

## Special Issue: Preventive Conservation

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## PREFACE

The basic concept of preventive conservation—that preventing damage is more efficient than expensive repair—has been recognized for centuries, if not millennia (Lambert 2010). That the concept is often sacrificed to expediency or poor planning has plagued its implementation for equally as long. It is only in the past few decades that there has been strong recognition that for cultural property, preventive care is fundamental to sound conservation practice (Plenderleith and Werner 1971, Roy and Smith 1994). As the papers in this volume demonstrate, preventive conservation has now expanded to incorporate a broad array of collection care practices. This expansion works well for natural history collections in which there are often vast numbers of specimens or objects for which care must be holistic or risk being ineffective.

The professions and professional organizations that have an interest in sound collection care are growing, and reflect the support for good practice across the entire museum field. The resources provided by these groups are of use to everyone who deals with collections in any way. New approaches to risk assessment and risk management provide mechanisms for resource allocation in traditional areas of preventive conservation, such as museum environments, as well as to issues of facility quality and maintenance, fire protection, collection documentation, and emergency management, among others. The idea that exhibition design should address risk management for collections is especially important in an era when there has been an increasing emphasis on public access to collections, or at least the appearance of openness in displays.

As conservation research continues to provide information essential to risk management, the breadth of issues that should be considered in collection care will continue to grow. This argues for integrated resources to bring new knowledge to the widest possible audiences. Although conservators openly share this type of information among themselves, the creation of the American Institute for Conservation's (AIC) Collection Care Network (CCN) is a major effort to open the conversation to all interested parties. This has the added advantage of allowing the conservation field to share in the many advances in collection care developed by other museum professions.

The Society for the Preservation of Natural History Collections (SPNHC) has long been involved in collection management and preventive conservation. *Collection Forum* has been a seminal journal for these topics. The articles appearing in its pages have been mined by professionals across many types of museums. It seems fitting, therefore, that to celebrate the formation of CCN, AIC asked permission to present a session at the 2012 SPNHC Annual Meeting and publish the papers from the meeting in *Collection Forum*. We hope the session and papers are the start of a long and mutually beneficial relationship between two organizations with many common goals.

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# RESOURCES FOR PREVENTIVE CONSERVATION AND COLLECTIONS CARE

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*Abstract.*—Risk assessment, disaster planning, environmental monitoring, maintenance of collections spaces, integrated pest management, and development of collection policies and procedures are some of the methodologies that foster preservation of cultural heritage and are a part of responsible stewardship. Collection care professionals, especially those working with natural science specimens that number in the thousands or millions, know that the everyday practices of preventive conservation contribute to greater overall collections preservation and prevent damage that requires time-consuming and expensive interventive treatment. Preventive care projects almost always benefit from an interdisciplinary approach with input from conservators and the full range of staff who work with collections in other capacities. This paper aims to raise awareness of valuable resources that can aid collection stewards in promoting, planning, and executing collaborative preventive conservation and collections care activities for the natural history community. Internet links to resources mentioned in this paper are included.

## INTRODUCTION

Preventive care has been promoted for over 20 years as an efficient, effective, and systematic way to mitigate damage to collections and extend preservation (Michalski 1990, Rose 1991, Rose and Hawks 1995). By addressing the forces responsible for damage and loss, preventive care has a greater ability to protect an artifact or specimen and its corresponding information in a way that remedial conservation treatment or restoration can never achieve. One of the original guiding tenets of preventive conservation is the “Agents of Deterioration” concept (Michalski 1990, 1994; Waller 1994; Canadian Conservation Institute [CCI] 2011a). First outlined in 1987 and published in 1990 by Stefan Michalski and later appended by Robert Waller, the list of Agents identifies forces that cause deterioration and damage in collections:

1. Physical forces
2. Fire
3. Water
4. Thieves and vandals
5. Pests
6. Pollutants
7. Light and radiation
8. Incorrect temperature
9. Incorrect relative humidity
10. Custodial neglect

Consideration of the Agents of Deterioration (hereafter called “Agents”) should promote holistic thinking about collection care and, when combined with comprehensive collection assessments, can increase understanding of both the inputs and outcomes of preservation efforts, so that resources can be appropriately allocated. This paper aims to

raise awareness of valuable resources that can aid collection stewards in promoting, planning, and executing preventive conservation and collections care activities. Although some of the resources listed are international in scope or authorship, most of those included are geared towards the North American preservation community. It also should be clear that this selection focuses on online, free, or easily obtainable resources that are relevant to the natural history community. All resources mentioned in this paper, including internet links, are included in the Appendix, and are organized by topic.

#### ASSESSMENT TOOLS

The list of Agents provides a framework for identifying risks to a collection. Using this framework often results in the development of a long list of pressing needs. Prioritizing preventive care activities that will respond to these needs is often a challenge.

