Histogram portraying the currency of information gathered from seven major information sources.

they did provide some feedback on their personal experience of cultivation and escape to the wild.

Response Time

Botanical clubs are slow in response time because they communicate with members periodically (e.g., sending out quarterly newsletters). Botanical gardens were also slow because most communication activity is on-site (visitors) rather than external (Fig. 7). The Invasive Species Councils were rapid because early detection is an issue as is rapid information exchange. They copied emails to large groups of supporters. Web and library self searching is rapid because all information is received within minutes. Conservation Data Centers (CDCs) had little to provide and their support depends on being useful, so their response to questions tends to be rapid. The Herbarium network is an interdependent cooperative group that is anxious to ensure that collections are used to maximum advantage—this attitude and a continuous ongoing exchange of information ensures rapid response.

Association with Experts

Only two sources had conspicuously less association with experts (Fig. 8). These were the botanical clubs and the Web (where information came from both amateurs and experts, and often lacks peer review).

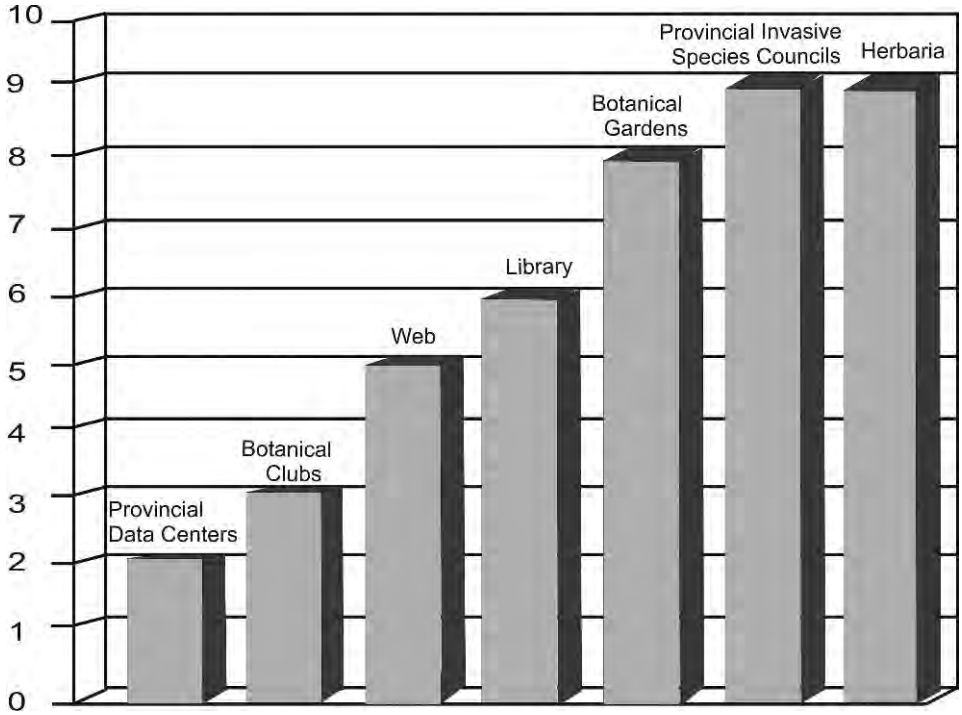

Figure 6. Histogram portraying the uniqueness of useful information gathered from seven major information sources.

Overall Rating

With regard to the questions, the best sources are the herbarium and Provincial Invasive Alien Councils networks (Fig. 9). The Web turned out to be less useful than anticipated and botanical clubs varied in the extent of a proactive role in problems relating to the flora.

Discussion

Answers to the Basic Questions

We found that, although widely planted in Canada for many decades, sea buckthorn has escaped only in local regions of southern Alberta. This suggests a limited ability to become a serious invasive. However, the taxonomic complexity of the group (Swenson and Bartish 2003) and the possibility of the different taxa having differing capabilities to be invasive in Canada indicate a need for more study. Scotch broom also has been widely introduced in Canada over a long period but has become a serious problem only in southwestern British Columbia. This might seem to suggest that it need not be a concern elsewhere. However, climate warming and development or introduction of adapted genotypes could be a problem. This is based on recent indications of spread into parts of both British Columbia and the Canadian Maritime Provinces where it did not occur previously. In the latter region, heathlands (including coastal and interior barrens) and blueberry cultivation could be impacted. This information provides a clear basis for future management actions for both species, including both field experiments and monitoring. Although the present examples are pertinent, there are other aspects of using collections to provide information on invasive plants; for example, to predict spread

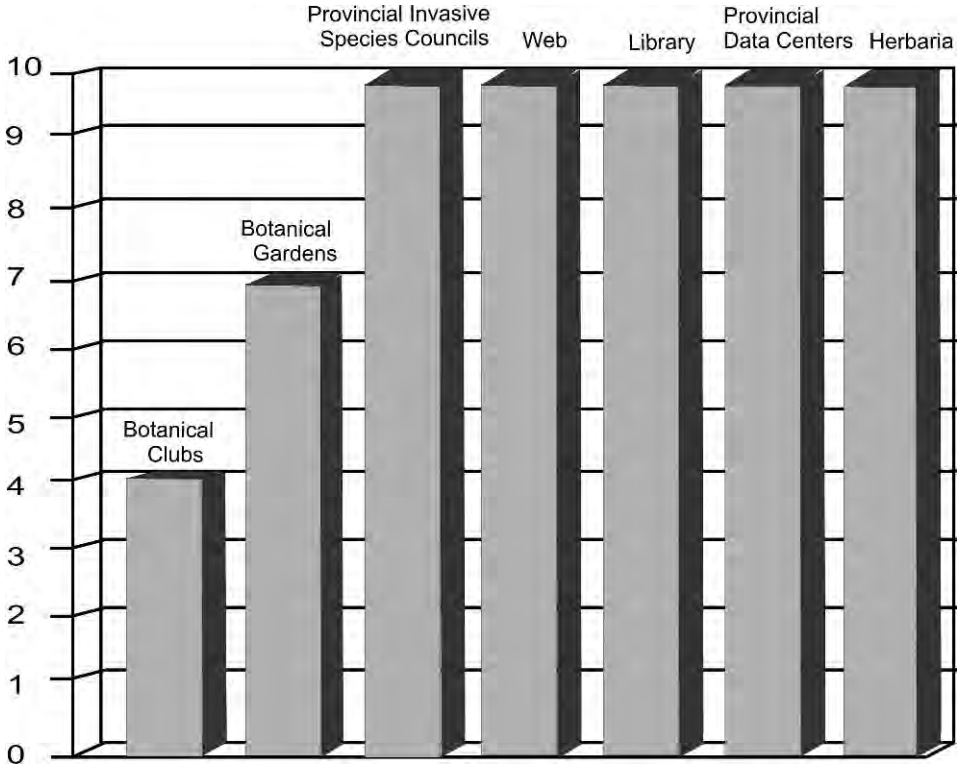

Figure 7. Histogram portraying the response time for seven major information sources.

using climate and climate-change models (Catling and Mitrow 2011a, 2011b) and for studying the characteristics of invasions using proportion curves (Deslisle 2003).

Quality and Quantity of Information

Management can be costly and should be based on information of the highest quality. Of course, the quality of information varies with the source. The collection-based information not only is closely associated with experts, but it also meets internationally accepted standards of accuracy (Chapman 2005b, c). Furthermore, the information from collections was usually accurate, specific, and represented a sample of effort over a long time period playing an extraordinary role in providing useful data. The high quality and quantity of data from the Invasive Species Councils relates to their specific mandate of invasive species management.

Collections Are Underrated

Although this study suggests that collections can be the best source of information, they and their associated network are underrated because a number of aspects were not considered. For example, there is a huge amount of unrealized information content in a collection. It is not just compilation of information, but contains vouchers that can be checked to avoid confusion and can provide additional and improved information.

Another way in which collections and collection network can act more effectively as a source, is through arrangement for acquisition of an orphan collection in the case of a complete lost of funding of one of the network members. This kind of preservation of

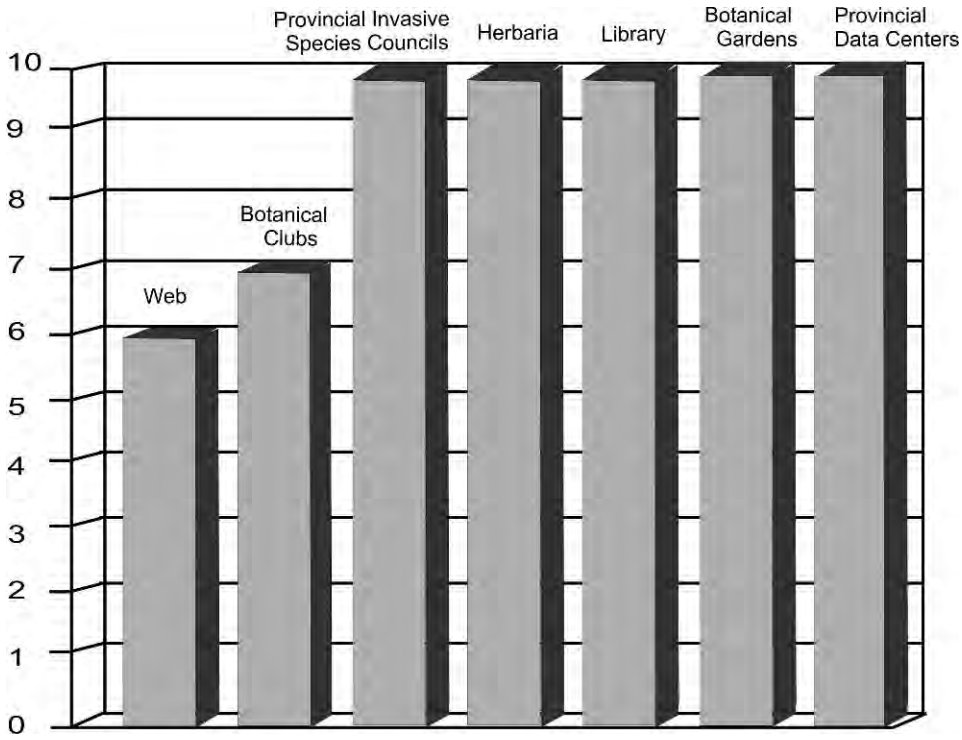

Figure 8. Histogram portraying the association with experts for information gathered from seven major sources.

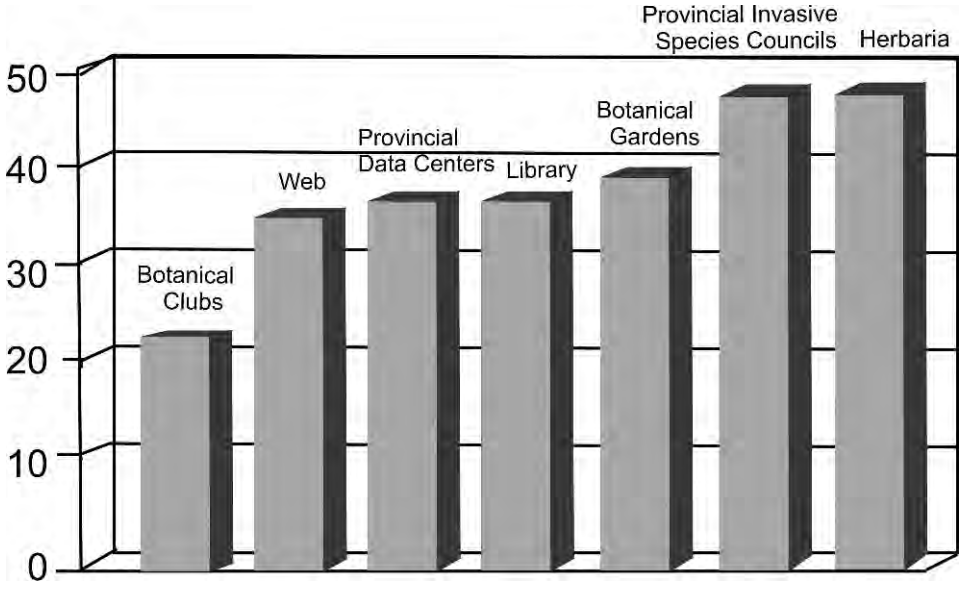

Figure 9. Histogram illustrating the overall rating for information gathered from seven major sources.

records (specimens) by arrangement for deposition is less likely to occur among members of other data-providing groups.

Because collections are a primary source, the data have not been copied or manipulated, so errors are minimized. This could be taken into account as a measure of the efficiency of data transcription or in other ways. Regardless of the level of efficiency, collections with primary data always will be the most accurate source.

Many Sources of Value

The seven sources differ in their mandates and all are very useful in addressing their primary mandate. For example, the CDC might have achieved the highest rating for information on the occurrence and status of endangered plants in Canada. The herbarium network provides the unique contribution of supplying information that only can be derived from older material, as well as new information from other sources (e.g., molecular analyses indicating the patterns of variations that need to be protected).

Some sources likely will increase in value in the future. For example, as increasing data from collections becomes available on the Web, it could increase the importance of the Web as a source. Within Canada, as projects such as "Canadensys" become more mature and serve data from multiple sources, Web-based information will be more robust. It could become equivalent to that in other parts of the world (e.g., Consortia of California Herbaria).

Two aspects of the results are particularly important: 1) All of the sources provided some useful and unique information, including those whose mandate would seem restrictive to the subject area; and 2) The results suggest strongly that a collection network can be the very best source of information on certain important ecological questions. Our hypothesis that the herbarium collections network remains a superior source of information on invasive plants, although there has been a substantial recent increase in other sources of information on this subject, was clearly supported. We speculate that analyses would reveal the collections network to be of major, if not central, importance in many other subject areas involving economy and environment. In a world of ever-increasing information sources, collections remain at the forefront.

Acknowledgments

The Canadian herbaria, the Canadian Conservation Data Centers, the provincial Invasive Species Councils distributed across Canada, the selected Canadian botanical gardens and arboreta, and Canadian botanical clubs kindly participated in this analysis, which would have been impossible without their extensive help. Dr. Richard K. Rabeler of the University of Michigan and Dr. F. R. Cook of the Canadian Museum of Nature provided helpful comments on the manuscript.

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Appendix 1

The Sources Utilized, Including Both the Communicating Group and Electronics

Canadian Herbarium Network.—The herbarium network consists of 30 Canadian herbaria listed in Index Herbariorum (Thiers 2012) and elsewhere (Boivin 1980, Rothfels 2003). These Canadian herbaria are curated by staff at universities and museums, one in a provincial ministry and another in a federal department. Their holdings range from 12,000 to 1.5 million specimens. The herbarium staffs vary from one part-time to five full-time employees, and all have associated scientific experts. The larger collections tend to have more diverse coverage, whereas the smaller ones often have specific provincial and/or regional coverage.

- ACAD: Acadia University; http://herbarium.acadiau.ca/
- ALTA: University of Alberta; http://vascularplant.museums.ualberta.ca/
- CAN: Canadian Museum of Nature; http://nature.ca/en/research-collections/our-collections/botany-collection
- DAO: Agriculture and Agri-Food Canada; http://www4.agr.gc.ca/AAFC-AAC/display-afficher.do?id=1251393521021&lang=eng
- HAM: Royal Botanical Gardens; http://www.rbg.ca/Page.aspx?pid=319
- LKHD: Lakehead University; http://www.lkhdherbarium.ca/
- MMMN: The Manitoba Museum; http://www.manitobamuseum.ca/main/botany/2010/05/27/41-uses-for-a-dead-plant/
- MT: University of Montréal; http://www.biodiversite.umontreal.ca/center/collections/herbier-marie-victorin?lang=en

- MTMG: McGill University, Macdonald Campus; http://www.mcgill.ca/herbarium/
- NBM: New Brunswick Museum; http://www.nbm-mnb.ca/index.php?option=com_content&view=article&id=133&Itemid=1196
- NFLD: Memorial University of Newfoundland; http://collections.mun.ca/cdm4/description.php?phpReturn=typeListing.php&id=63
- NFM: Provincial Museum of Newfoundland and Labrador; http://www.therooms.ca/museum/
- NSAC: Nova Scotia Agricultural College; http://nsac.ca/envsci/collections/herb.asp
- NSPM: Nova Scotia Museum of Natural History; http://museum.gov.ns.ca/mnhnew/en/home/whattoseedo/collections/botany.aspx
- PMAE: Royal Alberta Museum; http://www.royalalbertamuseum.ca/natural/botany/collects/collects.htm
- QFA: Université Laval; http://www.herbier.ulaval.ca/news.php
- QK: Queen's University; http://www.queensu.ca/biology/facilities/herbarium.html
- QUE: Herbier du Québec, Complexe scientifique; http://www.formulaire.gouv.qc.ca/cgi/affiche_doc.cgi?dossier=1846&table=0
- SASK: University of Saskatchewan; http://www.herbarium.usask.ca/
- TRT: Royal Ontario Museum; http://www.rom.on.ca/collections/curators/dickinson.php
- TRTE: Erindale College, University of Toronto; http://www.erin.utoronto.ca/~trteherb/index.htm
- UAC: University of Calgary; http://www.ucalgary.ca/herbarium/node/8
- UBC: University of British Columbia; http://www.beatymuseum.ubc.ca/herbarium/index.html
- UNB: University of New Brunswick; http://www.unb.ca/herbarium/herbarium_highlights.html
- UPEI: University of Prince Edward Island; http://islandora.ca/node/327
- UWO: University of Western Ontario; http://www.uwo.ca/biology/facilities/herbarium/herbarium.htm
- V: Royal British Columbia Museum; http://www.royalbcmuseum.bc.ca/Natural_History/Plants.aspx
- WAT: University of Waterloo; http://biology.uwaterloo.ca/services-and-resources/herbarium
- WIN: University of Manitoba; http://home.cc.umanitoba.ca/~bford/herbarium.html
- WLU: Wilfrid Laurier University; http://www.wlu.ca/homepage.php?grp_id=2147

Canadian Conservation Data Centers (CDCs).—There are eight independent CDCs covering all ten provinces and the Yukon Territory. The CDCs, also known as Natural Heritage Information Centers usually represent a single province or territory, with the exception of the Atlantic Canada Conservation Data Center, which represents the provinces of New Brunswick, Nova Scotia, Prince Edward Island, and Newfoundland–Labrador. A significant equivalent exists in the government of the Northwest Territories (NT), and Nunavut (NU) also was contacted. The CDC's mandate largely is to conduct biological inventories to track and document populations of species at risk, study and classify communities, analyze conservation issues, provide conservation services, and make their data widely available. The main Web site is: http://www.natureserve-canada.ca/en/cdcs.htm. The eight CDCs are as follows east to west across Canada:

- Atlantic Canada Conservation Data center; http://www.accdc.com/home.html

- center de données sur le patrimoine naturel du Québec; http://www.cdpnq.gouv.qc.ca/
- Ontario Natural Heritage Information center; http://nhic.mnr.gov.on.ca/
- Manitoba Conservation Data center; http://www.gov.mb.ca/conservation/cdc/pubs.html
- Saskatchewan Conservation Data center; http://www.biodiversity.sk.ca/
- Alberta Conservation Information Management System; http://www.tpr.alberta.ca/parks/heritageinfocenter/ecocommunities/default.aspx
- British Columbia Conservation Data center; http://www.env.gov.bc.ca/cdc/
- Yukon Conservation Data center; http://www.env.gov.yk.ca/wildlifebiodiversity/cdc.php

We also contacted the Department of Environment and Natural Resources in NT (http://www.enr.gov.nt.ca/_live/pages/wpPages/home.aspx) and the Department of Environment in NU (http://env.gov.nu.ca/).