One way to guide decision making is by conducting a risk assessment so that resources are allocated based on data and not anecdotal ideas of need. Developed by R. Robert Waller, former conservator at the Canadian Museum of Nature and now founder of Protect Heritage Corporation, the *Cultural Property Risk Analysis Model* (Waller 2003) evaluates the impact and likelihood of specific risks on a specific collections unit. Specific risks within each Agent of Deterioration are selected for analysis. For example, if the damaging effects of water on collections are to be studied, specific risks such as roof leaks, burst pipes, and a flash flood from a nearby river should be analyzed. The risks examined are determined by the institution performing the risk assessment, thus tailoring the approach to the institution. Likewise, the specific risks' impacts on specific collection units are studied. It is clear that water would have more damaging effects on hygroscopic collections such as wood and textiles than it would on stone and ceramics. Conducting an institution-wide risk assessment provides important data that administrators will find useful in prioritizing preservation work. If a full collection risk assessment is not possible for an institution, Heritage Preservation's (HP) Risk Evaluation and Planning Program material provides site questionnaires, checklists, and a risk prioritization worksheet to guide institutions through an organized preservation planning campaign (Heritage Preservation 2009). Another institutional assessment tool that can be useful for smaller institutions is The Birmingham Museums and Art Galleries Risk Awareness Profiling Tool (RAPT) (Birmingham Museums and Art Galleries 2010). In addition to conducting the assessment, this site also includes useful resources to assist collections staff in developing better risk awareness.

Whereas collection risk assessment studies the impact of certain damaging forces, *Benchmarks in Collection Care* (developed by the UK Council for Museums, Libraries, and Archives) is a self-evaluation tool for institutional collection care practices. The evaluation poses questions on storage, handling practices, loan practices, collections use, emergency preparedness, and several other factors, and has the respondent assign scores of good, better, and best. Originally developed as a PDF in 2002, *Benchmarks in Collection Care* was updated with a spreadsheet and explanatory support documents in 2011. This tool is available through *Collections Link* (2011), the Web site of the UK's Collections Trust, which has a number of other collection care resources available through its Web site. For small to mid-size institutions without preservation expertise in-house or where a fresh perspective is needed on prioritizing preservation activities, the Heritage Preservation Conservation Assessment Program (CAP) is a useful place to start. CAP grants allow recipients to bring in an assessor for their collections and historic structures to document current conditions and provide a roadmap for tackling them with

short, medium, and long-term priorities. A CAP report provides a useful roadmap for addressing preventive care projects in order of greatest need or as resources allow. It also provides a foundation for seeking other grant funding. Guidelines for applying for a CAP are available on the HP Web site (Heritage Preservation 2012c).

Once risks are identified and prioritized, the next step is to devise mitigation strategies. A variety of current resources to support mitigation of those preservation risks are organized below within the framework of the ten Agents of Deterioration. The resources will support routine collection care activities, specialized challenges, and overall management of an institutional preservation program.

## AGENTS OF DETERIORATION

### *1. Physical Forces*

In *A Public Trust at Risk: The Heritage Health Index Report on the State of America's Collections* (Heritage Preservation 2005), it was found that only 11% of institutions have adequate storage facilities for their collections, and at 65% of institutions, collections are in need of treatment due to improper storage. Improper storage or enclosure was listed as the primary cause of significant damage to collections, and damage from handling was related to improper storage because these conditions made item retrieval more risky (Heritage Preservation 2005). There are several resources that provide information useful to establishing good practices for how collections are stored and handled.

The Preparation, Art Handling, and Collections Care Info Network (PACCIN) started as a resource organization for collection staff involved in packing and crating of collections. Formally organized as a committee under the American Alliance of Museums (AAM), PACCIN holds workshops and PrepCon, a conference focused on preparation, art handling, and other related topics. The PACCIN (2012) Web site presents a number of articles on practical collection care issues, from mountmaking, testing vehicles for local object transport, Radio Frequency Identification (RFID), and solutions for moving large or difficult objects.

Since 2008, a biennial Mountmakers Forum has been held and hosted by a different institution each year (2008 at the Getty in Los Angeles, 2010 at the National Museum of the American Indian in Washington, D.C., and 2012 at the Field Museum in Chicago). This conference is a venue for mountmakers, preparators, conservators, and other professionals to share innovative solutions to tough installation problems. This group is becoming increasingly active and organized in professionalizing their approach to mountmaking and working collaboratively with museum colleagues to ensure safe display of complex collections.

Most museums display far fewer collection items than they store, making storage spaces the locus of much preventive care activity (Heritage Preservation 2005, Smithsonian Institution 2010). Overall storage organization is paramount. Re-org is a Web-based resource created by the International Centre for the Study of the Preservation and Restoration of Cultural Property (ICCROM) that provides a no-cost tool to assist institutions in evaluating their storage (ICCROM 2012). Step-by-step directions, through a storage condition report, help the user document comprehensive information about the building, management, the collection, and its storage environment. Re-org then leads the institution through steps to implement storage reorganization goals. This is a helpful tool in preparing grant applications because it allows institutions to document their organized approach to assessing storage needs using a known matrix, and creates documentation that can be used to assess and document progress over time.