Provincial Invasive Species Councils and Committees across Canada.—There are 12 established Provincial Invasive Species Councils across Canada and one (Nunavut) that has an equivalent organisation (see below from east to west across Canada). These committees are working to minimize the negative ecological, social, and economic impacts caused by the introduction, establishment, and spread of invasive plants. They are dedicated to protection and management of natural areas. Their work involves awareness and understanding of invasive plant issues and encourages action to assist in early detection, prevention and education regarding invasive alien species. Management practices in order to control and eradicate further spread of invasive alien species are also highlighted. Main Web site: http://mymotiontide.com/invasiveplantcouncilbc.ca/images/stories/documents/Nat_Map_Contacts_Dec09.pdf.

- Memorial University of Newfoundland Botanical Garden; www.mun.ca/botgarden/home.php
- Prince Edward Island Nature Trust; www.islandnaturetrust.ca
- Invasive Species Alliance of Nova Scotia (ISANS); www.invasivespeciesns.ca
- New Brunswick Invasive Species Council; www.unb.ca/herbarium/Invasives/Home.html
- Québec Interdepartmental Committee on Invasive Species; www.mddep.gouv.qc.ca
- Ontario Invasive Plant Council (OIPC); www.ontarioinvasiveplants.ca
- Invasive Species Council of Manitoba (ISCM); www.invasivespeciesmanitoba.com
- Saskatchewan Invasive Species Council (SISC); www.saskinvasives.ca
- Alberta Invasive Plant Council (AIPC); www.invasiveplants.ab.ca
- Invasive Plant Council of British Columbia (IPCBC); http://www.invasiveplantcouncilbc.ca/
- Yukon Invasive Species Council (YISC); http://environmentyukon.gov.yk.ca/wildlifebiodiversity/invasivespecies.php
- Government of the Northwest Territories; www.gov.nt.ca
- Nunavut: Currently there is no established invasive plant group in Nunavut but the equivalent would be at the NU Department of Environment; http://env.gov.nu.ca/

Canadian Botanical Gardens/Arboreta.—We selected a group of the largest Canadian botanical gardens and arboreta from different provinces across Canada (from east to west):

- Memorial University of Newfoundland Botanical Garden, Newfoundland; http://www.mun.ca/botgarden/

- The Fredericton Botanic Garden, New Brunswick; http://www.frederictonbotanicgarden.com/about.html
- Jardin botanique de Montréal, Québec; http://www2.ville.montreal.qc.ca/jardin/jardin.htm
- Morgan Arboretum, Québec; http://www.morganarboretum.org/
- CEF Dominion Arboretum, Ontario; http://dsp-psd.pwgsc.gc.ca/Collection/A42-104-2005E.pdf
- Great lakes Forest Research Center Arboretum, Ontario; http://scf.rncan.gc.ca/subsite/glfc-arboretum/the-arboretum/5
- Niagara Park Commission, Ontario; http://www.niagaraparks.com/
- Oshawa Valley Botanical Gardens, Ontario; http://ovbgoshawa.ca/
- Royal Botanical Gardens, Ontario; http://www.rbg.ca/Page.aspx?pid=193
- University of Guelph Arboretum, Ontario; http://www.uoguelph.ca/arboretum/
- Morden Arboretum Research Station, Manitoba; http://www.mordenmb.com/residents/researchstation.shtml
- Devonian Botanic Garden, Alberta; http://www.ales.ualberta.ca/devonian/
- Olds College Botanic Garden, Alberta; http://www.bgci.org/garden.php?id=3177
- Butchart Gardens, British Columbia; http://www.butchartgardens.com/index.php?option=com_frontpage&Itemid=1
- Royal Roads University Botanical Gardens, British Columbia; http://www.bgci.org/garden.php?id=4489
- University of British Columbia Botanical Garden and center for Plant Research, British Columbia; http://www.botanicalgarden.ubc.ca/
- VanDusen Botanical Garden, British Columbia; http://www.vandusengarden.org/
- Woodland Gardens Arboretum, British Columbia; http://www.arbnet.org/morton-register/canada/woodland-gardens-arboretum.html

Canadian Botanical Clubs.—These clubs were established for social activities, education, and to preserve biodiversity. Members of botanical clubs are devoted people from professionals to amateurs. They organize plant exhibitions, shows, competitions, field trips, and seminars. The sample of clubs which were selected across Canada was as follows (from east to west across Canada):

- New Brunswick Botanical Club; http://www.macbe.com/botanyclub/home.html
- Flora Quebeca, Québec; http://www.floraquebeca.qc.ca/
- Ottawa Field Naturalist Club, Ontario; http://www.ofnc.ca/
- Ontario Horticulture Association, Ontario; http://www.gardenontario.org/
- Garden Club of Ontario; http://www.gardenclubsofontario.ca/
- Field Botanists of Ontario; http://www.trentu.ca/org/fbo/
- Manitoba Horticultural Association; http://www.icangarden.com/document.cfm?task=viewdetail&itemid=4998
- Saskatoon Horticultural Society, Saskatchewan; http://www.saskatoonhortsociety.ca/About_Us.html
- Alberta Horticultural Society, Alberta; http://www.icangarden.com/clubs/AHA/
- Calgary Horticultural Society, Alberta; http://www.calhort.org/
- Pacific Northwest Palm and Exotic Plant Society, British Columbia; http://www.hardypalm.com/
- Sunshine Coast Conservation Association, British Columbia Sunshine Coast; http://www.thescca.ca/index.php?option=com_content&task=view&id=207&Itemid=1

- Conservation Association, British Columbia; http://www.thescca.ca/
- Master Gardeners Association, British Columbia; http://www.bcmastergardeners.org/

Web Searchs.—The searches, done online using Boolean logic keywords and phrases, was as follows:

- "alien" or "invasive" and "Canada sea buckthorn"
- "alien" or "invasive" and "British Columbia sea buckthorn"
- "alien" or "invasive" and "Alberta sea buckthorn"
- "alien" or "invasive" and "Saskatchewan sea buckthorn"
- "alien" or "invasive" and "Manitoba sea buckthorn"
- "alien" or "invasive" and "Ontario sea buckthorn"
- "alien" or "invasive" and "Quebec sea buckthorn"
- "alien" or "invasive" and "Maritimes sea buckthorn"
- "alien" or "invasive" and "New Brunswick sea buckthorn"
- "alien" or "invasive" and "Nova Scotia sea buckthorn"
- "alien" or "invasive" and "Prince Edward Island sea buckthorn"
- "alien" or "invasive" and "Newfoundland sea buckthorn"
- "alien" or "invasive" and "Yukon sea buckthorn"
- "alien" or "invasive" and "Northwest Territories sea buckthorn"
- "alien" or "invasive" and "Nunavut sea buckthorn"
- "alien" or "invasive" and "Canada *Hippophae rhamnoides*"
- "alien" or "invasive" and "British Columbia *Hippophae rhamnoides*"
- "alien" or "invasive" and "Alberta *Hippophae rhamnoides*"
- "alien" or "invasive" and "Saskatchewan *Hippophae rhamnoides*"
- "alien" or "invasive" and "Manitoba *Hippophae rhamnoides*"
- "alien" or "invasive" and "Ontario *Hippophae rhamnoides*"
- "alien" or "invasive" and "Quebec *Hippophae rhamnoides*"
- "alien" or "invasive" and "Maritimes *Hippophae rhamnoides*"
- "alien" or "invasive" and "New Brunswick *Hippophae rhamnoides*"
- "alien" or "invasive" and "Nova Scotia *Hippophae rhamnoides*"
- "alien" or "invasive" and "Prince Edward Island *Hippophae rhamnoides*"
- "alien" or "invasive" and "Newfoundland *Hippophae rhamnoides*"
- "alien" or "invasive" and "Yukon *Hippophae rhamnoides*"
- "alien" or "invasive" and "Northwest Territories *Hippophae rhamnoides*"
- "alien" or "invasive" and "Nunavut *Hippophae rhamnoides*"
- "alien" or "invasive" and "Canada *Cytisus scoparius*"
- "alien" or "invasive" and "British Columbia *Cytisus scoparius*"
- "alien" or "invasive" and "Alberta *Cytisus scoparius*"
- "alien" or "invasive" and "Saskatchewan *Cytisus scoparius*"
- "alien" or "invasive" and "Manitoba *Cytisus scoparius*"
- "alien" or "invasive" and "Ontario *Cytisus scoparius*"
- "alien" or "invasive" and "Quebec *Cytisus scoparius*"
- "alien" or "invasive" and "Maritimes *Cytisus scoparius*"
- "alien" or "invasive" and "New Brunswick *Cytisus scoparius*"
- "alien" or "invasive" and "Nova Scotia *Cytisus scoparius*"
- "alien" or "invasive" and "Prince Edward Island *Cytisus scoparius*"
- "alien" or "invasive" and "Newfoundland *Cytisus scoparius*"
- "alien" or "invasive" and "Yukon *Cytisus scoparius*"

- "alien" or "invasive" and "Northwest Territories *Cytisus scoparius*"
- "alien" or "invasive" and "Nunavut *Cytisus scoparius*"
- "alien" or "invasive" and "Canada scotch broom"
- "alien" or "invasive" and "British Columbia scotch broom"
- "alien" or "invasive" and "Alberta scotch broom"
- "alien" or "invasive" and "Saskatchewan scotch broom"
- "alien" or "invasive" and "Manitoba scotch broom"
- "alien" or "invasive" and "Ontario scotch broom"
- "alien" or "invasive" and "Quebec scotch broom"
- "alien" or "invasive" and "Maritimes scotch broom"
- "alien" or "invasive" and "New Brunswick scotch broom"
- "alien" or "invasive" and "Nova Scotia scotch broom"
- "alien" or "invasive" and "Prince Edward Island scotch broom"
- "alien" or "invasive" and "Newfoundland scotch broom"
- "alien" or "invasive" and "Yukon scotch broom"
- "alien" or "invasive" and "Northwest Territories scotch broom"
- "alien" or "invasive" and "Nunavut scotch broom"

Library Literature Searches.—Journal searches of the BIOS system were done using the following keywords:

- invasive and scotch broom
- weed and scotch broom
- crop and scotch broom
- alien and scotch broom
- Canada and scotch broom
- scotch broom
- *Cytisus scoparius*
- invasive and *Cytisus scoparius*
- weed and *Cytisus scoparius*
- crop and *Cytisus scoparius*
- alien and *Cytisus scoparius*
- Canada and *Cytisus scoparius*
- invasive and sea buckthorn
- weed and sea buckthorn
- crop and sea buckthorn
- alien and sea buckthorn
- Canada and sea buckthorn
- sea buckthorn
- *Hippophae rhamnoides*
- invasive and *Hippophae rhamnoides*
- weed and *Hippophae rhamnoides*
- crop and *Hippophae rhamnoides*
- alien and *Hippophae rhamnoides*
- Canada and *Hippophae rhamnoides*

HIGH-THROUGHPUT DIGITIZATION OF ORIGINAL MUSEUM SOURCE DOCUMENTATION

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Abstract.—The Yale Peabody Museum of Natural History, in collaboration with three other units at Yale University, was given the opportunity to use Kirtas robotic scanners to preserve original museum source documentation. All of the museum documentation from 12 divisions was identified, prioritized, and evaluated for copyright status. Trained Peabody staff scanned the documentation on the Kirtas scanners and processed them into PDFs, which were then integrated into the KE EMu museum collections management system. This article provides a look at procedures that were developed, problems that occurred, a summary of the results, and the benefits of digitization.

INTRODUCTION

As good stewards, one of the most important things staff can do in a museum environment is to preserve the contents of a museum's original source documentation. Original source documentation includes any original written or printed material that provides information about an object during its discovery or time of study. More often than not, this is the only source of information as no copy of the original material exists. If the original material deteriorates, all of the valuable information it contains will be lost. The key is to reproduce the original material before this happens. Digitization is a way of transforming the original information in its physical form to a digital form that will allow people access to the information without handling the original. This digital preservation not only makes this archival information searchable but allows people to share information as well.

Kirtas Technologies, Inc., generously loaned Yale three APT Bookscan 2400 scanner units through the Office of Digital Assets and Infrastructure (ODAI), to be used collaboratively to digitize documentation across the Yale University community (Fig. 1). ODAI is developing a University-wide digital information strategy and helps to provide collaboration between units around campus, including museums and libraries, that are interested in developing strategies and systems for digital preservation (ODAI 2011). ODAI's sponsorship of these machines is part of their larger effort to create a shared digitization center for staff and faculty to use digital technologies to enhance access to collections for teaching and learning. Through this loan, the Yale Peabody Museum and the participating units on campus—Yale Center for British Art, Yale University Library, Beinecke Library, and the Cushing/Whitney Medical Library—were given the opportunity to digitally preserve their original museum source documentation and utilize it for research and teaching. The Peabody Museum utilized one of these scanning machines for this project.

MATERIALS

Each scanner unit consists of three computers, each with 1.8 TB of storage and seven software programs. Computer 1 contains the KABIS Manager, which is the primary user interface for the scanner, and controls Camera 1. Computer 2 contains the software for Camera 2. Computer 3 contains the post-processing software—ProcLauncher, Book

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Figure 1. Kirtas APT Bookscan 2400 scanner (retail value: approximately $200,000 plus yearly maintenance contract).

Scan Editor (BSE), Quality Assurance (QA), and OCR Manager—as well as the space to store the initial scanned images to the post-processed images to the final PDFs.

Even though it is called a scanner, each machine actually takes high-resolution photographs (either JPGs or TIFFs) of the book pages. Each scanner is equipped with two 16.6 megapixel Canon Mark II cameras, which are positioned upside down on metal ears on top of the scanner. They are positioned at a 90° angle opposite the pages they are shooting, ensuring a straight shot of the documentation. The cameras are hooked up to the computers, and options, such as F-stop, ISO, white balance, and shutter speed can be controlled by the operator and manipulated by the software, eliminating the need to alter options on the camera manually. This is critical because it minimizes the chances of the user jostling the camera and lens.

Below the cameras lie the cradle which holds the documentation, either bound or unbound (Kirtas Technologies 2010b), in place while it is being photographed. The 110° angle of the cradle keeps the spine of a book straight while the pages are turned. This is the best position for a book as there is low stress on the spine—far improved from scanning books on a flatbed scanner. There are three important parts to the cradle: the focusing laser, the robotic arm, and the fluffer. Once the book is centered on the cradle, the focusing laser is used to find the center of the book and will focus the cameras accordingly. This is an important step because many errors can be fixed in post-processing; however, focus is not one of them. If the images are out of focus, they will have to be taken again.

The robotic arm comes with two interchangeable heads: one for small books, one for large books. The head acts as a vacuum and when placed on the page gently sucks the page and turns it so that the next set of images can be taken. The Kirtas scanner can be used in automatic or manual mode. In automatic mode, the user can change the speed of the robotic arm, which can automatically turn pages anywhere from 300 pages per hour to 2,400 pages per hour. At its top speed, the scanner would be able to scan a 300-page book in 8 minutes; it would take a human about 1 hour to scan the same amount of pages by hand on the same scanner. To accommodate varying page thickness, the amount of suction is adjustable. Both of these options can be controlled by the operator through the software. Manual mode, in which the operator turns pages by hand, is sometimes needed if a book has brittle pages.

The robotic arm works in conjunction the fluffer, which is positioned on both the top and bottom of the right side of the cradle. It is designed to blow air out into the pages, which allows them to separate or ''fluff'' up. By allowing the pages to separate, the robotic arm is then free to turn one page a time. The force of air blown out of the fluffer can also be controlled by the user through the software.

When a book is ready to be scanned, clamps are lowered, either manually or automatically, at the top and bottom of the pages. The cameras fire, and images are taken of the left and right pages. The clamps then move up off the pages, and a short burst of air is blown into the remaining pages on the right side of the book. This ''fluffs'' up the pages and allows them to separate so that the robotic arm can gently select one page and turn it. The clamps then come back down on the new set of pages, and the next set of images is taken.

Once all of the photos are taken, a template is then made using one right and one left page. The pages can be cropped, rotated, and color balanced (Kirtas Technologies 2010a). Once this is completed, the template is then applied to the entire book. The time it takes to apply the template is directly proportional to the size of the book. Once the template has been applied to all of the digital images, the user is given a chance to adjust

individual pages. This is known as the Quality Control (QC) step. Once the digital images complete this step, the software pushes them into the Quality Assurance (QA) step, in where the operator visually inspects for mistakes. The processed images are then moved to the optical character recognition (OCR) manager, where they are compiled into a PDF. Because these original museum source materials are handwritten, the result is not a searchable PDF, as OCR is not available for handwriting.

Methods

A list of 954 items was compiled from all 13 divisions at the Peabody. Due to the large number of items, material was divided into three phases. Phase 1 items were deemed top priority because collection staff referred to them often; they included ledgers and catalogs that were usually the oldest and in the worst physical shape. Phase 2 consisted of field notebooks, diaries, bound correspondence, and the like. Phase 3 consisted of loose written material that was pertinent to objects in the collection. Each item was entered into EMu as its own multimedia file and given a unique internal record number (IRN).

A representative from Kirtas Technologies led a 3-day onsite initial training session at Yale during which five Peabody staff were trained along with seven other Yale University staff from various units. For 2 months after the initial training, Peabody staff tested the machine with various types of written material to see what original museum source documentation it could handle. A 220-step method was devised that would take each one of the original museum source materials from hard copy to digital PDF. Images were shot as 300 dpi JPGs, as this was sufficient for the nature of the material and had a smaller storage footprint than TIFFs. All documents were imaged at actual size. Extensive color correction was not employed, since the nature of the documentation and their use as digital files did not necessitate calibrated color. However, the QC step in the Kirtas software allows the operator to apply color correction as needed. For this project, it was decided to have the digital images as close in color to the original documentation as possible, so color correction was minimal.