Whereas Re-org works at the storage room level, one of the primary resources for information on storage at the artifact/specimen level was developed by the Society for the Preservation of Natural History Collections (SPNHC). The book *Storage of Natural History Collections: Ideas and Practical Solutions*, edited by Rose and de Torres, 1992, and first published in 1992, presents designs for a wide variety of collection types and storage methods. The implied target audience for the text was natural history collections, but collections professionals from other disciplines have noted the book's usefulness in stimulating creativity in storage support design and construction. With the book soon to be out of print, a new method of disseminating this type of information is in the development stage. STASH: Storage Techniques for Art, Science, and History collections, a project of the Foundation of the American Institute for Conservation (FAIC) in partnership with SPNHC, will create a Web site to present the original 114 articles from the book as well as new content. New design submissions will be reviewed by a multiorganizational editorial committee consisting of representatives from SPNHC, AAM, PACCIN, and others. The online site will enhance exchange of storage support information in a dynamic format that can incorporate the expertise of different fields of preventive care practice. Working through both Re-org and STASH will allow institutions to make significant improvements in storage that should have a profound effect on care at both a macro and a micro scale.

#### *2, 3, and 4. Fire, Water, Thieves, and Vandals—Emergency Preparedness and Security*

Much of the damage preventive conservation works to combat is a slow and everyday process. However, preservation planning must include prevention or at least mitigation of the inevitable catastrophic event caused by fire, water, wind, and destructive acts stemming from human activity. Many institutions are not prepared for such events; 80% of US collecting institutions do not have a written emergency/disaster plan with trained staff to carry it out (Heritage Preservation 2005). Several resources are available to assist in planning for the four phases of emergency management activity: 1) preparedness, 2) response, 3) recovery, and 4) mitigation.

For those museums at the beginning of an emergency planning effort, dPlan is a free online resource that helps smaller institutions perform a risk assessment and write an emergency plan (Northeast Document Conservation Center 2006). After registering, institutions complete an emergency plan template by answering questions about their institution, key personnel, collections, insurance, local salvage resources, and any disaster preparedness activities already in place. Both a template and an educational resource, dPlan explains the importance of each aspect of the plan, guiding institutions in creating an emergency plan. The completed plan may be printed or saved as a PDF.

The MuseumSOS Web site, hosted by the American Museum of Natural History (AMNH) contains useful information from the 2004 SPNHC conference that focused on emergency planning and response (AMNH 2005). Papers presented at the conference covered all four phases of emergency management and many are available for download in their entirety. For the museum engaged in its own planning effort, resources at this site include information from health and safety and risk assessment to case studies on handling of compromised objects and documentation. This site also includes articles on museum partnerships in emergency response.

The Heritage Emergency National Task Force (HENTF) is an important initiative of Heritage Preservation (HP), a national non-profit organization that focuses on the preservation of cultural heritage. The Task Force is a partnership of 41 national service organizations and federal agencies that protects cultural heritage from the damaging

effects of natural disasters and other emergencies by creating a wide range of important and useful resources:

One of the more innovative HENTF programs is Alliance for Response (AfR), whose chapters introduces and familiarizes the reader with the emergency needs of cultural institutions to local first responders such as fire and police. AfR has seventeen chapters in different cities throughout the country. Materials explaining how to establish an AfR chapter are available at Heritage Preservation's Web site (Heritage Preservation 2012a).

One important aspect in navigating the response phase of an emergency is understanding first responders' language and hierarchy. Incident Command System (ICS) is a hierarchical method of organization and communication for emergency response and recovery. ICS was developed to combat miscommunications between government agencies responding to California wildfires in the 1970s that needlessly led to deaths and widespread property damage. A systematic hierarchy, standardized roles, and established communication rules aim to limit injury, confusion, and overtaxing of limited resources in stressful and dangerous situations. A recent publication by David Carmicheal (2010), *Implementing ICS at the Institutional Level*, demonstrates how this organizational hierarchy can work effectively for museums too. Basic courses in ICS are available online from Federal Emergency Management Agency (FEMA) at no cost, and paired with Carmicheal's text can aid museums in visualizing how their museums should organize to respond and recover from emergencies.

Hard lessons learned during Hurricane Katrina and other major storms resulted in HENTF's Lessons Applied resources (Heritage Preservation 2006). The tools focusing on the response phase and after include the poster "Working with Emergency Responders: Tips for Cultural Institutions," and the Web site Guide to Navigating Federal Emergency Management Agency and Small Business Administration Disaster Aid for Cultural Institutions (Heritage Preservation 2008). Information on training courses and funding opportunities for planning are also available on the site.

Resources from HENTF to assist in the recovery and mitigation phases include the *Field Guide to Emergency Response*. The handbook and associated DVD are designed for immediate use in a disaster with simple, clear instructions, downloadable forms, checklists, and video clips to help staff organize essential disaster response functions and tackle common threats to collections. The guide can be used in conjunction with the popular and newly updated *Emergency Response and Salvage Wheel*. The wheel focuses on salvage techniques to combat water damage. Both the Field Guide and Wheel are available for purchase through the HP Web site (Heritage Preservation 2012b). The wheel is now also available as a free app called *ERS: Emergency Response and Salvage*. It is available from the iTunes for Apple devices and Google Play for Android devices.

The American Institute for Conservation—Collection Emergency Response Team (AIC-CERT) is available 24/7 when outside advice and assistance is needed for response and recovery phases (see Appendix for contact information). AIC-CERT responds to the needs of cultural institutions during emergencies and disasters through coordinated efforts with first responders, state agencies, vendors and the public.

### 5. Pests

Heritage Preservation's Heritage Health Index Report (2005) found that approximately 75% of institutions require an integrated pest management program (IPM) with 20% of them considering IPM as an urgent need. IPM is a strategy that emphasizes prevention and minimizes the use of toxic chemicals to manage and eliminate pests. A



functional IPM plan works to reduce the possibility of pests accessing collections, monitors levels of pest activity, and if necessary, deals with remedial treatment. The control of pests in collections requires museum-wide support. Starting with top level administration, all employees have a role in IPM. Administrators prioritize the funding needed for an IPM program. Registrars could be responsible for the initial inspection of works when they enter the museum. Collection-care team members can monitor insect traps and regularly clean storage areas. All staff must dispose of food trash properly, and the housekeeping staff must empty those receptacles in a timely manner. The downside to IPM is that it is time consuming and, like some other preventive care projects, it can be hard to put a price tag on the benefits of the time expenditures. However, because pesticides and fumigants are increasingly limited for institutional use, a reasonable IPM plan is really the only viable option for preventing infestations in collections.

The Integrated Pest Management Working Group (IPM-WG), an ad hoc group of museum and pest professionals, has created two useful resources for institutions to use in developing all parts of an IPM plan. The Museum Pests Web site (IPM-WG 2012) is organized into sections covering prevention, monitoring, identification, solutions, and resources. Prevention information discusses the building envelope, environment, training, and risk assessment, and other parts of the Web site include resources for identifying and handling an infestation. The IPM-WG also manages the PestList listserv with over 600 members worldwide creating an online community willing and able to provide identifications and advice. Information on subscribing to the free listserv is available through the Museum Pests Web site.

The Museum Pests Web site (IPM-WG 2012) also lists many of the excellent UK IPM resources, including the What's Eating Your Collection Web site created by Collections Trust and the Birmingham Museums and Art Gallery, English Heritage's poster *Insect Pests Found in Historic Houses*, and the booklet *Pest Management: A Practical Guide* written by IPM expert David Pinniger (Pinniger n.d.).

### 6. Pollutants

The two general types of pollutants that contribute to the deterioration of museum collections are particulates and gasses. Particulate contaminants, commonly deposited via direct contact with artifacts, include dust, oils and salts from skin transferred during handling, and heavy metals such as arsenic that were used historically as pesticides on some types of museum collections. Gaseous, airborne contaminants can include ozone from the environment, and acidic gasses or organic acids such as sulfur dioxide, nitrogen oxides, and formaldehyde emitted by inappropriate storage or exhibit materials. These will cause chemical deterioration such as corrosion, yellowing, and embrittlement. *Pollutants in the Museum Environment: Practical Strategies for Problem Solving In Design, Exhibition and Storage* (2002) by conservator Pamela Hatchfield is a core text in this area of preservation. As the book's subtitle suggests, it details practical strategies for problem solving in design, exhibition, and storage and covers testing and mitigation.

There are many resources to help collections staff address particulate contamination in collections. While geared toward historic interiors and their furnishings, *The National Trust Manual of Housekeeping* (National Trust 2011) was recently revised and provides theoretical and practical information specifically about housekeeping, including how simple preventive procedures such as dust removal prevent the need for future expensive conservation treatment. For more information on pesticides and how to identify and deal with their presence in collections, Nancy Odegaard and Alyce Sadongei's *Old Poisons*,

*New Problems: A Museum Resource for Managing Contaminated Cultural Materials* (2005) provides important and comprehensive guidelines.

The National Park Service's Exhibit Conservation Guidelines CD-ROM provides narrative text, technical notes, and detailed illustrations to guide exhibit team members in incorporating conservation into the exhibition process (Harpers Ferry Center 1999). The guidelines provide useful information on a wide range of topics, including safe exhibition materials that avoid the use of products that cause pollutant damage. Building on this product, the Exhibition Standards & Guidelines, an online document available on the American Institute for Conservation WIKI site (AIC WIKI 2012a), will be hosting updated product information. Check back regularly as updated information becomes available.

Conservators use the Oddy Test to evaluate the suitability and stability of materials for exhibit construction and storage. Although this accelerated ageing test has its pitfalls, it provides a generally useful idea of how a material will respond over time. Many institutions conduct these tests independently with slight variations in test protocol, but it is hoped that institutions will choose to share this information and, when taken together, the information will prove useful to the entire community. This information is currently being collected for hosting on the Materials Testing page of the AIC WIKI site (2012b). This resource will evolve as contributions are accumulated.

### 7. Light

Visible light is, of course, necessary in museum environments. The standards that have evolved in the preservation community recognize that levels of light must be high enough to adequately view artifacts on display, but anything more than that causes unnecessary damage and should be limited. Institutions are paying increased attention to lighting now not just for preservation purposes, but also because lighting has a substantial impact on heating loads that affect the museum climate, and therefore on utility budgets.

The CCI's Ten Agents of Deterioration Web resource (2011a) includes a section on light, ultraviolet and infrared, which provides background and standards on different light sources, damage, and the control of lighting in collections. In addition, CCI's new online Light Damage Calculator (2011d) assists collections staff in understanding the light sensitivity of materials and in estimating damage caused by light exposure. Stefan Michalski, one of the CCI creators of the Calculator, gave a Connecting to Collections webinar which provides a useful introduction (see Appendix for webinar information).