All images were stored on Computer 3 for 3 months. This allowed time for the PDF to be reviewed by the Kirtas operators as well as time for alterations or rescanning, if necessary. After 3 months, only the initial images and the final PDF were kept on Computer 3. All other images were erased to save space on the hard drive. All final PDFs were transferred to a LACIE Rugged hard disk and physically delivered to the head of computer systems at the Peabody. The PDFs were then uploaded to EMu as multimedia attachments. A low-resolution copy was kept in EMu. A high-resolution copy was kept in the Yale Digital Asset Management system (DAM). Currently all digitized documentation is available only to Yale internal researchers. Once all the documentation has been digitized, all materials that can be displayed under the ''fair use'' policy will be available for external researchers.

Four of the trained Peabody staff emerged as dedicated Kirtas operators. The Anthropology, Invertebrate Zoology, and Vertebrate Paleontology divisions each had an operator to scan their materials. The fourth operator was responsible for all materials from the remaining divisions at the Peabody.

Problems arose even before digitization began. First, Peabody had just completed moving about 4 million objects and their documentation from the main museum in New Haven to Yale's West Campus, the newly acquired research collection facility in West Haven. Although it is only 8 miles away, with documentation in both locations, it proved challenging to coordinate times and methods of transferring materials.

Peabody Copyright Status Checklist

Name:_____ Date:_____

Division:_____ Phone:_____

Book Title:_____ IRN:_____

1) Item Description:

- ☐ Ledger/Catalog/Receipt Book
- ☐ Field Notebook/Journal
- ☐ Bound Book
- ☐ Art/Illustration
- ☐ Loose Leaf
- ☐ Other:_____
- ☐ Pamphlet
- ☐ Thesis
- ☐ Map
- ☐ Photograph
- ☐ Correspondence

2) Is the material published?

☐ Yes. Continue to Question 4. ☐ No. Continue to Question 3.

3) Was the material written/prepared on Yale time and/or with Yale money?

☐ Yes. The material belongs to Yale and can be copied.

☐ No. See Guidelines for Unpublished Works.

4) Does the publication have a Yale University copyright notice?

☐ Yes. This work is copyrighted by Yale and can be copied. ☐ No. Continue to Questions 5.

5) Is there a written agreement with the copyright owner that transfers permission/copyright to Yale?

☐ Yes. This work is under copyright but can be copied by Yale. ☐ No. Continue to Question 6.

6) Is the publication date prior to 1923?

☐ Yes. The material is no longer protected by copyright and can be copied. ☐ No . Continue to Question 7.

7) Is the publication date prior to 1978 and publication lacks a copyright notice?

☐ Yes. The material is probably not protected by copyright and can be copied. ☐ No. Continue to Question 8.

8) Was the work prepared by a U.S. government employee in the course of his/her employment?

☐ Yes. The material is not protected by copyright and can be copied. ☐ No. Continue to Guidelines.

☐ I have determined, to the best of my ability, the aforementioned materials are public domain, or

☐ I have determined, to the best of my ability, that Yale owns copyright and/or has the right to make copies , or

☐ I have determined, to the best of my ability, that Yale has the right to create archival copies of these materials, according to the doctrine of fair use.

Disclaimer: the use of material under copyright requires permission of the owner.

Signature:_____ Date:_____

PEABODY MUSEUM OF NATURAL HISTORY, YALE UNIVERSITY
170 WHITNEY AVENUE, P.O. BOX 208118, NEW HAVEN, CT 06520-8118 USA
www.peabody.yale.edu — peabody.collections@yale.edu

Figure 2. Copyright checklist devised to evaluate copyright of all documentation to be digitized.

The second challenge was tackling the copyright issue with all of the original museum source documentation. Although most of our material was created by Yale employees and Yale owned the copyright, there were a few items that had been donated, and it was unclear whether copyright was transferred to Yale. In cases such as these, there are four major questions that need to be asked as a rule of thumb when copying materials:

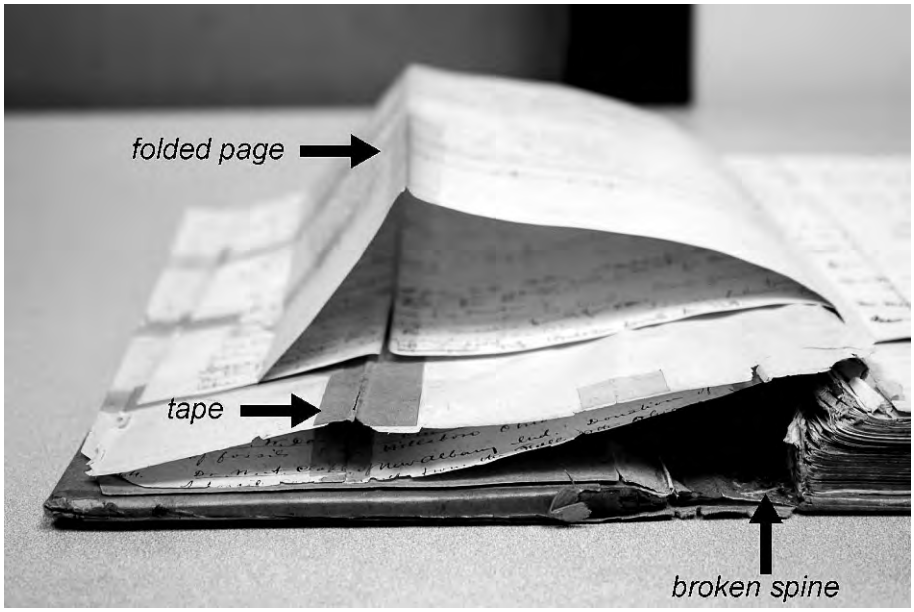

Figure 3. Various preservation challenges prominent in our Phase 1 materials.

1. What is the copied material going to be used for?
2. What is the nature of the copyrighted work?
3. What portion of the work will be used?
4. What effect will the use have on the value of the work in the marketplace?

The answers to these questions will help determine whether the material falls under the US fair use policy. To organize the chaos, a one-page checklist was devised as well as a set of guidelines that were given to all divisions (Fig. 2). The copyright guidelines for this project were based on the US Copyright Office (US Copyright Office 2008) and Campus Copyright Rights and Responsibilities (Association of American Universities 2005).

Through a series of yes and no questions, each division was required to fill out a checklist for each item to determine whether it was possible to copy the documentation. If the documentation could be legally copied, the sheet was then signed by a collections manager. The documentation would then be transported to the Kirtas scanning room at West Campus. Before any of the Kirtas trained Peabody staff scanned an item, the copyright checklist was double checked. If the checklist was not signed by a collections manager, if Yale did not own the copyright, or if the material could not be copied under the doctrine of fair use, the documentation was not digitized.

Challenges

In December 2009, with 279 materials in Phase 1, the team began digitizing. It was quickly discovered that 23% of the ledgers were too large for the scanner (spine length $>$ 13 inches/33.02 cm), and they were put aside to be dealt with later. Of the materials that were able to be digitized, it was discovered that the Peabody team (consisting of four operators) was able to complete about 16 ledgers a week. However, challenges emerged in which manual mode was used (about 100 pages/hour), without the robotic arm, which in

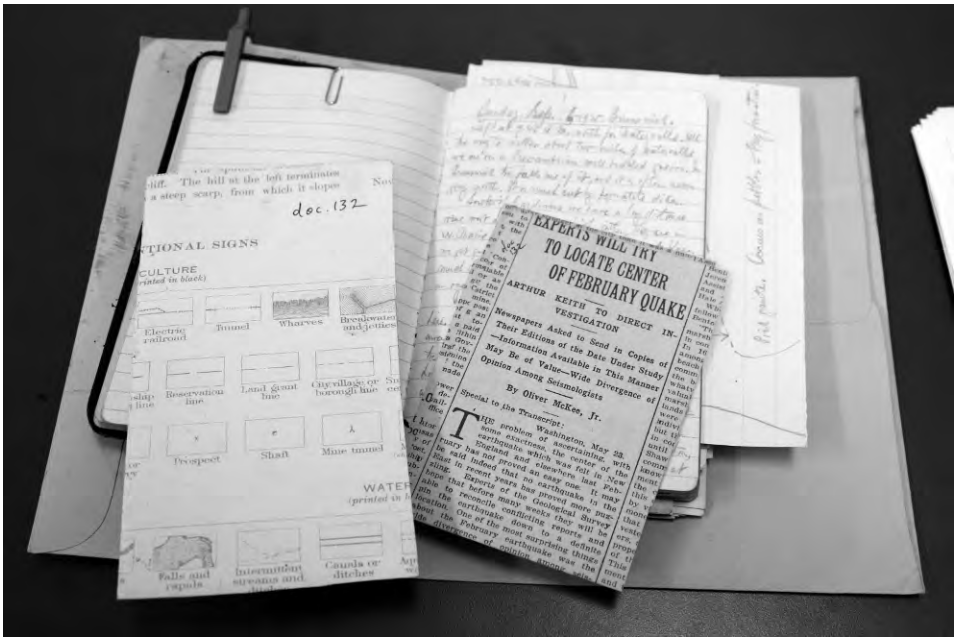

Figure 4. Loose materials randomly stuck between the pages of a field notebook.

the end slowed production. This reduced production was considered acceptable as the team wanted to ensure that the books were handled with care and scanned accurately.

One of the major obstacles was that a large amount of the documentation had preservation issues (Fig. 3). There were several examples of broken spines, loose pages, pages that were folded, and most prominently pages that had been taped over the years. Each ledger was evaluated for stability (such as brittleness of pages or stability of spine) and each of its "quirks" (such as folded pages, inserts, or items stapled to pages) reviewed before going to the scanner. If a ledger was too fragile, it was put aside to be dealt with later. Most ledgers were too fragile to be used with the robotic arm, so the pages had to be turned manually, allowing the book to be stabilized by the cradle but using human hands to deal with all of the quirks in the ledger.

Several instances arose of loose documentation that were inserted between pages of notebooks and ledgers (Fig. 4). This material was related to the original museum source material but was of various sizes. These pieces were scanned as they appeared in the ledger, on manual mode. If page numbers were added to the ledger in the QC stage, these loose materials would not receive a page number. Aside from postcards, photographs, and receipts for bacon purchased for field collecting trips, one of the most interesting finds was a newspaper clipping discovered in the 1899 field journal of the noted paleontology professor Richard Lull (Fig. 5). The clipping was dated Saturday evening, 3 June 1899, and was sandwiched between the pages of Lull's journal entries. On Friday, 2 June 1899, while doing field work in Medicine Bow, Wyoming, Lull writes of hard rainstorms that sent his party running for cover around 4:00 PM. Soon after, 10 men on horseback arrived, armed with revolvers and rifles. They turned out to be a deputy sheriff and his posse looking for six train robbers who had held up a Union Pacific train called the *Overland Limited*. The thieves had used dynamite to blow open the train's safe and escaped with anywhere from $600 to $60,000. The posse ate supper with Lull and his

Figure 5. Part of the scanned newspaper clipping from Lull's journal.

team, waited for the rain to stop, and then continued their pursuit. Lull's journal entry ends there, but a newspaper clipping added some fascinating details. The clipping describes the robbery and Union Pacific's offer of a reward of $1,000 for each outlaw, dead or alive. The article goes on to say that the train robbers were from a remote hideout called Hole-in-the-Wall in the Big Horn Mountains. The head of these train robbers was a man named Robert Leroy Parker, aka Butch Cassidy!

Several divisions had documentation with foldouts that were too large to fit on the Kirtas machine (Fig. 6). To solve this problem, the Peabody's 21 megapixel Canon Mark III camera was set up on a stationary tripod boom attached to a table to take overhead pictures of the foldouts. Images were taken as JPGs and were combined with the JPEGs from the Kirtas machine, which were then processed together. Ledgers that were too large for the Kirtas scanner (exceeded a spine length of 13 inches/33.02 cm) were also photographed this way. Their images were transferred to the Kirtas machine and then processed with the Kirtas software.

Vertebrate Paleontology had several bound volumes of correspondence printed on carbon paper (Fig. 7). It was discovered that if a photograph was taken of the top correspondence, the pages below it were visible, due to the fact that the paper was so thin. To solve this problem, a plain sheet of white paper was manually placed between the letters as they were imaged. With the paper being so delicate and the placement of the white paper, each of these volumes had to be scanned on manual mode. This proved to be very time consuming as each volume averaged 900–1,000 pages.

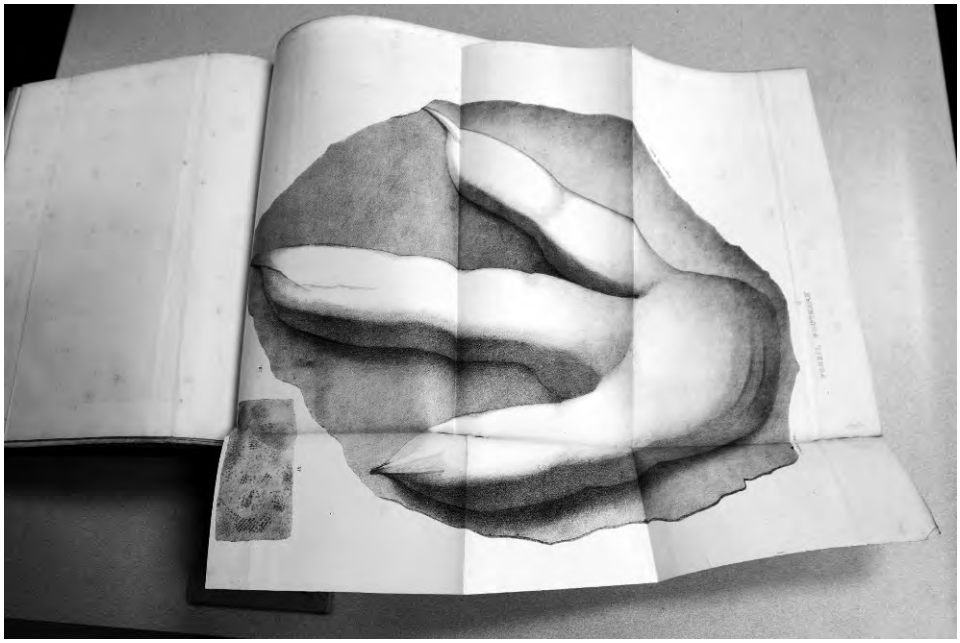

Figure 6. Foldout from a vertebrate paleontology book that was too big for the Kirtas scanner.

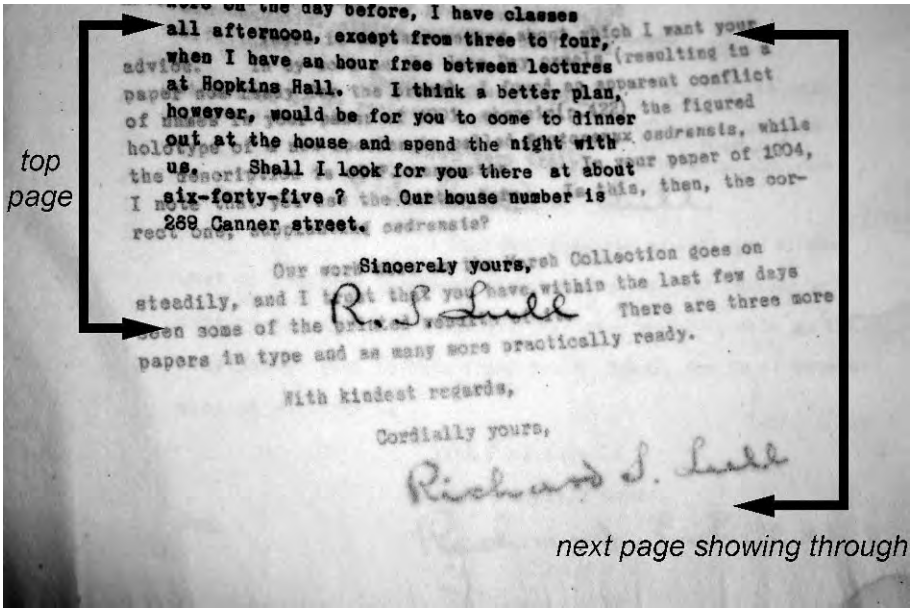

Figure 7. Bound carbon correspondence. Because of the fact that the paper is so thin, the page below (arrow on the right) can be seen through the top page (indicated by arrow on the left).

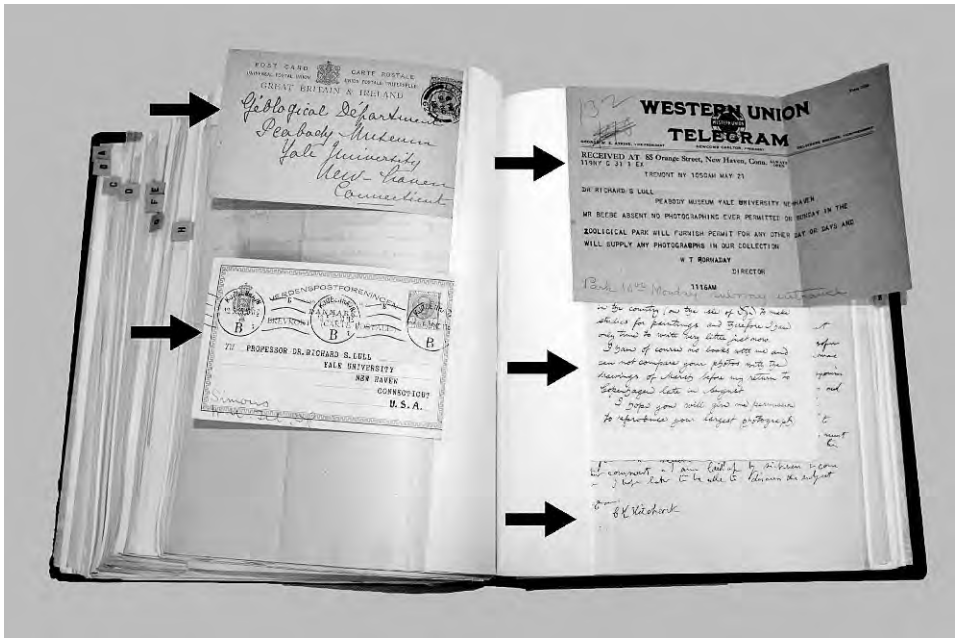

Figure 8. Arrows indicate the various sizes and placement of items in a "scrapbook."