Much of the current focus in museum lighting is on the use of light-emitting diodes (LEDs). The Connecting to Collections webinar "Introduction to LED Lighting" (see Appendix) is a 65-minute recorded program that provides a useful overview of the use of LEDs in collections. Guidelines for Selecting Solid-State Lighting for Museums by Jim Druzik and Stefan Michalski (2011), is a resource that compares LEDs to traditional lighting, and provides information about lighting efficiency and cost. This publication is now available at no cost from the Getty Conservation Institute (see Appendix for address). For guidance on the current state of the field as it pertains to collections, visit the Sustainable Practices page of AIC's Committee on Sustainability in Conservation Practice on the AIC WIKI (2012c).

### 8 and 9. Incorrect Temperature and Relative Humidity (RH)

Management of a correct climate for collections continues to be an issue for many institutions. Decision making on proper preservation environments is hindered by the

lack of data about the reaction of objects to subtle changes in climate, dogmatic reliance on strict set points of 70°F (21°C) and 50% RH, and is complicated by conversations about sustainability and increasing energy costs. Although many institutions tend arrays of hygrothermographs and/or dataloggers, the collection of data often ends without analysis or understanding of clear outcomes that climate control should produce. Paired with the lack of clear and collegial communications with facilities engineers, managing climate control for collection areas can cause woes for staff relations and budgets. In order to better understand shared goals, scientists, conservators, and environmental engineers have been working together to develop resources to document, analyze, and understand environmental data, and to suggest best practices for collections preservation.

As institutions begin to evaluate whether strict adherence to guidelines of 70°F (21°C) and 50% RH is possible or necessary, it is important to understand how the field arrived at these numbers and why. Two documents can assist in improving communication and identification of shared goals between facilities and collection staff. Standards of operation were created by the American Society for Heating, Refrigeration, and Air Conditioning Engineers, and were published as the *ASHRAE Handbook* (ASHRAE 2011). The handbook includes a chapter on Museums, Galleries, Archives, and Libraries (MGAL). Developed by museum scientists and museum-minded environmental engineers, ASHRAE's MGAL chapter provides common ground over which collections and facilities professionals can begin discussions about creating the right environments. This document provides a useful benchmark for understanding a facility and a collection in context. For a more comprehensive discussion of this topic, collection care staff should consider purchasing *PAS 198:2012: Specification for Managing Environmental Conditions for Cultural Collections* (British Standards Institute 2012). This new document from the UK British Standards Institute was developed in conjunction with The National Archives (UK) and outlines a management program for climate, light, and pollutants within institutions. It contains a highly useful annotated bibliography.

Pamela Hatchfield's 2011 article *Crack Warp Shrink Flake: A New Look at Conservation Standards* was published in AAM's *Museum* magazine, in conjunction with an expanded version on the AIC WIKI (2012a). It provides a useful introduction to the current reevaluation of climate control guidelines. Another useful resource in understanding why this discussion is so timely is *The Plus/Minus Dilemma: The Way Forward in Environmental Guidelines* (see Appendix for Web site), which describes the joint International Institute for Conservation (IIC) and AIC event held in 2010 to examine the issue.

In order to evaluate whether broadening environmental guidelines is appropriate for a particular collection, it is necessary to have data on the environmental conditions to which the artifacts are conditioned. The Connecting to Collections online community has hosted two webinars with details on choosing either a standalone datalogger or evaluating a wireless monitoring system (Connecting to Collections Online Community 2012). These presentations include recordings of the webinars and associated handouts that can be used to guide equipment purchase decision making by focusing on project needs and equipment capabilities. They also highlight relevant resources such as *Conserve O Gram 3/3: Comparing Temperature and Relative Humidity Dataloggers for Museum Monitoring* (see Appendix for Web site).

Once the data is collected, the goal is to use it to mitigate inappropriate conditions and guide necessary decision making. The Image Permanence Institute's (IPI) new eClimateNotebook Web site (IPI 2012) combines and replaces features from the

ClimateNotebook desktop software and pemdata.com Web-based program. Although the site works seamlessly with IPI's own PEM2 datalogger, it also works with some other datalogger files. The program facilitates data analysis, reporting, and linking of information, such as an event log. The program is now available for a subscription fee at IPI's eClimateNotebook Web site (IPI 2012).

### 10. Custodial Neglect and Disassociation

Custodial neglect, as an Agent of Deterioration, addresses damage that occurs through lack of action and due diligence. Every institution should have a collections management policy that outlines the conscientious stewardship by trained staff to maintain their physical and intellectual integrity. Custodial neglect includes failure to gain title upon acquisition, incomplete accessioning, and lack of appropriate subsequent inventory and documentation necessary to verify a collection item's security and condition. Dissociation is a concept that captures risks to the intellectual information that gives objects meaning and purpose. An object that loses its identity and connection to documentation loses its meaning within a collection.