There were also several bound volumes of "scrapbooks" (Fig. 8). These volumes consisted of related original museum source documentation that were bound together. They were of various shapes and sizes consisting of postcards, letters, telegrams, newspaper articles, and business cards as can be seen by the arrows in Figure 8. In some cases, a sheet of white paper was inserted between items to get a clear shot of the top item. Since they were of various sizes and bound at different points in the books, the robotic arm could not be used, and these all had to be turned manually.

Results

There was a high demand for digitization, and the team was inundated with original museum source material from all divisions. There are currently a total of 1,010 items, which increases every day. Of these, 282 items are ledgers and 728 are notebooks and field journals. A total of 311 items (31% of total) have been successfully scanned, totaling 54,844 pages. Seventy-eight percent of this scanned documentation had to be scanned by hand, which caused our scanning speed to drop. A total of 590.17 man hours (exclusive of training) has been dedicated to scanning and processing, which averages to 100 pages per hour. After 8 months in production, 68% of the Phase 1 ledgers have been completed on the Kirtas scanner. The remaining ledgers are oversized and will be photographed with the overhead camera. Eighteen percent of the Phase 2 materials—notebooks and field journals—have also been completed using the Kirtas scanner. All completed PDFs have been placed in the EMu database as a multimedia file and can be accessed by all Peabody divisions. While there are no plans in place yet, it is the long-term goal to have each catalog number in EMu linked to a ledger page and any other original source documentation related to it.

Conclusions

Although it is never easy to pioneer new methods and procedures, this project has demonstrated that Kirtas technology is beneficial in the digitization of various types of original museum source documentation. This information can now be digitized into a modern electronic format and shared easily. This saves wear and tear on the original ledger while allowing access to information that may have not been available. Catalogs, ledgers, field notebooks, and correspondence can now be digitally preserved without past worries of fading ink and broken spines or lost to disasters such as fires and water damage.

This project has also demonstrated the importance of preserving original museum source documentation. Peabody staff members referring to original documentation are thrilled not only to have the convenience of a digital copy of this material at their fingertips, but to also save wear and tear on the physical material. This project has opened new lines of communication within units across Yale as the stepping stone to a university-wide digital collaborative effort. In fact, this project is just a small part of the digitization effort that has spread to cultural heritage institutions across the nation. Other projects pioneering this effort include the Digital MVZ Project (Museum of Vertebrate Zoology at Berkeley 2011) at the University of California, Berkeley, the Field Book Project (Smithsonian Institution 2010) at the Smithsonian Institution, and the National Digital Library Program (Library of Congress 1995) at the Library of Congress, as well as many more supported by IMLS, CLIR, and NEH. It is clear that digitization is an integral part of the future of museums. By embracing this technology, we will be able to continue to uphold our duty as good stewards and preserve the past.

Acknowledgments

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PARALOID™ B-72: PRACTICAL TIPS FOR THE VERTEBRATE FOSSIL PREPARATOR

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Abstract.—Paraloid™ B-72, an ethyl methacrylate/methyl acrylate copolymer manufactured by Rohm and Haas, is increasingly favored as the first choice of conservators and vertebrate fossil preparators for a wide variety of tasks. Scientific tests of this acrylic resin have demonstrated outstanding resistance to degradation under normal conditions of exposure and the ability to remain clear, soluble, and removable or reworkable over time. Paraloid B-72 has an intermediate hardness and strength and is soluble in acetone, ethanol, and other solvents, each of which imparts different working properties. These intrinsic properties of Paraloid B-72 are advantageous, but appropriate use also depends on technique—the practical aspects of handling and manipulating this polymer. Many of these techniques come from diverse conservation disciplines unrelated to paleontology and are scattered throughout the literature. Others, particularly those developed by paleontology preparators, are not published at all. Although by no means complete, this literature review and compilation of practical tips contributed by our colleagues provides guidance to the use of this valuable polymer in vertebrate paleontology. Topics include mixing ratios, an easy way to make solutions using cheesecloth, recommendations for containers, how to easily clean jars and keep lids from sticking, various means of dispensing solutions such as tubes, bottles, and syringes, advice for consolidation by immersion or spray application, tips for reactivation of dried resin with solvent or heat, joining techniques for very small and very large specimens, and tips for removal. Although no single adhesive or consolidant is suitable for every situation, Paraloid B-72 is an excellent candidate for many vertebrate fossil preparation tasks.

PARALOID B-72

Fossil preparation typically includes many tasks, such as joining, consolidation, coating, and gap filling, that require the use of adhesive resins or polymers. Those who prepare fossils are responsible for evaluating the specimen and the task at hand and for choosing an appropriate adhesive and consolidant. It is a responsibility they share with conservators of objects in other fields such as art, ethnography, and archaeology. Although no single adhesive is perfect for every situation, one type of acrylic co-polymer, Paraloid™ B-72, is increasingly favored as the first choice of conservators and fossil preparators for a wide variety of tasks. Custom-made solutions of Paraloid B-72 dissolved in various solvents have many advantages over other polymers or resins commonly used in paleontology.

ADVANTAGEOUS PROPERTIES

Paraloid B-72 Is a Very Stable Material

Conservators and a growing number of fossil preparators favor Paraloid B-72 for its outstanding resistance to degradation under normal conditions of exposure and its ability to remain clear, soluble, and removable over time. Cast films of Paraloid B-72 have been extensively tested (Feller and Curran 1975; Feller et al. 1981; Down et al. 1996; Lazzari and Chiantore 2000; Chiantore and Lazzari 2001; Down 2009). In his 1978 paper "Standards for the Evaluation of Thermoplastic Resins," R.L. Feller designated Paraloid B-72 as a Class A resin, a classification given to the few polymers that have expected useful lifetimes of greater than 100 years (Feller 1978). Used as a picture varnish in

average museum conditions, Paraloid B-72 should remain colorless and soluble in its original solvent for more than 200 years (Feller et al. 1981:194). Of course, the suitability of any adhesive is dependent upon the application (Down 2009:97). Although not directly related to its use on fossil substrates, test results demonstrating the superior long-term stability of Paraloid B-72 together with a long history of various uses on a wide variety of objects since 1947 (Horie 2010:165) support the reasonable expectation of good long-term performance on fossils under museum conditions. A very good overview of polymer science, including testing, is provided by C.V. Horie in the second edition of his classic reference book *Materials for Conservation: Organic Consolidants, Adhesives and Coatings* (2010).

Paraloid B-72 Is Reworkable

Like other common solution adhesives such as polyvinyl butyral (PVB) and polyvinyl acetate (PVAC), Paraloid B-72 sets by the evaporation of the solvent and can be redissolved repeatedly as needed. The ability to be redissolved and reworked is generally preferable to the insolubility of adhesives that set by chemical reaction (cyanoacrylates and epoxies), unless these are required for other reasons. For a basic introduction to solution and reaction adhesives see Davidson and Alderson (2009). Paraloid B-72 may also be softened and reworked with heat; see the discussion below on heat reactivation and manipulation.

Paraloid B-72 Has an Intermediate Hardness and Strength

Paraloid B-72 as a pure solid has an intermediate hardness, is resilient but rigid, and has a relatively high glass transition temperature [Tg] of 40°C [104°F]) (Rohm and Haas 2007). This means that, when fully set, it should not flow or slump under moderate environmental conditions. Paraloid B-72 has a higher Tg than polyvinyl acetate polymers such as McGean B-15 that may become tacky or slump at elevated room temperature (Horie 2010:137). For a general discussion of glass transition temperature see Horie (2010). Paraloid B-72 generally forms weaker bonds than the reaction adhesives (e.g., epoxies and cyanoacrylates) but is strong enough for many structural joins, particularly if the specimen is afforded proper support. Paraloid B-72 is, however, slow to release the last traces of solvent and develop a full strength bond (Horie 2010:155; Podany 2001:27). For more discussion of solvent retention times see Horie (2010:89–92), Carlson and Schniewind (1990), and Schilling (1988:111).

Paraloid B-72 Is Versatile

Solutions of Paraloid B-72 are readily manipulated to control viscosity, set time, and penetration. Concentrated solutions of Paraloid B-72 mixed with acetone are remarkably sticky adhesives and are often an excellent substitute for less desirable fast-setting adhesives frequently used for quick assembly of fragments, such as 5-minute epoxies (which are likely to degrade over time) or cyanoacrylates sprayed with accelerators (which often cause green discoloration). By changing solvents, altering solution concentration, adding a bulking agent, or modifying the application technique, Paraloid B-72 can be used as a consolidant, coating, or gap filler. Paraloid B-72 may also be used with sheets of pliable materials such as Reemay® spunbonded polyester or thin fiberglass cloth as a facing or backing. Two case studies illustrating multiple uses of Paraloid B-72 for single specimens are provided by Buttler (1994) (a sub-fossil hippopotamus) and Stollman et al. (2005) (a recent blue whale). The use of Paraloid B-72 to make very strong

but reversible structural joins on stone objects, either alone or as a barrier layer with epoxy, is discussed in Podany et al. (2001) and Jorjani et al. (2009). For examples of bulking Paraloid B-72 for gap filling of stone and fossils, see Krumrine and Kronthal (1995), Larkin and Makridou (1999), and Wolfe (2009). Examples of consolidation with Paraloid B-72 are provided by Rossi et al. (2004) (cremated bone), Snow and Weisser (1984) (ivory), and Koob (2009) (ceramics and glass). The various solvents for Paraloid B-72 and their effects, properties, and uses are discussed in more detail in a subsequent section.

Buy the Right Product

Industrial names and numbers for polymers are confusing, and manufacturers or formulas can change over time, resulting in purchasing errors. Paraloid B-72 is widely available through conservation suppliers, but caution should be exercised to ensure that the correct product is ordered. Paraloid B-72 is currently manufactured by Rohm and Haas, a subsidiary of Dow Chemical, and is identified chemically as a copolymer of ethyl methacrylate and methyl acrylate monomers (PEMA/PMA). Other Rohm and Haas ''Paraloids'' such as Paraloid™ B-67 are not PEMA/PMA and are not equivalent to Paraloid™ B-72. The abbreviation ''B-72,'' used by itself, can be confused with other types of adhesives such as Butvar® B-72, a polyvinyl butyral (PVB) manufactured by Solutia. Before 1997 Paraloid was marketed outside Europe as ''Acryloid™.'' Paraloid products purchased before 2001 were manufactured before Rohm and Haas was sold to Dow Chemical (presumably without changing the formula). Paraloid B-72 purchased before 1976 had a different appearance (white, irregular lumps), a slightly different chemical composition, and was not soluble in ethanol (De Witte et al. 1978). Links to more information about Paraloid B-72 are listed in the Appendix under Useful Websites.

The best way to ensure that you are purchasing the right product is to use the chemical identity in addition to the trade name, grade, and manufacturer (i.e., Rohm and Haas Paraloid B-72 ethyl methacrylate/methyl acrylate copolymer).

Shelf Life

Paraloid B-72 is extremely stable and has an indefinite shelf life. It is normally supplied as pellets (Fig. 1) in quantities as small as eight ounces, but larger quantities may be purchased and stored for many years without risk of deterioration. The very long shelf life of Paraloid B-72 as a solid is an advantage compared to liquid reaction adhesives with relatively short shelf lives.

Solvents

Paraloid B-72 is readily soluble in acetone. It is also soluble in lab-grade ethyl alcohol (ethanol), although some workers report problems with cloudiness from water in the ethanol, possibly exacerbated by high RH (Phenix 1992:25; Koob 2009:118). Toluene may also be used, as well as some other less common solvents (Rohm and Haas 2010); each solvent imparts different properties to the liquid and ultimately to the solid. For a discussion of solvent effects on polymer properties see Hansen (1995) and Sakuno and Schiewind (1990). It is preferable to purchase solvents from laboratory suppliers; hardware store solvents are more likely to contain unwanted additives or impurities (Erhardt 2001). Chemical contamination from impure solvents may cause yellowing and deterioration of otherwise pure Paraloid B-72.

Figure 1. Paraloid™ B-72 is supplied as pellets of pure polymer with an effectively indefinite shelf life.

Acetone as a Solvent for Paraloid B-72

Solutions of Paraloid B-72 in acetone are more volatile than those in ethanol and thus set faster. This makes acetone a good solvent for a quick-setting adhesive, e.g., for rapid assembly of fragments; however, acetone may not always be the best choice of solvent for a penetrating consolidant. Even if acetone solutions penetrate deeply, rapid evaporation tends to draw the polymer back out to the surface—a phenomenon known as "reverse migration." Reverse migration is readily observed when consolidating in hot, windy field conditions but also occurs under common laboratory conditions. Reverse migration may be mitigated by slowing evaporation, e.g., by covering with polyethylene sheeting or by lowering the temperature. The volatility of the solvent is not the only issue that influences the effectiveness of consolidation. Good penetration and retention are also dependent upon the complex physical and chemical interactions of a given solvent, polymer, and fossil substrate. Since these interactions are not well understood and every specimen is different, experimentation is almost always required when consolidating fossils. Experiments conducted by one of the authors (G.W.B.) with Paraloid B-72 in acetone suggest that the relationship between solution concentration and substrate porosity plays an important role in polymer penetration and retention. Best polymer distribution and retention was achieved by "priming" (pre-wetting) the specimen with pure acetone or very dilute consolidant solution, then applying the most concentrated solutions that would readily penetrate a given fossil. The author also experimented with slurries of sand and acetone solutions of Paraloid B-72. His results, figured by Horie (2010:110), demonstrated decreased reverse migration with increased concentration. For a discussion of the factors involved in penetration and migration, see Domaslowski (1987–1988) and Hansen et al. (1993).

A Paraloid B-72 solution in acetone is usually the best choice for joining fragments, and very rapid assembly is often possible, especially of porous fossils that can absorb the

Figure 2. Developing tack for adhering two fragments.

solvent. More dense, less absorbent fossils may require special manipulation to speed setting. For example, Koob describes a technique he calls ''developing tack'' by repeatedly pulling apart and rejoining fragments until the adhesive grabs (Fig. 2) (Koob 1986, 2009). This is often very effective for dense fossils that are sturdy enough to tolerate the process.

Using acetone alone with Paraloid B-72 for joining fragments or for surface coatings sometimes results in rapid ''skinning'' of the polymer and the creation of bubbles, an effect that may be reduced by the addition of up to 10% ethanol.

Ethanol or Toluene as a Solvent for Paraloid B-72

Ethanol is less volatile than acetone thus ethanol solutions of Paraloid B-72 set more slowly. Ethanol solutions may set too slowly for convenient use as an adhesive for joins, but in some situations they may perform better than acetone solutions for consolidation. Paraloid B-72 is also less readily soluble in ethanol than in acetone, which may result in better consolidant penetration and polymer retention. As mentioned previously, consolidation of fossil substrates usually requires experimentation to achieve the best results. Penetration may be aided by pre-wetting the substrate with ethanol before applying the consolidant solution.

Toluene is an effective solvent for Paraloid B-72, with a volatility even lower than ethanol, and is often preferred by conservators as a solvent for coatings and consolidation (of wood, for example: Kucerova and Drncova 2009). Toluene, however, is a much larger molecule than acetone and results in a significantly higher viscosity than similar concentration solutions in acetone (Koob pers. comm.). Although this may limit primary penetration of the consolidant solution, it may also limit the adverse effects of polymer reverse migration. Toluene is more toxic than acetone or ethanol, and it is especially important to acquaint oneself with the risks and employ appropriate precautions when working with toluene, particularly for consolidation tasks requiring large volumes of solvent. A great deal of information about solvent safety is available online.

For more tips on consolidation and how to counter reverse migration, see the discussions of immersion and vapor chambers below.

Acetone and Ethanol Mixtures as Solvents for Paraloid B-72

Mixtures of acetone and ethanol are sometimes used to manipulate viscosity and set time, but the user should be aware that these solvents are more toxic when combined (see below). The addition of ethanol (5–10% by volume) to Paraloid B-72 solutions in acetone often helps to reduce bubbling, e.g., when a very smooth base coat is required when labeling specimens. Koob recommends the addition of 10–15% ethanol, when using acetone solutions of Paraloid B-72 in hot conditions, to decrease bubbling and stringiness and to increase working time (Koob 2009:118).

Solvent Health and Safety

Most organic solvents, including acetone, ethanol, and toluene, are toxic and flammable to some degree. All solvents should be used with a good understanding of their hazards. Keep solvents away from sources of ignition. Avoid contact with the skin. Use appropriate personal protection from fumes. A well-ventilated room may suffice for small quantities of acetone or ethanol, but a fume hood is recommended for handling larger quantities (e.g., when mixing solutions or consolidating large surface areas). Toluene should be handled under a fume hood. Extra caution is appropriate when handling mixtures of acetone and ethanol because acetone acts synergistically to increase the toxicity of ethanol (Canadian Centre for Occupational Health and Safety 1997–2000; Caledon Laboratory Chemicals 2010).

Containers

When it comes to choosing a container for Paraloid B-72 solutions, the choice is usually between glass and solvent-resistant plastic. However, even the most resistant plastic containers are acetone permeable, and their contents tend to thicken and solidify over time. Most plastics, even Nalgene® low-density polyethylene, are eventually degraded by solvents and may release contaminants into the solution. Glass jars do not degrade, but the materials lining the inside of lids may be prone to deterioration and may require isolation with a nonstick liner (see discussion below on how to keep lids from sticking or deteriorating). Lab-grade glass jars are more expensive than Mason jars or common food jars but may be cleaned and re-used repeatedly.

An Easy Way to Clean Jars

An easy way to clean residual solution and gummy rims of glass jars is to soak them in water. If the jar is filled with water before the solvent has evaporated, the residue will immediately become opaque and rubbery and peel off easily like a skin (Fig. 3).

How to Keep Lids from Sticking or Deteriorating

Stuck jar lids may be avoided using several methods. Jim McCabe of the Royal Tyrrell Museum, Canada, uses Formula Five® mold release wax to prevent lids from sticking (McCabe, pers. comm.). Other workers have used Teflon® plumber's tape. Many conservators and fossil preparators prefer to use silicone-coated Mylar® (available from conservation suppliers). A small square is placed over the jar and the lid screwed down tight to prevent evaporation (Fig. 4). Silicone-coated Mylar also protects the solution if

Figure 3. An easy way to clean glass jars by soaking in water before the solution has evaporated and peeling out the residue.

the lid liner decays. Silicone-coated Mylar is usually supplied in large rolls that are pricy but worth the expense.

Preparing Paraloid B-72 Solutions

If simply added to a container of solvent, Paraloid B-72 pellets take considerable time to dissolve and have a tendency to settle as a thick, gummy layer on the bottom of the container. Constant stirring helps, either by hand or with a magnetic stirrer. An interesting technique used by Vicen Carrió-Lluesma at the National Museum of Scotland employs a lapidary polisher to provide constant rotation of the jar (Carrió-Lluesma pers. comm.). Paraloid B-72 is more soluble in acetone than in ethanol; thus it may dissolve faster and form more concentrated solutions in acetone than in ethanol.

Figure 4. A baby formula jar. The lid is screwed down over a small square of silicone-coated Mylar to prevent sticking.

Figure 5. An easy way to mix Paraloid B-72 by suspension in a cheesecloth bundle tied with sewing thread inside a glass jar partially filled with solvent.

The Cheesecloth Method of Mixing Paraloid B-72

The most efficient and effective method to dissolve Paraloid B-72 does not require any stirring and was first described by conservator Stephen Koob in his excellent 1986 paper on the use of B-72 as an adhesive for ceramics (updated in Koob 2009). Koob weighs B-72 beads and then wraps them in a cheesecloth bundle. The bundle is tied and suspended with sewing thread inside a glass jar partially filled with solvent (Fig. 5). The height of the bundle is adjusted so that the bottom lightly touches and wicks up the solvent, visibly releasing a stream of dissolved B-72. The dissolved polymer settles to the bottom of the container, leaving relatively pure acetone above to rapidly dissolve the remaining solids in the cheesecloth bundle. It is important to leave the mixing container undisturbed until the solids are completely dissolved (4–12 hours, depending upon the concentration of the solution being prepared). The empty bundle is then removed, and the solution is simply swirled to mix. For very large quantities, one of the authors (G.W.B.) reports success using Hubco® cloth geological sample bags instead of cheesecloth to mix gallons of solution.

Concentration

Weight-to-Weight versus Weight-to-Volume

Adhesive and consolidant solutions can be prepared either by combining specific weights of polymer and solvent (w/w) or by combining a specific weight of polymer and a specific volume of solvent (w/v). In each case, the resulting concentration can be expressed as a percentage. For most uses on fossil vertebrates the difference is not critical. The important point is to properly indicate on the container label and in your documentation which method you are using to prepare your solutions and to designate the units of measure used (w/w or w/v). Also keep in mind that concentrations will tend to increase over time because of solvent evaporation from storage and dispensing containers

Table 1. Approximate mixing formulae for Paraloid B-72 solutions.

Solution	Paraloid B-72 (g)	Solvent	Fumed silica	Actual concentration (%)
1:1 (w/w) stock adhesive	100	100 g	1.5 g (2 tablespoons)	50
1:5 (w/v) stock consolidant	100	500 ml	None	~17
1:20 (w/v) dilute consolidant	25	500 ml	None	~5

during use. In any case, regardless of the concentrations prepared, adjustments usually must be made to accommodate specific uses and specimen/substrate properties (especially porosity).

Accurate percentage concentration can be calculated for either weight/weight or weight/volume solutions, but in common practice in preparation labs, this is not necessary. Perhaps the most convenient way to prepare solutions is to simply combine ratios of polymer and solvent using weight-to-volume units, for example, 30 g of Paraloid B-72 to 100 ml of solvent. This would result in a 3:10 (w/v) solution. Precise percentage concentrations, if needed, can be simply calculated using readily available formulas; see Table 1 for examples. Either method of preparing and labeling stock solutions is acceptable as long as the method and labeling are consistent and understood by lab staff.

1:1 Weight/Weight "Koob Recipe" for Paraloid B-72 Adhesive

The cheesecloth method is effective for preparing solutions in acetone for concentrations up to 50% (weight/weight). To prepare very concentrated solutions (above 80%) Koob recommends allowing evaporation of acetone from the solution to achieve the desired concentration. To improve rheology and other properties of high-concentration solutions intended for use as an adhesive, Koob adds a small amount of fumed silica. One of the author's (A.D.) stock adhesive solution is made with 100 g of Paraloid B-72 in 100 g of acetone with two rounded teaspoons of Cabosil® fumed silica added. The solution is allowed to sit before use in order to release the air bubbles introduced by stirring.

1:5 Weight/Volume Stock Solution for Consolidation, Dilute as Needed

The cheesecloth method also works for thinner solutions. It is often convenient to make a 1:5 (w/v) stock solution of Paraloid B-72 (e.g., 100 g of Paraloid B-72 in 500 ml acetone or ethanol). This may be diluted with more solvent as needed. Preparators often work with small containers of consolidant that are left open for hours, and concentrations will change with evaporation of the solvent. Fedak (2006) discusses a method of using capillarity to monitor concentrations. Finding the best concentration to consolidate a particular fossil substrate is often a matter of "feel" and may require experimentation. As mentioned previously, best results may be achieved by pre-wetting the specimen with pure solvent or very dilute consolidant and then applying the most concentrated solutions that will penetrate readily.

Tips for Dispensing Concentrated Solutions

Concentrated ("thick") solutions of Paraloid B-72 in acetone are very sticky and make excellent adhesives for joining, as described by Koob for ceramics. However, their stickiness and stringiness can make them challenging to dispense.

Figure 6. The "Koob Tube," a self-loaded tube for dispensing thick solutions of Paraloid B-72 in acetone.

Tubes for Dispensing Thick Solutions

Koob (1986, 2009) describes a very good method for dispensing thick (50%) solutions by self-filling aluminum tubes (the "Koob Tube" is ubiquitous in conservation laboratories) (Fig. 6). Filled tubes may be stored unopened for years without drying out. Commercially filled tubes of Paraloid B-72 are available through conservation suppliers, and for small quantities the convenience may be worth the extra expense. Note, however, that these commercial formulations may contain unwanted additives. HMG B-72 is a popular brand that currently contains 10–25% nitrocellulose (Conservation Resources 2008). Nitrocellulose is a compound known to age poorly and was apparently added to the formula beginning in 1995 (Nel and Lau 2009).

Squeeze Bottles for Dispensing Thick Solutions

Plastic squeeze bottles are effective for dispensing or for transferring thick solutions to tubes or syringes without a sticky mess. Matthew Brown at the University of Texas recommends 2-ounce (60 ml) Nalgene® drop-dispenser bottles (Brown, pers. comm.). Plastic bottles, unlike glass, are not completely impermeable or resistant to attack by acetone and are not recommended for long-term storage of solutions.

Syringes for Dispensing Thick Solutions

Conservators at the American Museum of Natural History prefer syringes to dispense viscous adhesive solutions (Alderson, pers. comm.). The Monoject™ 412 is a large syringe with a curved plastic tip that may be trimmed if necessary (Fig. 7, top). BD Luer Lok™ syringes may be purchased in a variety of sizes (e.g., 3 ml and 10 ml). These are used with interchangeable plastic Luer Lok™ tips that screw in place (Fig. 7, bottom). Tips may be stopped by inserting a ball-headed sewing pin or insect pin.

Figure 7. Syringes for thick and thin solutions: (top) Monoject™ 412, stopped with a ball-headed sewing pin; (bottom) a BD Luer-Lok™ syringe with Luer-Lok™ tip.

Figure 8. A clean paper towel wrapped around a sandbag is a stable, convenient way to wipe brushes after cleaning with solvent.

Jars and Brushes for Dispensing Dilute "Thin" Solutions

Fossil preparation often requires constant application of small amounts of consolidant by brush from a jar and then rinsing the brush in solvent. Small, bottom-heavy glass containers such as baby formula jars work well for this. As mentioned previously, a sheet of silicone-coated Mylar prevents jar lids from sticking. Brushes with solvent-proof handles may be kept inside larger jars to prevent the brushes from drying out. A clean paper towel wrapped around a sandbag is a stable, convenient way to wipe brushes (Fig. 8).

Nail-Polish and Other Brush Bottles for Dispensing Thin Solutions

One of the easiest ways to dispense thin solutions of Paraloid B-72 is with nail-polish bottles (Fig. 9). Bottles of either clear nail polish or nail hardener may be emptied, cleaned thoroughly with acetone, and refilled with Paraloid B-72 solutions. Nail-polish bottles and brushes are very commonly used to coat numbers with B-72 when labeling specimens, but they are also useful for repair of small specimens. Nail-polish bottles are especially good for students, volunteers, and researchers who may not be accustomed to handling adhesives. One of the authors (G.W.B.) uses low-density polyethylene bottles with conical Yorker dispensing caps for dispensing thin as well as thick solutions (Fig. 10). A solvent-proof brush may be inserted through the cap aperture and left in place. This makes it easy to slide the brush down as the solution drops, keeping the bristles wet. To use, the cap is simply unscrewed like a nail-polish bottle. Because of the solvent permeability of polyethylene, however, solution concentration can increase over time. Using Yorker caps on glass bottles with compatible threads rather than polyethylene bottles would probably limit solvent loss.

Figure 9. For dispensing thin solutions, clear nail-polish bottles are very convenient (rinsed well, refilled, and relabeled).

Squeeze Bottles, Droppers, and Syringes for Dispensing Thin Solutions

Small plastic squeeze bottles may be fitted with various needle tips for dispensing drops. Justy Alicea at the American Museum of Natural History and Joe Groenke of Stony Brook University use Nordson EFD® dispense tips of either metal or flexible plastic, of various diameters, for dispensing Paraloid B-72 (Fig. 11). These are adhered onto small drop-dispenser bottles with thick Paraloid B-72. The tips may be removed and cleaned by soaking in solvent for re-use (Alicea, pers. comm.). Large squeeze bottles are often employed in the field for bulk consolidation, but one of the authors (A.D.) prefers a more controlled application with disposable plastic droppers out of a wide-mouthed plastic jar. Droppers are equally useful in the lab and the field for dripping applications over large areas and into cracks and for squirting up into undercuts (Fig. 12). Thin solutions may also be loaded into syringes and injected into cracks. Koob (2009) describes the repair of glass objects by assembling fragments with tape and injecting Paraloid B-72 into the joins.

Immersion in Thin Solutions

Achieving deep penetration of solution adhesives like Paraloid B-72 is often problematic, and numerous workers have experimented with immersion using different polymers, solvents, and concentrations. Schniewind and Kronkright (1984) compared Paraloid B-72 with Butvar B-98 PVB and various PVAC resins for immersion treatment of a large wooden canoe. Barclay (1981) experimented with many resins including Paraloid B-72 in toluene for the consolidation of a wooden fire engine by brushing and also by immersion under vacuum. Nakhla (1986) studied natural resins and synthetic resins including Paraloid B-72 in various hazardous solvents for consolidation of wooden Egyptian artifacts by brushing, dripping, and immersion under vacuum. Kres and Lovell (1995) used four different resins, including Paraloid B-72 in toluene, for consolidation by brushing and immersion of archaeological bone. Koob (2009) describes an interesting technique for consolidating ceramics inside a plastic bag by capillary action (‘‘wicking

Figure 10. A low-density polyethylene bottle with a Yorker cap. The bottle on the right is outfitted with a solvent-proof brush.

up'') using 5–15% solutions of Paraloid B-72 in acetone or acetone/ethanol. For vertebrate fossils, useful descriptions of immersion techniques (not specific to Paraloid B-72) are provided by Rixon (1976:18–25), Anderson et al. (1994), and Koob (1984). The effectiveness of immersion as a consolidation treatment and the ability of a specimen to withstand immersion will vary considerably among different fossils and substrates. The literature cited above should be reviewed thoroughly to enable an informed decision regarding the safety and suitability of this technique for a given fossil.

Consolidation with Thin Solutions in a Vapor Chamber

Deep penetration may be encouraged by applying the consolidant to the specimen inside an enclosure containing a solvent vapor atmosphere. Vapor chambers are often simple bags or tents of polyethylene sheeting filled with fumes from open dishes of solvent (Fig. 13). Hansen et al. (1993) introduced the use of vapor chambers for the consolidation of porous, matte paint. In addition to aiding penetration and counteracting polymer reverse migration, vapor chambers help reduce the glossiness that many workers have noted is typical of Paraloid B-72 on the surface of objects. Koob's capillary consolidation technique uses a bag that functions as a vapor chamber to slow evaporation and reduce gloss (Koob

Figure 11. Two-ounce Nalgene® drop-dispenser bottles may be fitted with Nordson EFD® dispense tips.

2009). It should be noted that vapor chambers can be a very effective way to soften and release prior joins made with Paraloid B-72 or other soluble adhesives. This effect must be considered before placing a specimen in a vapor chamber to avoid unintentional damage to anything soluble on the specimen, including joins, labels, and inks.

Spray Application of Thin Solutions

One of the authors (G.W.B.) has had success in large-scale consolidation using a commercial-grade sprayer designed to apply acetone-based stains and sealants to concrete. An SP Systems® SP35ACT sprayer was used with acetone solutions of Paraloid B-72 to consolidate multiple *in situ* skeletons preserved at Ashfall Fossil Beds State Historical Park, Nebraska (Fig. 14). The highest concentration used was approximately 1 part Paraloid B-72 to 9 parts acetone by weight (a 10% w/w solution.) Four soaking applications were made over 2 days, each application consisting of about 2 gallons of solution. For this particular bone preservation and porous ash substrate, no surface gloss was noted. Depth of penetration and retention of polymer were excellent.

Tips for Reactivating Dried Solutions

Solvent Reactivation with Brushes, Syringes, and Tweezers for Large and Small Joins

Sometimes joins may be made by painting or dripping Paraloid B-72 solution on the surfaces to be adhered, allowing it to dry and then redissolving the surface with more

Figure 12. Disposable plastic droppers are equally useful in the lab and the field for dripping applications over large areas and into cracks and for squirting up into undercuts.

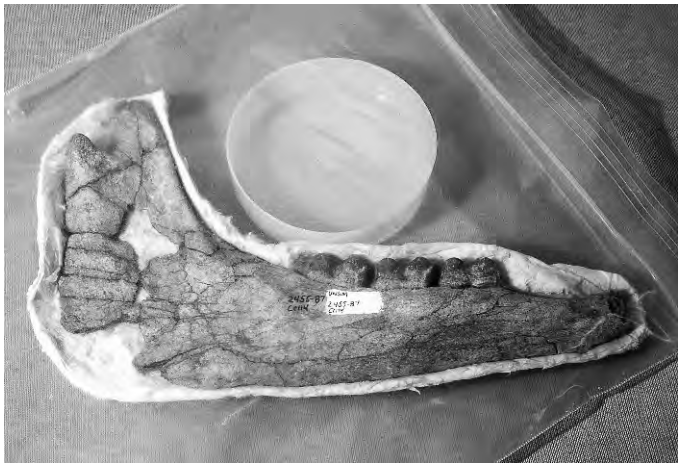

Figure 13. A simple vapor chamber made from a polyethylene bag filled with fumes from open dishes of solvent.

solvent before joining. This technique has been refined by Jim McCabe of the Royal Tyrrell Museum, using acetone as the solvent. As the adhesive dries he uses a spatula to work out any bubbles that form. Once the adhesive has set up and all the bubbles are worked out, he reactivates the bonding surface by brushing on acetone or applying it with a syringe. In some cases the pieces can be reassembled dry and acetone wicked into the join with a syringe to reactivate the adhesive (McCabe pers. comm.). This technique minimizes the amount of solvent (and solvent retention) inside joins with large bonding surfaces (see previous section on hardness and strength for discussion of solvent retention).

Figure 14. One of the authors (G.W.B.) using a SP Systems® SP35ACT sprayer to apply a solution of Paraloid B-72 in acetone at Ashfall Fossil Beds State Historical Park, Nebraska. Active ground-level ventilation prevents the heavier acetone fumes from rising to breathing levels.

Figure 15. Tiny joins may be made by reactivating and reworking Paraloid B-72 with tweezers and a drop of acetone.

McCabe has also developed an innovative technique for making very small joins using a fine syringe (1 ml with a 30 gauge needle) filled with acetone. A small globule of thick Paraloid B-72 is picked up and transferred with the syringe tip. The adhesive is deposited on the fossil surface by gently flowing acetone out of the syringe. One milliliter syringes allow excellent precision to apply small amounts of solvent (McCabe pers. comm.). Minute amounts of solvent can be dispensed without using the syringe plunger; finger warmth on the syringe barrel will provide a very controlled flow due to thermal expansion of the solvent.

For the application of very small amounts of Paraloid B-72 with a brush it is not always necessary to dip into a solution. Marilyn Fox of the Peabody Museum, Yale University, keeps a small porcelain teacup at hand with a dried residue of Paraloid B-72 on the bottom. She reactivates the residue as needed with solvent and a small brush (Fox, pers.comm.). It may also be possible to detach a tiny piece of dried film, place it where needed with tweezers, and then reactivate it with solvent *in situ*.

Very fine, pointed tweezers are commonly used by preparators to wick up and apply tiny amounts of cyanoacrylate adhesives, but this technique usually does not work for Paraloid B-72 solutions because of overly rapid solvent evaporation and polymer stickiness. A clever technique used by Joe Groenke at Stony Brook University and Constance Van Beek at the Field Museum, Chicago, employs a brush to apply the solution and then tweezers to transfer tiny amounts of pure solvent to redissolve and rework the dried Paraloid B-72 (Fig. 15) (Groenke and Van Beek pers. comm.). This is an excellent technique for micro-applications of Paraloid B-72.

Heat Reactivation and Manipulation

Paraloid B-72 is a thermoplastic resin with a Tg of 40°C (104°F) and thus may be softened and reworked with gentle heat. Conservators commonly exploit this property using hair dryers and heated tools. Use of a desk lamp and hair dryer to adjust joins made

with Paraloid B-72 on ceramics is discussed briefly by Koob (2009:116–117). One of the authors (G.E.B.) has used a heat gun (held at a distance with his hand as a temperature indicator) to soften and realign joins when rebuilding complex comminuted fossil specimens and considers it far superior to solvent for this purpose. Obviously, care must be taken to ensure that the specimen can withstand heating without incurring damage. Wolfe mentions the use of heated spatulas to apply dried mixtures of bulked Paraloid B-72 for filling gaps and losses (Wolfe 2009:135). Anthropology conservators at the American Museum of Natural History make frequent use of an Englebrecht temperature-controlled electric spatula with an overlay of silicone-coated Mylar to manipulate solidified fills made with Paraloid B-72 and glass micro-balloons. Heat may also be used to help remove lids or caps that have become stuck to jars of consolidant or adhesive (Koob pers. comm.). Exploiting the thermoplastic properties of Paraloid B-72 is currently not a common practice in vertebrate fossil preparation but would be worthy of further investigation.