Marie Malaro's *A Legal Primer on Managing Museum Collections* (2012) continues to be a solid resource. As former Counsel at the Smithsonian Institution, Malaro's book is a ready reference to any collection staff drafting policy or wading through difficult issues without benefit of institutional counsel. The initial section covers creation of a comprehensive collections management policy, including what needs to be outlined about acquisitions, deaccession, loans, insurance, and legal and ethical standards of care of collections and records maintenance. Specific information about laws, conventions, and international agreements assist museum staff in navigating the securing of clear title for their collections. In this third edition, new information regarding digital use of collections images and traditional care for indigenous objects is included. There also is copious information on the legal and ethical responsibilities of museums to provide access to their collections, while providing a safe environment for staff and visitors and collections use, including artists' rights and copyright. This volume is helpful in educating administration and board members about the intricacies of the museum's legal and ethical responsibilities.

*Museum Registration Methods*, edited by Rebecca Buck and Jean Allman Gilmore (2010), continues to be another core reference with solid and comprehensive information on a wide variety of collection topics. As in earlier versions of the book colloquially known as MRM5, essays from many authors outline labeling, storage, and documentation practices. Additionally, the new volume also expands on professional issues for those who perform registration and includes in-depth information on managing collections use and documentation.

The Registrar's Committee of the American Association of Museums (RC-AAM) promotes the needs and goals of museum registrars and other practitioners involved in collection care. Their informative and very active listserv has long been a resource for registrars and collection managers around the country, providing information about a wide range of storage and documentation challenges. At RC-AAM's Web site (2012), a Form and Policy Swap section allows members to view and download documents and build upon other museums' work. Having good policy and procedure documents in place should help ensure that an institution is following accepted standards of practice and is allocating resources for collection care. RC-AAM has actively promoted sharing

documents with the goal of standardizing information formats between institutions; e.g., the Standard Facility Report and other loan practices.

Due to internal changes in the AAM committee structure, in late 2011, a group of registrars decided to form an independent organization named the Association of Registrars and Collection Specialists (ARCS). A Web site with bylaws and the names of founding members has been established (ARCS 2012). This will be a resource to watch.

#### GENERAL RESOURCES

In 2005, Heritage Preservation published *A Public Trust at Risk: The Heritage Health Index Report on the State of America's Collections*. This report of the first comprehensive survey to assess the condition and preservation needs of US institutions showed that a great number of American collections held in the public trust were at risk. In addition to being a tool for advocacy within museum administrations and outside of the museum, the report resulted in the development of several important initiatives. The Institute for Museum and Library Services (IMLS) created *Connecting to Collections* (see Appendix for Web site) to provide resources for institutional efforts to ensure the best possible care for collections. Although some of their programs have been completed, the Web site has comprehensive online resources from the initiative's past events and programs, information on current grant funding opportunities and the Connecting to Collections Online Community. The Connecting to Collections Online Community, funded by IMLS, HP, and the American Association for State and Local History (AASLH) addresses the critical need of access for small and under-resourced institutions for quality collection care information by featuring resources, a discussion board, and access to webinars.

To address basic collection care needs for The National Park Service's (NPS) 397 units NPS developed the Conserve O Gram series, hosted on their Web site (National Park Service 2012). These documents, a series of short leaflets, are free online and tackle specific questions of museum practice, from caring for amber collections to cleaning volcanic ash off of objects. The National Park Service's *Museum Handbook* (2006) is a great place to start when developing institutional collection care policies and procedures. Organized in three sections (Museum Collections, Museum Records, and Museum Collections Use) the reference covers issues from working with different types of collections, housekeeping, handling and shipping, emergency preparedness, and meeting different disciplines' documentation standards to creating reproductions and display of museum objects.

Similar to the Conserve O Grams, the Canadian Conservation Institute (CCI) has a series of technical notes developed for their member institutions on caring for different types of collections. Since 2010, the CCI Notes are available free online (CCI 2011b). For more in-depth information, CCI publishes Technical Bulletins on specific topics such as dealing with a mold outbreak and developing an integrated pest management policy. These are available at low cost through the CCI Web site (CCI 2011c).

In addition to these resources, many large institutions worldwide, including the Library of Congress, the US National Archives and Records Administration (NARA), The Institute of Conservation (ICON), and the National Archives of Australia, provide strong collections care information for free on their Web sites. There are also many key resources created by the conservation community that might not be well-known outside of the field. One example is the Western Association for Art Conservation (WAAC) Newsletter. Since 1978, WAAC, a nonprofit organization, has been publishing their

newsletter, which includes articles on a range of topics pertaining to conservation and museums. Back issues are well-indexed and available for free online (WAAC 2012).

### CONCLUSIONS

Ultimately, all preventive care activities center on systems. Preservation work often flounders under a piecemeal approach. Administrations can resist allocating resources for the systematic application of preservation projects, under the erroneous impression that preservation is a passive activity, managed by some occasional housekeeping and inventory. As the conservation community has developed higher standards for preventive care, many institutions struggle with a lack of sufficient staff hires, institutional recognition, or necessary resources. Part of the issue is visibility of preventive care. Traditionally, collection care activities have been considered work that takes place behind the scenes. However, as conservation windows and on-view conservation labs have been developed to educate the public about conservation, some museums have put more routine preventive care activities on display too. Notably, the National Trust in the UK schedules some preventive care activities with a public interaction component. The conservation team at Knole House has started a blog (National Trust 2012), sharing information about their efforts and challenges. Not only does this blog provide an informal exchange of information among professionals, but it also allows the public to see what sorts of preservation challenges museum staff face.