Removing Paraloid B-72

Reversibility (a polymer's ability to be removed without damage to the specimen) should be considered before applying any polymer. For a discussion of the conservation principle of reversibility and practical problems of reversing treatments see Appelbaum (1987) and (Horie 2010). In our experience, Paraloid B-72 is less easily redissolved and adheres more strongly to fossil substrates than Butvar® B-76 PVB and McGean B-15 PVAC. As mentioned in the discussion of hardness and strength, Paraloid B-72 retains solvent for a very long time, thus going through rubbery and leathery stages before becoming hard and more brittle when the solvent has completely evaporated. These stages may be exploited when removing fresh coatings or fresh excess adhesive squeezed out of joins. Earlier stages are easier to redissolve; later, more brittle stages may be easier to pick off with a needle, especially if the excess has bubbled. Older, completely set coatings may be removed by brushing with acetone until redissolved and then blotting with brushes, cotton swabs, or tissue, or by applying a poultice with an absorbent material such as cotton or tissue soaked in solvent, covered with polyethylene sheeting, as long as the specimen surface is not damaged by this treatment. Surface consolidants may be removed or reduced in this manner, but penetrating consolidation treatments in general are not fully reversible, even by soaking in solvent. For discussion of the limitations of removability, especially of consolidants, see Horie (1982). Undoing joins generally requires time for the solvent to penetrate into the interior of the join. Small or fresh joins require little time; large and completely set joins are much slower to release. Soaking in solvent to undo joins is possible only with very robust specimens that can withstand this treatment without damage. Other methods of feeding solvent into a join over time include vapor chambers (described in the discussion on consolidation) or poulticing as described above.

Conclusion

Paraloid B-72 has many desirable properties, but even the best materials can fail if they are not appropriate for a particular application. Successful use of any adhesive requires thought and a good understanding of the specimen, knowing what you want the adhesive to do, and a familiarity with what the adhesive is *capable* of doing. This familiarity can come only with experience. The authors recommend that all fossil preparation labs keep at least two stock solutions available for experimentation: thick Paraloid B-72 in acetone and a thinner solution in ethanol. Various combinations and concentrations can be mixed

from these stock solutions to suit the needs of the job at hand. Although no single adhesive or consolidant is suitable for every situation, Paraloid B-72 is an excellent candidate for many vertebrate fossil preparation tasks.

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Appendix

Useful Websites

http://cameo.mfa.org/
http://www.conservation-wiki.com/index.php?title=Chapter_V_-_Polymeric_Varnishes
http://talasonline.com/photos/instructions/paraloid_b-72_data.pdf
http://www.dow.com/products/product_detail.page?display-mode=tdsandproduct=1121222

Suppliers

Acetone resistant sprayer, SP Systems®, SP35ACT sprayer, http://www.spsystemsllc.com/industrialcon/sp10act_sp35act.html.

BD Luer Lok™ syringes, 3 to 10 ml, $15–$25 per box of 100, http://www.coleparmer.com/catalog/product_index.asp?cls=15116, also available from ConservationResources.com.

Disposable plastic droppers (polyethylene transfer pipettes), Fisher Scientific no. 13-711-7M, $42.29 per box of 500.

Englebrecht WzII control unit and heat spatula arm, $310 for unit, $44 for heat spatula arm, available from Kolner LLC, 23 Grant Avenue, New Providence, New Jersey 07974, tel.: 718-802-1659.

Glass jars, 32-oz-wide-mouth clear glass Wheaton jars, Scientific Instrument Services no. W216907, $80.86 per case of 12.

Luer Lok™ polyethylene taper tip needles, LEM954 blue tip (smallest), $17.00 per pack of 50, https://www.labemco.com/pages/cart.php?s=LEM954.

Monoject™ 412 curved tip syringe, about $3.00 each. Pet and craft suppliers sell smaller quantities than medical or veterinary suppliers.

Nail-polish bottles, Rachael's Supply.com, no. K08, $12.95 per case of 10 bottles with brushes and caps (note: requires assembly), http://www.rachelssupply.com/bottle.htm.

Nail-polish bottle alternative, Brucci®; nail hardener has a good brush. Empty and rinse well with acetone. Duane Reade pharmacy or similar store. About $5.00 each.

Nalgene® LDPE drop dispenser bottles, 60 ml (2 oz), https://www.fishersci.com.

Nordson EFD® dispense tips, 5120-B (pink), 5125-B (red), 5125PPS-B (plastic), http://www.efd-inc.com/Tips/.

Paraloid™ B-72, Talas no. TFK028003, $47.50 per 5 lb bag. Also available from ConservationResources.com.

Self-loading metal tubes, Conservation Resources Int'l, $14.00 per box of 10, http://www.conservationresources.com/Main/section_21/section21_13.htm.

Silicone-coated Mylar®, Talas no. TFM004004, $75.00 per roll (15 inches×150 feet) (38 centimeters × 46 meters).

Yorker spout caps, http://www.yorkerpackaging.com/spout.html.

TISSUE AND DNA BANKING AT THE NEW YORK BOTANICAL GARDEN

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Abstract.—Source materials for DNA sequence data are increasingly under demand as these data are routinely utilized in phylogenetic, systematic, biodiversity, species barcoding, conservation, and genomic research. Repositories of DNA-rich materials (e.g., tissues and genomic DNA samples) provide a valuable source of specially prepared, readily available research materials for current and future research. Policies and procedures developed for a repository of tissue and genomic DNA samples at the New York Botanical Garden are discussed, and information concerning public access to data about these samples and supporting specimens is presented.

Introduction

DNA sequences have become a major source of data utilized in modern phylogenetic, systematic, biodiversity, species barcoding, conservation, and genomic research. Repositories of tissue and genomic DNA samples provide a readily available source of materials specifically prepared for obtaining sequence data, increasing the likelihood of high-quality sequences and research results (Miller 1998, 1999; Bridge et al. 2003). As community-wide demand for DNA-rich research samples is increasing, these repositories are reducing the need for expensive, repetitive, or often impossible field collection and may stimulate research that would otherwise not be undertaken (Miller 1998). Furthermore, collecting samples intended for destructive use helps to maintain the integrity of museum specimens (Miller 1998, 1999; Metsger 1999; Wood et al. 1999). Development of DNA-rich collections at biological resource centers already engaged in regional survey-based research will likely be the most economical means to effectively sample biodiversity (Adams 1997, 1998). Institutions housing natural history specimens are consulted by taxonomic specialists, thus increasing the probability that vouchers have up-to-date identifications. These institutions are likely to have well-developed collections policies and the infrastructure for collections stewardship, including data and image sharing.

International interest in coordinated banking of plant DNA resources for molecular-based research was initiated as early as the 1980s (Adams 1989; Rice 2006; Gemeinholzer et al. 2011). As with traditional biological collections, multiple DNA resource facilities will increase the likelihood that species are documented across their geographic distribution, and duplication between facilities will ensure the availability of material in the event of loss (Adams 1998; Gemeinholzer et al. 2011). Collections policy recommendations for nonhuman DNA and tissue collections to uphold the objectives of the Convention on Biological Diversity (CBD; www.cbd.int) and regulations of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES; www.cites.org) in the stewardship of research collections have been advanced

(Williams et al. 2003, Davis et al. 2006a, 2006b; Donaldson 2006; Davis 2008). However, a consensus on curatorial standards, data schema, and a framework for the effective interoperability (Mill 2003) of DNA repositories has lagged (FAO 2010; W. Applequist pers. comm.; J. Coddington pers. comm.).

Here we describe some of the materials selected and practices developed for curating and administering the repository at the New York Botanical Garden (NYBG).

DNA Banking at NYBG

The overall goal of the NYBG DNA Bank is to provide long-term storage for plant and fungal samples from the geographic regions in which NYBG staff works, and to make these samples available for noncommercial, nonapplied research aimed at understanding biodiversity and its underlying causes, such as natural selection, evolution, and biogeography. The majority of the repository is the result of staff field collections and extractions produced during research conducted at NYBG. Presently DNA extraction is research driven; because routine extraction protocols are not optimal for all taxa, on-demand extractions as a service are not part of the normal workflow. Extractions are undertaken when a request would exhaust a tissue sample. The genomic DNA aliquots are documented and are available to the research community.

The facility has dedicated freezer storage and curatorial and bench work space in a modern laboratory building that is supported by an on-demand back-up electrical generator. For personal safety and sample integrity, staff have access to fume hoods for handling hazardous chemicals, including silica gel. DNA extraction and work involving chloroform or ethidium bromide are conducted in isolated rooms within the research lab (see Kapinos and Graham 2006 for details on safety).

Tissue and Genomic DNA Curation and Storage

Database

Prior to a concerted effort to develop a repository for use beyond NYBG research, laboratory researchers independently managed their tissue and DNA samples using Freezerworks software (Dataworks Development, Inc.), following its successful use in the Ambrose Monell Cryo Collection at the American Museum of Natural History (New York, New York). However, this system proved unsatisfactory for several reasons: it lacked automation in critical fields, did not employ the well-developed data dictionaries for botanical collections, and, paramount to efficient collections management and use, was not associated with more extensive voucher data in other databases.

The database platform used by the Science Department at NYBG is KE EMu, developed by KE Software (http://www.kesoftware.com/emu). Modules were implemented to record DNA Bank samples in the existing large database of herbarium specimens—including many vouchers for DNA Bank samples. EMu uses a client-server design with a client interface available for Windows® operating system on personal computers and an object-oriented relational database (Texpress, KE) available for both UNIX® and Windows servers. KE EMu has modules for interactive data entry and collections management functions, using large data dictionaries (e.g., Thiers, continuously updated), and user-populated, searchable drop-down lists to improve data integrity. A single field or all fields can be copied from the previous record increasing data entry efficiency (e.g., seven of eight fields to record microtube location can be entered with a single keystroke).

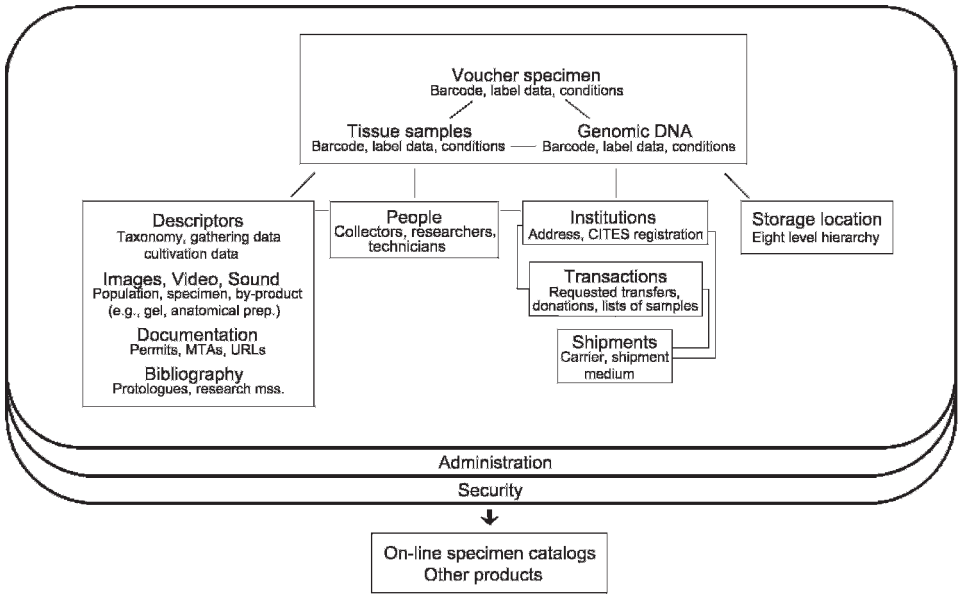

Figure 1. Relationship of the database collections modules for DNA, tissue, and herbarium specimens at the New York Botanical Garden. Administration and security functions overarch all elements of the database.

At NYBG, a single series of barcode numbers is used for all collections in the Science Division (herbarium specimens; their constituent parts, such as separate fruits; DNA Bank; and other laboratory collections). Thus, each item has a unique numerical identifier and elements from a gathering are electronically associated. Figure 1 depicts the relationship of DNA Bank data modules and other elements in the database. Fields specific to the DNA Bank are listed in the Appendix.

Sample Labels

The DNA Bank uses both preprinted and printed on-demand barcode labels, which are human- and machine-readable (code 128 symbology). Thermal printing produces sharp image edges and accurate bar widths, resulting in superior scanning performance over laser printing. Thermal transfer printing was selected because of the known durability of the image to exposure to abrasion, light, chemicals, and temperature changes. All labels were selected after the cryogenic integrity of the adhesives was tested with repeated freezing and thawing under a variety of temperature and humidity conditions; the lowest temperature was that of liquid nitrogen. For tissues, a copy of the voucher herbarium specimen label is inserted in the sample bag, and a preprinted label (Brady Corporation) with barcode and number is affixed to the exterior of the bag. Barcode labels for tubes of genomic DNA are produced using NiceLabel software from a Microsoft® Excel file interface on a Mark II thermal printer (DATAMAX®). Data are printed at 300 dpi on a white field that is wrapped over by a continuous clear portion to further ensure longevity of the images and secure labels to the tube (see Appendix). The rich meta-data content on the labels (Table 1) serves the needs of the broad range of researchers and technicians intended to use and curate the collection. Tube lids are labeled with full freezer location information (see Appendix) on laser thermal printed labels (Brady Corporation).

Table 1. Data on genomic DNA microtube labels stored in the New York Botanical Garden repository.

NYBG
Barcode and number
Taxonomy (bi- and tri-nomials)
Collector
Collection number
DNA extractor
Extraction code (user-defined)
Extraction date
Voucher barcode number
Voucher herbarium acronym[a]

[a] Herbarium acronym of vouchers is included because multiple extracts of some collections may be prepared from museum source material from multiple herbaria.

Tissue Samples

Tissue samples are generally collected directly into resealable storage bags (4 inch square × 4 mil thick polyethylene) and are labeled in the field with the collection number using a permanent marker. An alternative method preferred by some collectors is isolating samples in teabags or coffee filters and drying several samples together in a larger container (see Miller 2006; and Paton 2006 for reviews of collecting procedures). Silica gel desiccant sufficient to dry the quantity of tissue is added (see Adams and Ge-lin 1991); samples are monitored to ensure rapid drying. To curate the sample for long-term storage, the silica gel is refreshed if needed and the amount adjusted to approximately 10 g, depending on the quantity of the tissue. The tissue sample is labeled and databased (Appendix), including the storage location. Tissue samples are stored in a linear series of barcode numbers in general purpose freezers at −20°C (see Adams and Ge-lin 1991). Samples are contained in 4 1/8 × 16 1/2 inch cardboard trays (test weight 32 lb). These custom-order trays are inexpensive, are easily replaced if damaged by moisture, and maximize the storage efficiency of standard freezers that are not designed for specimen storage (Fig. 2). Sealed plastic containers would be more desirable; however, they are expensive and are not readily available in sizes that would economize storage. The trays hold an average of 120 samples, thus, there is an average of 2,640 samples per freezer.

Genomic DNA Samples

One of two DNA extraction protocols is generally followed at NYBG: a modified CTAB method (e.g., Struwe et al. 1998) or the DNeasy® protocol (Qiagen). Quality is observed on a 1% agarose gel using markers of known molecular weight. Genomic DNA is stored in 1.5 ml, free-standing, polypropylene microtubes, with tethered caps and an ethylene propylene o-ring. The sample is databased, including the precise location in a high-density freezer inventory system (see Appendix). Freezer location on the tube lid label facilitates rapid and accurate insertion and rapid retrieval of samples. Microtubes are stored in 100-cell cardboard boxes at −40°C. Genomic DNA samples are added to the next available cell; because extract production is research driven, taxonomically related samples are usually stored near each other, making retrieval and reinsertion efficient.

A goal of the DNA Bank is to never exhaust a sample by preparing in-house DNA extractions or fully amplifying the genome from a DNA aliquot; however, it is likely there

Figure 2. A tissue storage freezer in the DNA Bank of the New York Botanical Garden.

will be some attrition. To maximize storage efficiency a simple query can determine vacated storage cells (i.e., occupied racks searched for null grid cell values).

Access to DNA Samples and Standardized Data

Easy access to well-documented DNA-rich samples and voucher specimens facilitates diversity research, taxonomic identification of specimens and samples, and verification of published results. The NYBG DNA Bank website provides search (Table 2) and sample request functions. The data are managed along with the data that populate NYBG's Virtual Herbarium, which has stringent protocols in place to restrict internet access to collection data pertaining to rare or endangered taxa. Search results include all taxonomic and collection data of the corresponding voucher herbarium specimen, and specimen images, distribution maps, and reference to external databases (e.g., GenBank accession numbers) if available. Recently, NYBG became the first international participant of the DNA Bank Network (2009–). This network began as a German initiative in 2007 and links independent DNA and tissue banks of natural history collections via a central web portal (DNA Bank Network 2009; Gemeinholzer et al. 2011). This initiative promoted contributions to nonhuman biobanking standards for optimized tissue and DNA samples (Gemeinholzer et al. 2010).

Table 2. Search criteria for the New York Botanical Garden DNA Bank online catalog.

Sample type (genomic DNA or tissue)
APG III order[a]
Family
Taxonomy (bi- and tri-nomials)
Collector
Collection number
Continent
Country
Secondary political unit
Elevation range
Barcode number (NYBG)
External database accession number (e.g., GenBank)

[a] APG III 2009.

The explicit aim of the DNA Bank Network is to close the gap between biological specimen collections and molecular sequence databases. The network uses GBIF infrastructure (Global Biodiversity Information Facility; http://www.gbif.org) to reference tissue and DNA samples to the voucher specimen via wrappers/xml files. GBIF makes use of four sample identifiers: CatalogNumber (e.g., specimen barcode number), InstitutionCode, CollectionCode, and the wrapper URL. This enables other systems—like the DNA Bank Network—to link unique objects (e.g., a DNA sample to a voucher specimen). The data concept allows all partner institutions to use their individual database management system and make their data and samples readily available to the scientific community. Presently, more than 42,000 samples from five network partner institutions are available to the scientific community in compliance with CBD guidelines and CITES regulations.

Material Transfers

Requests of Material from NYBG

In accordance with the policies set forth in a Material Transfer Agreement (MTA; http://www.nybg.org/science/dna-bank.php), and in the spirit of the CBD, transfers are made to the scientific community for noncommercial, nonapplied research aimed at understanding biodiversity and its underlying causes. The agreement prohibits unauthorized transfer of material to a third party, but requires data sharing in the public domain (e.g., via GenBank). An online catalog of available samples is searchable by numerous criteria (Table 2). Selected search results can be down loaded to an Excel spreadsheet to request samples. The file includes information for staff to process the request (e.g., sample location) and pertinent data for the requesting party such as DNA reconstitution information. This file is also the vehicle by which researchers can later provide enhancements to NYBG's database, including updated voucher identifications, GenBank accession numbers, and publication citations. Requests for samples are accompanied by a signed MTA and a brief description of the research. A single MTA may cover more than one transaction when material requires separate transactions because of different shipment methods (e.g., specimens on dry ice and tissue samples).