Recently, preventive conservators and collection staff developed a desire to organize around their professional goals and challenges. Within the American Institute for the Conservation of Historic and Artistic Works, the Collection Care Network (CCN) recently formed to promote a preventive approach to preservation and to represent the interests of all collection care practitioners who have long been without a professional organization. The immediate priorities of the CCN are to create a large community of preventive conservation practitioners and the allied professionals (such as architects, engineers, entomologists, lighting designers, and others) to develop preservation strategies, create an exchange for reliable preservation information, and serve as a conduit for like-minded organizations to partner and collaborate on developing preservation best practices. Membership in the CCN is available to all AIC members through the AIC Web site (AIC 2012).

Preventive care requires collaborative efforts. The tenets of effective preventive care rely on the exchange of preservation information between museum professionals and other related professions to create useful collection care tools. In order to be successful, collections stewards must foster the creation of effective preservation systems, applying collection risk assessment, and methodically tracking the impact of application of resources in mitigating risks to collections. Doing so will not only improve preventive care but will create a systematic way to identify and meet preservation challenges and will foster the next generation of preservation resources.

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## APPENDIX

### Assessments

- Protect Heritage: [www.protectheritage.com](http://www.protectheritage.com)
- Heritage Preservation Risk Evaluation and Planning Program: [www.heritagepreservation.org/REPP/](http://www.heritagepreservation.org/REPP/)
- Benchmarks in Collection Care: [www.collectionslink.org.uk](http://www.collectionslink.org.uk)
- Conservation Assessment Program: [www.heritagepreservation.org/cap/index.html](http://www.heritagepreservation.org/cap/index.html)
- Birmingham Museums and Art Galleries Risk Awareness Profiling Tool (RAPT): [www.raptonline.org.uk/welcome.asp](http://www.raptonline.org.uk/welcome.asp)

### Physical Forces

- 3<sup>rd</sup> International Mountmakers Forum held at the Field Museum of Natural History, Chicago, Illinois (click on the Past tab for information on past meetings: [fieldmuseum.org/happening/mountmakers-forum-home](http://fieldmuseum.org/happening/mountmakers-forum-home))
- PACCIN—Preparation, Art Handling, and Collections Care Information Network: [www.paccin.org](http://www.paccin.org)
- Re-org: [www.re-org.info](http://www.re-org.info)
- Rose, C.L. and A.R. de Torres. 1992. *Storage of Natural History Collections: Ideas and Practical Solutions*. Society for the Preservation of Natural History Collections. Society for the Preservation of Natural History Collections, Iowa City, Iowa. 346 pp.



*Fire, Water, Thieves and Vandals a.k.a. Emergency Preparedness*

- AIC-CERT: [www.conservation-us.org/disaster](http://www.conservation-us.org/disaster). For immediate assistance in a collections emergency call (202) 661-8068
- dPlan: [www.dplan.org](http://www.dplan.org)
- Museum SOS: [www.Museum-sos.org](http://www.Museum-sos.org)
- Heritage Emergency National Task Force (HENTF): [www.heritagepreservation.org/programs/taskfer.htm](http://www.heritagepreservation.org/programs/taskfer.htm)
  - HENTF Lessons Applied: [www.heritagepreservation.org/lessons](http://www.heritagepreservation.org/lessons)
  - Alliance for Response: [www.heritagepreservation.org/AfR/index.html](http://www.heritagepreservation.org/AfR/index.html)
  - Field Guide to Emergency Response & Emergency Response and Salvage Wheel: [www.heritagepreservation.org/catalog/product.asp?IntProdID=33](http://www.heritagepreservation.org/catalog/product.asp?IntProdID=33)
- Implementing ICS at the Institutional Level: [www.rescuingrecords.com/ics.html](http://www.rescuingrecords.com/ics.html)
- Federal Emergency Management Agency Incident Command System Resource Center: [training.fema.gov/EMIWeb/IS/ICSResource/index.htm](http://training.fema.gov/EMIWeb/IS/ICSResource/index.htm)

*Pests*

- Integrated Pest Management Working Group: [www.Museumpests.net](http://www.Museumpests.net)
- What's Eating Your Collection: [www.whatseatingyourcollection.com/](http://www.whatseatingyourcollection.com/)
- Insect Pests Found in Historic Houses poster available as a pdf: [www.english-heritage.org.uk/publications/insect-pests-historic-houses-poster/](http://www.english-heritage.org.uk/publications/insect-pests-historic-houses-poster/)
- Pinniger, D. n.d. Pest Management: A Practical Guide: [www.collectionslink.org.uk/discover/pest-management/1149-pest-management-a-practical-guide](http://www.collectionslink.org.uk/discover/pest-management/1149-pest-management-a-practical-guide)

*Pollutants*

- Hatchfield, P. 2007. *Pollutants in the Museum Environment*. Archetype, London, UK. 203 pp.
- National Park Service, Exhibit Conservation Guidelines CD-ROM: <http://www.nps.gov/hfc/products/cons/ex-con-guidelines.htm>
- AIC WIKI: Exhibition Standards & Guidelines and Materials Testing: [www.conservation-wiki.com](http://www.conservation-wiki.com)
- *The National Trust Manual of Housekeeping: The Care of Collections in Historic Houses Open to the Public*. Butterworth-Heinemann, Oxford, UK. 2011.
- Odegaard, N. and A.Sadongei. 2005. *Old Poisons, New Problems: A Museum Resource for Managing Contaminated Cultural Materials*. Altamira Press, Walnut Creek, CA. 160 pp.