Requests to Deposit Material at NYBG

As mentioned above, the majority of the samples in the DNA Bank have resulted from staff collecting efforts and research conducted at NYBG. However, tissue samples are

accepted from other institutions and individuals provided that they are relevant to and consistent with our goals and acquisition policy, and that a voucher specimen is deposited in an herbarium with an active loan program, preferably the William and Lynda Steere Herbarium of NYBG. Similarly, well-documented genomic DNA samples that are considered to be of high quality will be considered for inclusion.

Conclusion

Tissue and DNA banks are valuable research collections that support the documentation and understanding of biodiversity. These repositories will become increasingly more valuable as they are further developed and utilized, and as field collecting samples becomes more expensive, increasingly difficult due to political reasons, or impossible due to extirpation or extinction. Interoperability of these repositories and development of data standards needs to be coordinated on a global scale.

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Appendix. Summary of data captured for tissue and genomic DNA samples in the New York Botanical Garden repository, and additional fields required for recording transactions of these samples.

	Data type	Summary field[a]	Data entry mode	Sample data and notes
Tissue samples				
Voucher specimen	Alpha/numeric/ symbolic	Yes	Attachment[b]	L. M. Campbell 1048, *Xyris brevifolia* Michx., Xyridaceae (44.0)
Record type	Alpha/numeric/ symbolic	No	Drop-down list[c]	Specimen, DNA aliquot, tissue sample 01267848
Barcode number	Numeric	No	Scanned	
Access	Alpha/numeric	No	Drop-down list	Open, Open after publication, 5 years, Restricted
Access date	dd-mmm-yyyy	No	Keyed	01-Jan-2011
Access note	Alpha/numeric	No	Keyed	Check also with Horticulture
Preparer	Alphabetic	No	Attachment	Usually the voucher collector, however, may differ when material is cultivated
Preparation date	dd-mmm-yyyy	No	Keyed	01-Jan-2011
Preparation	Alphabetic	No	Drop-down list	Silica, dried museum material, fresh, CTAB, FTA card, formaldehyde mixture, ethanol
Tissue type[d]	Alphabetic	No	Drop-down list	Leaf, Flower, Pollen, Seed, Bark, Wood, Whole plant, Root, Thallus, Gametangia, Zygotes, Environmental, Mycorrhizal roots, Spore print, Basidium, Culture
Quantity	Alpha/numeric/ symbolic	No	Drop-down list	0 g, $\leq$ 1 g, $\geq$ 1 g, $\leq$ 5 g, $\geq$ 5 g
Location[e]	Alpha/numeric	Yes	Attachment	Freezer no. + box no.
Database accession[f,g]	Alpha/numeric/ symbolic	Yes	Keyed (pasted)	DQ188987
Extracted DNA				
Specimen	Alpha/numeric/ symbolic	Yes	Attachment	L. M. Campbell 653, *Abolboda linearifolia* Maguire–Accepted: Xyridaceae (44.0)
Record type	Alpha/numeric/ symbolic	No	Drop-down list	Specimen, DNA aliquot, Tissue sample
Barcode number	Numeric	No	Scanned	01497848
Access	Alpha/numeric/ symbolic	No	Drop-down list	Open, Open after publication, 5 years, Restricted
Access date	dd-mmm-yyyy	No	Keyed	01-Jan-2011
Access note	Alpha/numeric	No	Keyed	Bats, bees, and Brazil nut trees project
Tissue preparation	Alphabetic	No	Drop-down list	Silica, Dried museum material, Fresh, FTA card, Formaldehyde mixture, CTAB, Ethanol
Tissue type[d]	Alphabetic	No	Drop-down list	Leaf, Flower, Pollen, Seed, Bark, Wood, Whole plant, Root, Thallus, Gametangia, Zygotes, Environmental, Mycorrhizal roots, Spore print, Basidium, Culture

Appendix. Continued.

	Data type	Summary field[a]	Data entry mode	Sample data and notes
Relationship to voucher	Alphabetic	No	Drop-down list	DNA from specimen, DNA and specimen from same population, DNA from cultivated offspring, Image voucher only, Observation only, Voucher destroyed
Tissue notes	Alphabetic	No	Drop-down list	Azenic, Unialgal, Mixed, With epiphyte
Extractor	Alphabetic	No	Attachment	J. Deutsch
Extraction date	dd-mmm-yyyy	No	Keyed	01-Jan-2011
Extraction code	Alpha/numeric/ symbolic	No	Keyed	JJD-001
Extraction method	Alpha/numeric/ symbolic	No	Keyed	Struwe, L., M. Thiv, J. Kadereit, T. Motley, A.S-R. Pepper, J. Rova, K. Potgieter, P. White, and V. A. Albert. 1998. Harvard Papers in Botany 3:199–214.
DNA type	Alphabetic	No	Drop-down list	Plastid, Nuclear, Mitochondrial
DNA medium	Alpha/numeric	No	Drop-down list	TE (10 mM tris, 1 mM EDTA), T (10 mm tris), TLE (10 mM tris, 0.1 mM EDTA)
DNA volume	Alpha/numeric/ symbolic	No	Drop-down list	0, ≤ 100 µl, ≤ 250 µl, ≤ 500 µl
DNA concentration	Alpha/numeric/ symbolic	No	Keyed	
DNA reconstitution	Numeric	No	Keyed	
Location[e]	Alpha/numeric	Yes	Attachment	Freezer+shelf+rack+box+grid cell
Database accession[f,g]	Alpha/numeric/ symbolic	No	Keyed	DQ188987
Clean-up method	Alpha/numeric/ symbolic	No	Keyed	Little, D. P. and D. S. Barrington. 2003. American Journal of Botany 90: 508–514.
Additions to transactions				
Shipment medium	Alphabetic	No	Drop-down list	Dry, Dry ice, Wet ice
MTA approval	dd-mmm-yyyy	No	Keyed	01-Jan-2011
MTA number	Alpha/numeric	No	Keyed	
Database information returned[h]	Alphabetic		Drop-down list	Full accession numbers, Partial accession numbers, None

[a] Summary data are concatinated from multiple fields from a single or multiple database modules.
[b] Attachments are records referenced from another database module.
[c] Drop-down lists are imported and may be added to by data enters with security rights to do so.
[d] Tissue type is not a multivalued field; however, the lookup list may contain multivalued entries (e.g., leaf and flowers).
[e] Location is concatinated from six heirarchical fields, each with a drop-down list.
[f] A multivalued field.
[g] Hyperlinks or text for other database records (e.g., GenBank).
[h] Return of data is recorded here; hyperlinks are recorded with the barcoded sample (see 7 above).

SHORT REPORT: INVESTIGATING THE EFFECTS ON TISSUE PRESERVATION OF DMDM-HYDANTOIN USING FTIR SPECTROSCOPY

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Abstract.—DMDM-Hydantoin is a potential alternative to using formaldehyde in museum fluid preserved collections. A small experiment was set up to explore the chemical changes induced in muscle tissue preservation with DMDM-Hydantoin using Fourier transform infrared spectroscopy. The results show that DMDM-Hydantoin has a very similar effect to formaldehyde, which further supports its use as a safer alternative to formaldehyde.

INTRODUCTION

Formaldehyde was first recognized for its preservative properties by Blum in 1893 (Down 1989) and has since been widely used for tissue fixation and preservation. However, occupational health and safety authorities throughout the world are now more strictly regulating the use of formaldehyde because of growing concerns over the carcinogenic risks to human health. With this in mind, van Dam (2003) explored a wide range of biocides currently registered for use in the pharmaceutical and cosmetic industry and identified dimethyloldimethyl hydantoin (DMDM-Hydantoin) as a potentially suitable replacement for formaldehyde in fluid-preserved natural history collections. DMDM-Hydantoin is defined as a formaldehyde-releasing agent and is primarily used as a preservative in cosmetic and personal care products. This study was set up to compare the effects on tissue preservation by DMDM-Hydantoin with identical samples preserved in formaldehyde and ethanol-based solutions, using Fourier transform infrared (FTIR) spectroscopy to monitor chemical changes. Infrared spectroscopy has proved to be a powerful tool for studying biological molecules (Stuart 1997). When a substance is exposed to infrared light, molecular-level vibrations can occur that are detected and measured by the FTIR spectrometer (e.g., see Derrick et al. 1999). Infrared spectrometry is particularly sensitive to the presence of functional groups on organic molecules, which enables a sample to be chemically characterized or even identified (Smith 1999). This makes FTIR a useful analytical technique for looking into chemical changes within organic materials in natural history collections (e.g., Williams et al. 1990; Gentner and Wentrup-Byrne 1999). In this study FTIR spectroscopy was used to monitor potential changes in vertebrate muscle tissue chemistry across differing preservation treatments, analyzing the results in a similar process to that used by Derrick (1991) in research monitoring ancient animal skin parchment degradation.

MATERIALS AND METHODS

Equal quantities of small even-sized cubes of lean pork meat were preserved in a variety of fluid preservatives (Table 1). After 1 and 2 months of preservation, small pieces of tissue were removed from each of the preserved samples. These were then briefly soaked in deionized water to wash out the original preserving solution, and then blot dried using filter paper. FTIR analysis involved removing small pieces from the blot-dried tissue sample and placing them directly on the diamond interface of the Universal ATR sampling accessory on a Perkin Elmer Spectrum One spectrometer. Each spectrum

Table 1. List of samples used in this study.

Sample	Notes	No. of samples
Fresh tissue		2
4% formaldehyde	Fixative	4
4% formaldehyde (buffered)	Fixative/preservative	4
10% DMDM-Hydantoin	Fixative/preservative—potential replacement for formaldehyde.	4
Absolute ethanol	Used for molecular preservation.	4
80% Industrial Denatured Alcohol (IDA)	Standard fluid preservative for many museums.	8
Air-dried tissue		2

collected was the sum of 10 scans captured at a resolution of 4 cm^{-1}. At least four separate spectra were obtained from each tissue sample. The resulting spectra were then analyzed on Spectrum 5.0 software for changes in the protein banding patterns by first normalizing the spectral data and then taking measurements for the peak heights, areas, and positions of the Amide I and Amide II bands (Fig. 1). The results of all the spectra for each tissue sample were then compiled and averaged with Excel and statistically analyzed with PAST (Hammer et al. 2001).

Results

The samples used in this study were clean muscle tissue with the resulting spectra strongly showing the characteristic amide stretching and bending vibrations pattern for protein (Stuart 1997) as shown in Figure 1. The pattern of these bands will be affected by changes to the structure of the protein from processes such as denaturation, hydrolysis, and oxidation. Two specific parts of the protein spectrum were closely analyzed in this study, namely, the Amide I peak at about 1,650 cm^{-1} and the Amide II peak at around 1,550 cm^{-1}. The Amide I peak arises mainly from the stretching vibrations in the C=O bonding with minor contributions from C-N bonding vibrations (Barth 2007). The Amide I position is determined by the conformation of the protein structure and the hydrogen bonding. Amide II is more complex than Amide I and is derived mainly from the N-H bending vibration and the C-N stretching vibration. Previous infrared spectrometry studies of collagen (e.g., Brodsky-Doyle et al. 1975) have indicated that the most noticeable change in the infrared spectrum during denaturation is in the Amide II band, which shifts from about 1,550 to 1,530 cm^{-1}. By noting the changes in the Amide I and Amide II band positions and calculating the wavenumber difference between them an estimate of the effect of denaturation of the tissue protein can be made, represented by an increase in the distance between the two band positions. In this study the fresh tissue control and the ethanol-preserved samples all had a band difference in the range of 88–90, while the DMDM-Hydantoin and formaldehyde-preserved samples all had a band difference of 94 and above.

Hydrolysis of the protein polypeptide chains would be apparent in the infrared spectra as an increase in the OH stretching or bending frequencies that occur at about 3,400 cm^{-1} and 1,650 cm^{-1}. The 1,650 cm^{-1} is also shared by the Amide I, and thus an increase in OH would result in an increase in the absorption, or height, of this band (Derrick 1991). This effect can be estimated by comparing the intensities of the Amide I and Amide II bands. The results in Table 2 show that the ethanol-based samples have an Amide I and

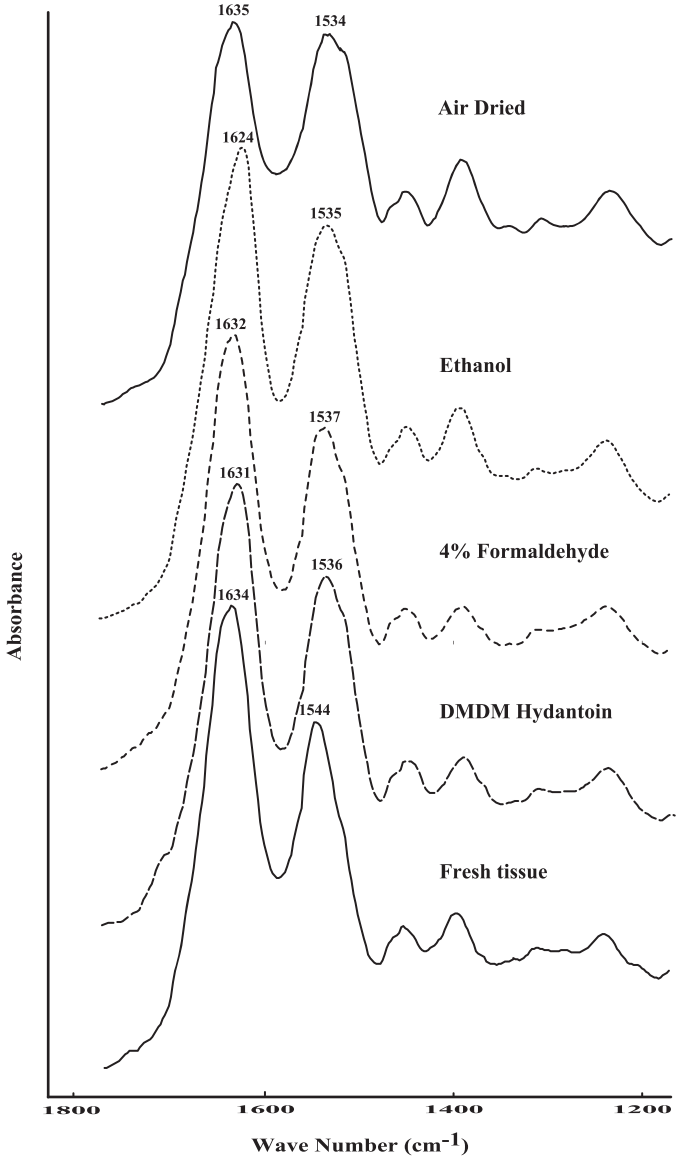

Figure 1. Infrared spectra of the principal Amide I and Amide II band region from (top to bottom): air dried, ethanol, 4% formaldehyde, DMDM-Hydantoin, and fresh tissue samples.

II absorbance ratio of 1.14–1.21, and the DMDM-Hydantoin/formaldehyde samples have a range of 1.28–1.29. For comparison fresh tissue samples have a ratio of 1.37, and air-dried samples have a ratio of 1.03.

The data from the differences in the Amide I and Amide II band positions and height ratios can be plotted graphically in a combined plot (Fig. 2), and this separates the alcohol-treated samples from the formaldehyde/DMDM-Hydantoin–treated samples. The fresh tissue control and air-dried sample clearly lie outside both of these treatment groups.

Table 2. Results for band position differences and Amide I and II peak height ratios (mean ± SD). The results shown here are the averages of all the readings obtained for each sample set after 2 months of preservation.

Sample	Band difference	Amide I/II ratio
Fresh tissue sample	87.7 ± 2.3	1.37 ± 0.05
Air-dried sample	100.7 ± 2.3	1.03 ± 0.01
4% formaldehyde	94.9 ± 1.0	1.29 ± 0.01
4% formaldehyde (buffered)	96.1 ± 2.5	1.29 ± 0.02
10% DMDM-Hydantoin	94.8 ± 1.4	1.29 ± 0.03
Absolute ethanol	89.1 ± 2.3	1.19 ± 0.02
80% IDA	88.8 ± 2.3	1.20 ± 0.02

Discussion

Samples preserved in alcohol-based solutions can be separated from those preserved in DMDM-Hydantoin or formaldehyde-based solutions by FTIR analysis. This reflects the differing chemistry of the solutions. Although both formaldehyde- and ethanol-based solutions can be classified as protein denaturants, they have differing effects on protein chemistry. Ethanol and IDA both have a denaturant fixative effect that displaces water in biological tissues and alters the tertiary structure of proteins by the disruption of the hydrophobic bonding. This changes the steric arrangement of the proteins in the tissue (Pearse 1980) but does not necessarily alter the functional group chemistry. Formaldehyde, and presumably DMDM-Hydantoin, has a more direct chemical effect on the protein tissue. With formaldehyde there is considered to be hydroxymethylation of

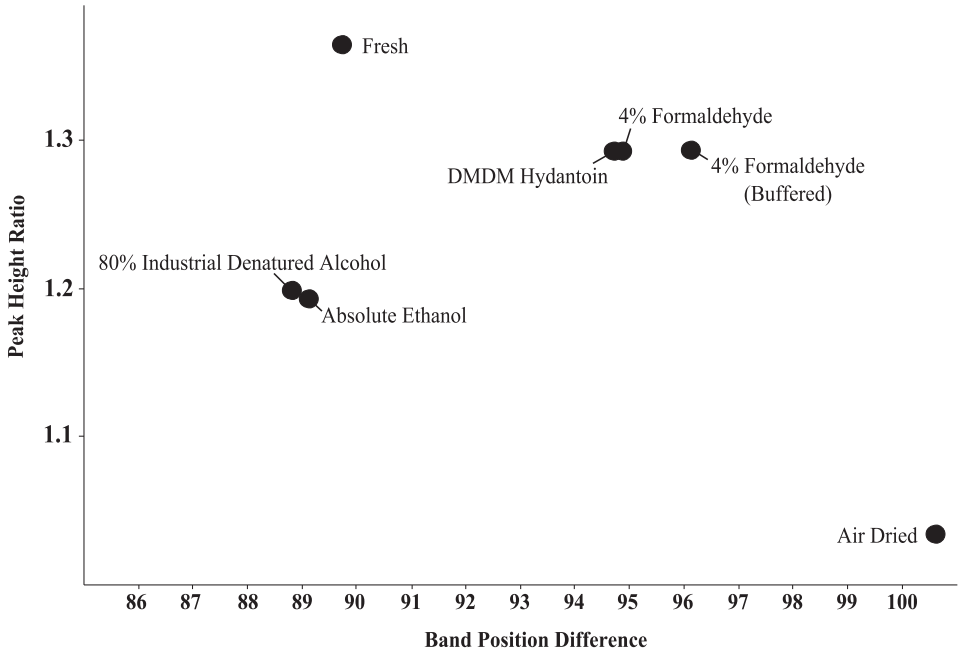

Figure 2. Combined plot of the differences in the Amide I and Amide II band positions and height ratios that separate the ethanol/industrial denatured alcohol–treated samples from the formaldehyde/DMDM-Hydantoin–treated samples. The fresh tissue control and air-dried sample clearly lie outside the treatment groups.

the imino and amino functional groups in the protein, generally resulting in cross-linking reactions (Jones 1976) that increase the chemical denaturation of the protein. This difference in effect on the chemical and structural conformation of the protein potentially explains the differences in the Amide I and II band positions. The ethanol-based solutions showed little variation in band difference between the fresh samples, whereas the formaldehyde-based solutions showed a greater difference suggesting greater denaturation of the protein through chemical reaction of the amine group with formaldehyde (Jones 1976). The results for the peak height ratio similarly reflect the differing chemistry of the ethanol- and formaldehyde-based solutions.

There are considerable differences in the levels of free formaldehyde between the DMDM-Hydantoin (0.2%) and the formaldehyde (4%) solutions used in this study. Much of the formaldehyde in DMDM-Hydantoin is bound within the chemical and released gradually over the lifetime of the chemical. However, whether the low concentrations of free formaldehyde are solely responsible for the results obtained in this study with DMDM-Hydantoin, or whether the bound formaldehyde has also had an effect on the results, has not been deduced from this study. It also raises the question whether there is an effective ''preservation lifetime'' of a formaldehyde releaser such as DMDM-Hydantoin.

Conclusion

The results show that DMDM-Hydantoin has a similar chemical effect on animal muscle tissue used as that of formaldehyde. Given DMDM-Hydantoin has lower toxicity and is safer to work with, this suggests that it is a suitable alternative to formaldehyde, especially when used for whole specimen preservation. However the long-term effective lifetime of this chemical as a preserving solution is still unknown.

Acknowledgment

I am grateful for the constructive and useful comments received from the three referees of this paper.

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ACCEPTANCE OF THE CAROLYN L. ROSE AWARD

John E. Simmons

Museologica, 128 E. Burnside Street, Bellefonte, Pennsylvania 16823-2010; Earth and Mineral Science Museum & Art Gallery, Pennsylvania State University, University Park, Pennsylvania 16802-5000; and Juniata College, 1700 Moore Street, Huntingdon, Pennsylvania 16652

It is a great honor to receive the Carolyn L. Rose Award for Outstanding Commitment to Natural History Collections Care and Management. I thank Tim White for nominating me for this undeserved honor and for his herculean efforts to drum up support for the nomination. To say I was surprised to receive this award would be an understatement—I was left speechless, which most of you know is an unusual condition for me to be in.

It means a lot to me to receive this award, particularly because it is named for Carolyn Rose, who I had the opportunity to know as a teacher and a friend, and to work with on several SPNHC projects.

I don't have time to thank everyone who has been important to the development of my career, but I would like to acknowledge my parents, as I was one of those lucky kids who was encouraged to visit museums and read as much as I wanted to as I was growing up. While still in elementary school, I decided that I wanted to work in a natural history museum. In 1963, at the Denver Museum of Natural History, I bought a pamphlet called Cigar Box Dioramas by Arminta Neal and realized that I didn't have to wait until I was an adult to work in a museum—I could start making my own exhibits at home. A few years later, at my local library, I found Vinson Brown's wonderful book *How to Make a Home Nature Museum* and taught myself how to collect, prepare, and catalog specimens.

In my freshman year in college I was lucky enough to get a student hourly job in the Natural History Museum at the University of Kansas, where I worked throughout my prolonged undergraduate career, mostly in herpetology, but also in birds, mammals, exhibits, and public education. After graduation, I worked at the Fort Worth Zoological Park and the California Academy of Sciences before returning to Kansas as a collections

manager. The University of Kansas provided me with opportunities for professional development that I would not have had at any other institution and some wonderful friends, especially Cathy Dwigans and Andrew Bentley.

The two things that had the biggest impact on my career, without doubt, were participating in the 1987 Collections Care Pilot Training Program (CCPTP) and joining SPNHC in 1988. These two events completely changed my ideas about how collections could be managed and should be managed. The people who have taught me the most about collections care are those I have met through SPNHC and the CCPTP, beginning, of course, with Carolyn Rose. Steve Williams and Rob Waller have been significant personal influences, and sometimes co-conspirators. Rob and Steve set the bar high with their standards of personal and scientific integrity and the warmth of their friendship. Sally Shelton and Beth Merritt, who were fellow CCPTP participants, have been the best and most loyal friends that anyone could ever hope to have.

Teaching was something I never intended to do, but I suspect that I have learned more from teaching collections care than I did from managing collections. I have been fortunate to work with a great bunch of students and workshop participants over the last 15 or 20 years. Muchisimas gracias to my friend and frequent collaborator Yaneth Muñoz-Saba, who opened the door for me to teach collections care in Latin America.

A very special thank you goes to Julianne Snider, the person who keeps me on track headed in the right direction, and who has enabled me to focus on the work that I think is most worth doing.

Most of all, I owe a huge debt of gratitude to Cathy Hawks. If I deserve this award at all, it is due to Cathy, who has been an outstanding teacher, an inspiring example, a wonderful colleague, and a good friend. Cathy has set the standard that all of us strive to emulate as collections care professionals and has shown us how important it is to share what we know with others. Like most other SPNHC members, I stand in awe of Cathy's professional knowledge and leadership, and her amazing generosity of spirit.

Thank you, very much, for this award.

Correction: Ms. Rose was listed as Carolyn B. Rose, rather than Carolyn L. Rose in volume 25.

PRESENTATION OF THE PRESIDENT'S AWARD TO ANDREW BENTLEY

Elana Benamy

Academy of Natural Sciences, Botany Department, 1900 Benjamin Franklin Parkway, Philadelphia, Pennsylvania 19103

I would like to nominate Andrew Bentley to receive the SPNHC President's Award. This award, created to recognize a person "whose activities have furthered the objectives of the Society through outstanding committee work, prolonged officer roles, or promotion of activities of the Society," is the perfect way to honor Andrew's contributions to SPNHC and the greater natural history collections community. Andrew has been an active SPNHC member for many years, serving on several committees during that time. His contributions span all three of the criteria for the SPNHC President's Award.

Andrew's work on two fronts has been truly extraordinary. Starting with the September 2003 issue Andrew, together with Lori Schlenker, has edited the SPNHC Newsletter. Always a useful publication, under Andrew's editorship, the newsletter has consistently been informative, punctual, and attractive. His gentle reminders to committee chairs to submit their reports by deadline ensured timeliness and completeness.

Second, perhaps of even greater long-range significance for our Society and the natural history collections community worldwide, Andrew has been tireless in his pursuit of clarification and easing of regulations regarding the transport of dangerous goods. He has been a persistent advocate for our needs and concerns regarding the shipping of museum specimens with the US Postal Service, US Department of Transportation (DOT), FedEx, and the International Air Transport Association (IATA). He has already received official letters of interpretation from the US Department of Transportation and the US Postal Service. Andrew has just announced that his years of arduous negotiation and advocacy have finally achieved results, with much of what he requested being incorporated into the new edition of the IATA Dangerous Goods Manual (52nd edition). This edition incorporates the A180 special provision that he worked on with IATA and DOT and becomes effective on 1 January 2011. These efforts will have a huge impact on our ability to ship specimens to our colleagues around the world and knowledge that they will arrive at their destinations safely.

Finally, Andrew is currently serving a three-year term as Council Member-at-Large, helping to steer our Society into more international prominence as it enters its next quarter century.

ACCEPTANCE OF THE PRESIDENT'S AWARD

Andrew Bentley

University of Kansas, Natural History Museum & Biodiversity Research Center, Dyche Hall, 1345 Jayhawk Boulevard, Lawrence, Kansas 66045-7593

I am most humbled and appreciative of this honor and recognition by my peers. When Jean-Marc first informed me of this I was completely surprised. This truly was not expected.

In informing me of my nomination (and as you have just heard), three factors were listed as contributing to my being given this award:

- My committee work
- My editorship of the newsletter and
- My work on dangerous goods.

I can safely say, as always, that none of these were accomplished in isolation, and I have a number of people to thank.

To all of those with whom I have worked on committees—thank you for your assistance and leadership and for helping me to serve the society in this way. I thoroughly enjoy my committee service and find it to be a rewarding mechanism of contributing and giving back to a society and its members to whom I owe so much—including not only numerous colleagues and friendships fostered over the years and my present position at the University of Kansas but also my wife, Lori, whom I met at the meeting in

Edmonton—my first meeting while still working in South Africa. We were the first official SPNHC marriage sent off on our wedding day from the Smithsonian by a number of Lori's colleagues and friends waving bouquets of spinach. I would encourage any new or existing members looking to give back to the society to look at getting involved in a committee.

I am most proud of our work on the Mentorship Committee of which I am now chair. The travel grant scheme has started with a bang and looks to expand and create much needed travel opportunities and mentorship to emerging professionals in our field. I am also hoping that our proposed international node program (putting the "I" in SPNHC) will follow soon to provide much needed and wanted assistance in other parts of the world—especially third world regions like Africa—a pet project of mine for obvious reasons.

A little less enjoyable, but equally as rewarding, is my work on the newsletter. I have tried, in the eight or so years that I have been editor, to improve the quality and content of the newsletter—hopefully with some success. An editor is only as good as the content he is provided, and so I am thankful to all those who have provided content over the years—even if sometimes it was under duress or through my constant badgering. I also have to thank Lori for her assistance with proofing and typesetting of the newsletter.

My work with dangerous goods has been the most rewarding. The two-and-a-half-year ordeal is finally over. With the recent publication of Special Provision A180 in the IATA manual we have completed the work on domestic (DOT and USPS) as well as IATA international regulations for the transport of dangerous goods. With all the naysayers telling me not to bother and "you will never get that done…" I have to first thank my dad for instilling in me the love of a challenge. He was always one to tackle something that others thought impossible. I also have to thank all those at the various agencies with which we worked (DOT, USPS, IATA, FedEx, UPS, and DHL) for their support and assistance. Without their help and guidance we could never have achieved what we have.

I also have to thank all those at KU—my two bosses, Ed Wiley and Jim Beach, for allowing me the time to dedicate to such a worthy cause and all the other collection managers for their support.

I do consider this award to be premature as I have so much unfinished business and so many other things I wish to tackle.

Most of all I have to thank my wife, Lori, and kids for supporting me through these and all my other endeavors.

Thank you all very much.

BOOK REVIEW

INTEGRATED PEST MANAGEMENT FOR COLLECTIONS, PROCEEDINGS OF 2011: A PEST ODYSSEY, 10 YEARS LATER, 2011, Peter Winsor, David Pinniger, Louise Bacon, Bob Child, Kerren Harris, Dee Lauder, Julie Phippard, and Amber Xavier-Rowe, eds. (English Heritage, London, Great Britain, 332 pp.)

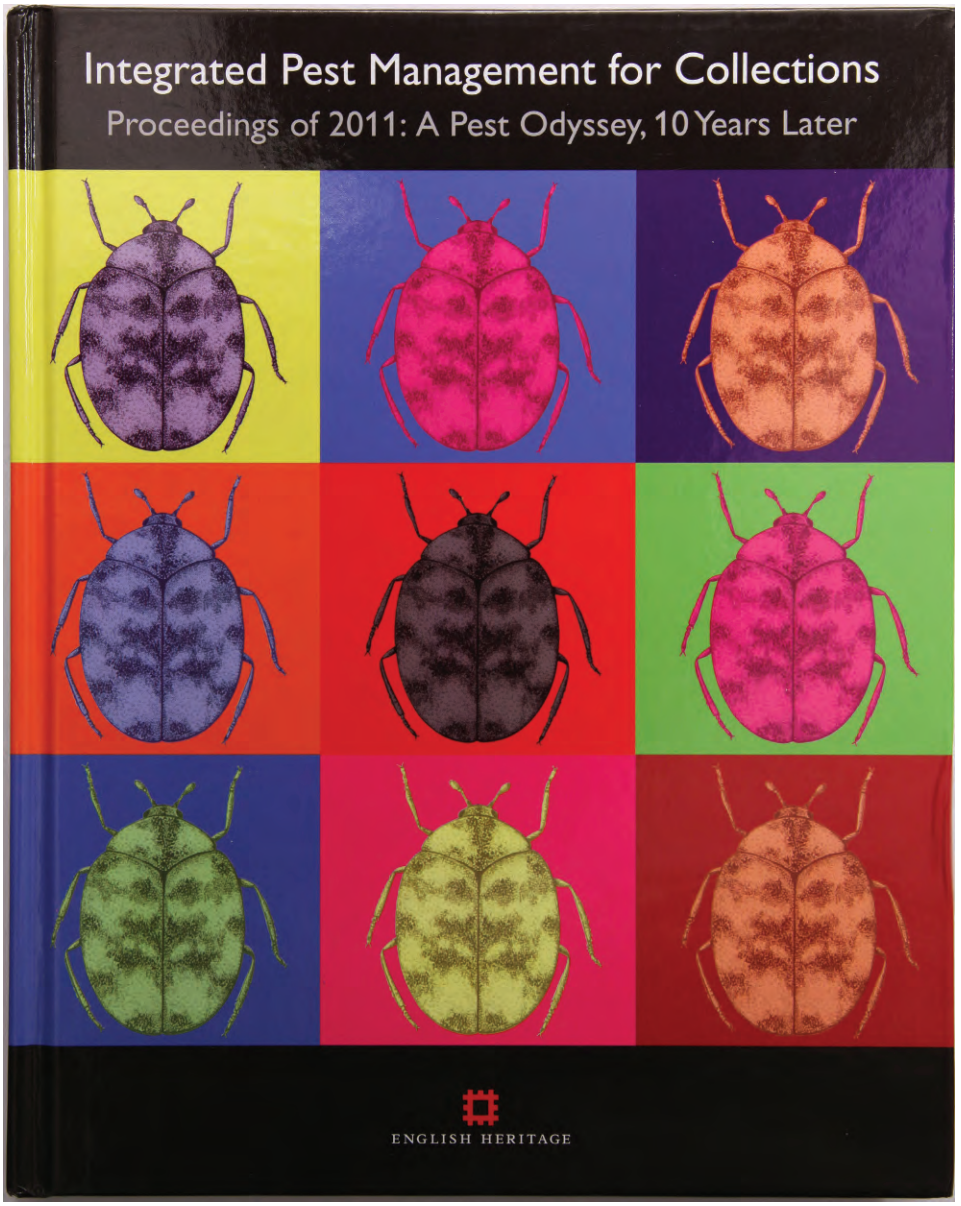
The first Pest Odyssey meeting was held in 2001 bringing integrated pest management (IPM) and museum professionals together from around the world. Ten years later, the 2nd Pest Odyssey met in London, UK, to explore the advances that have occurred in IPM. This book is a collection of papers based on oral presentations, from the 2011 meeting, together with abstracts of the poster presentations.

The editors state in the introduction to the volume that "one of the significant themes of the papers in the 2011 conference is that they demonstrate how IPM is becoming embedded in the practices of caring for and managing our cultural heritage collections and buildings." Nearly half of the papers presented in the book cover topics related to the practice of IPM within museums. Examples of these topics include a 10-year review of IPM practices within a museum, using IPM when designing museum buildings, and developing and implementing new IPM programs.

David Pinniger, an IPM consultant, authors the first paper, a synopsis of integrated pest management as a whole over the last 10 years. He touches on the treatment options that have been used, the idea of using "risk zones" for cost-effective IPM programs, and the pests themselves. Of the pests mentioned he spends the most time on the increase of webbing clothes moth infestations in the UK. Also covered are the adaptations this species seems to have made as well as the current control methods that are being employed. The paper expresses a concern about the webbing clothes moth in museum collections and how they will impact IPM around the world. This emphasis on the webbing clothes moth is carried throughout the book.

Three papers represent case studies of combating clothes moths, and a fourth deals with a new control option. The remaining papers cover different pests and pest infestations, as well as new treatments. Other articles of note include a review of a pest-tracking utility for KE Emu collection management software and a consideration of the effects of temperature treatments on DNA preservation. The poster presentations are given good coverage, with most having two-page layouts and including multiple images. The poster content matches well with the oral presentations; it can be hoped that at least some will be published as full articles in the future.

One shortfall of the book is organization. The papers do not seem to have been grouped in any particular order, at least not in an order that is easily recognized. From a user's perspective, the book would be easier to navigate if papers had been grouped together based on content. A paper on the brown carpet beetle, for example, is sandwiched between papers on control methods for clothes moths and a building design case study. In addition, some of the papers suffer from an excess of informality; although oral presentations can benefit from amusing titles that draw more interest at a meeting, these titles do little to explain what the paper is really about and can detract from the importance of their content. Many of the papers are UK based, and the book might have benefited from a broader geographic sampling. However, it is fairly clear that future meetings and publications will grow in this direction.



Editorially, the book reads well with sections clearly defined through efficient layouts. The tables and figures meld well with the text and are located near their reference, without the necessity of turning pages. The entire book is published in color, adding extra value to the graphs, tables, and images for the reader. Vibrant color figures help display data, and color images will aid in identification of featured pests.

While the printing quality alone sets this book apart from other IPM resources, the real-world experiences, current pest issues, and advances in pest control and tracking make this book a valuable resource for collections manager, IPM professionals, and

administrators. For those who are creating, implementing, or reviewing their own IPM programs, case studies offer new perspectives and different experiences. Reviews of old and new treatment options aid in the day-to-day activities of integrated pest managers and conservators who are dealing with new infestations. IPM literature is becoming more accessible online, but solid citable journal pieces and books are necessary tools for promoting IPM, implementing programs, and getting administration to buy in to the process. With the bonus of having a compact disk copy and being accessible with a few clicks of a pointing device, this compilation of papers catalogs the advances in IPM in the last 10 years and leads us to speculate about innovations in store in the future.—*Lynn Jones, Yale Peabody Museum of Natural History, 170 Whitney Avenue, New Haven, Connecticut 06516*