*Light*

- CCI's Ten Agents of Deterioration: Light, Ultraviolet and Infrared: [www.cci-icc.gc.ca/caringfor-prendresoindes/articles/10agents/chap08-eng.aspx](http://www.cci-icc.gc.ca/caringfor-prendresoindes/articles/10agents/chap08-eng.aspx)
- CCI's Light Damage Calculator: [www.cci-icc.gc.ca/tools-outils/ldc-cdl/index-eng.aspx](http://www.cci-icc.gc.ca/tools-outils/ldc-cdl/index-eng.aspx)
- Connecting to Collections: "Tour of the Canadian Conservation Institute's Online Light Damage Calculator": [www.connectingtocollections.org/lightcalculatorrecording/](http://www.connectingtocollections.org/lightcalculatorrecording/)
- Connecting to Collections: "Introduction to LED Lighting": [www.connectingtocollections.org/recording-community-webinar-introduction-to-led-lighting/](http://www.connectingtocollections.org/recording-community-webinar-introduction-to-led-lighting/)
- Druzik, J. and S. Michalski. 2011. Guidelines for Selecting Solid-State Lighting for Museums: [www.getty.edu/conservation/our\\_projects/science/lighting/lighting\\_component8.html](http://www.getty.edu/conservation/our_projects/science/lighting/lighting_component8.html)
- AIC Committee for Sustainable Conservation Practice - [www.conservation-us.org/LED](http://www.conservation-us.org/LED)

*Incorrect Temperature and Relative Humidity*

- *ASHRAE Handbook*: <http://www.ashrae.org/resources-publications/bookstore/handbook-online>
- British Standards Institute. Publicly Available Specification 198, *Specification for Managing Environmental Conditions for Cultural Collections* (PAS 198:2012): <http://shop.bsigroup.com/en/ProductDetail/?pid=00000000030219669>

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- The Plus/Minus Dilemma: A Way Forward in Environmental Guidelines, [www.iiconservation.org/sites/default/files/dialogues/plus-minus-en.pdf](http://www.iiconservation.org/sites/default/files/dialogues/plus-minus-en.pdf) (2 April 2013).
- Connecting to Collections Online Community
  - [www.connectingtocollections.org/recording-community-webinar-choosing-the-datalogger-that-is-right-for-you](http://www.connectingtocollections.org/recording-community-webinar-choosing-the-datalogger-that-is-right-for-you)
  - [www.connectingtocollections.org/wirelessdatalogger](http://www.connectingtocollections.org/wirelessdatalogger)
- Image Permanence Institute, eClimateNotebook: [www.eclimatenotebook.com](http://www.eclimatenotebook.com)
- National Park Service Conserve O Gram 3/3: Comparing Temperature and Relative Humidity Dataloggers for Museum Monitoring: <http://www.nps.gov/museum/publications/consveogram/03-03.pdf>

#### *Custodial Neglect and Dissociation*

- Malaro, M. 2012. *A Legal Primer on Managing Museum Collections*. 3<sup>rd</sup> ed. Smithsonian Institution Press, Washington, DC. 508 pp.
- Buck, R. and J.A. Gilmore. 2010. *Museum Registration Methods*. 5<sup>th</sup> ed. The AAM Press, American Association of Museums, Washington, DC. 516 pp.
- Registrar's Committee of the American Association of Museums (RC-AAM): [www.rcaam.org](http://www.rcaam.org)
- Association of Registrars and Collection Specialists (ARCS): [www.Arcsinfo.org](http://www.Arcsinfo.org)

#### *General Resources*

- Heritage Preservation. 2005. A Public Trust at Risk: The Heritage Health Index Report on the State of America's Collections. [www.heritagepreservation.org/hhi](http://www.heritagepreservation.org/hhi)
- Collection Care Network: [www.conservation-us.org/collectioncare](http://www.conservation-us.org/collectioncare)
- Knole House Blog: [knolenationaltrust.wordpress.com](http://knolenationaltrust.wordpress.com)
- Connecting to Collections Online Community: [www.connectingtocollections.org](http://www.connectingtocollections.org)
- National Park Service
  - Conserve O Gram: [www.cr.nps.gov/museum/publications/consveogram/cons\\_toc.html](http://www.cr.nps.gov/museum/publications/consveogram/cons_toc.html)
  - *Museum Handbook*: [www.nps.gov/museum/publications/handbook.html](http://www.nps.gov/museum/publications/handbook.html)
- Canadian Conservation Institute
  - CCI Notes: [www.cci-icc.gc.ca/publications/notes/index-eng.aspx](http://www.cci-icc.gc.ca/publications/notes/index-eng.aspx)
  - Technical Bulletins: [www.cci-icc.gc.ca/publications/orderpub-commanderpub-eng.aspx](http://www.cci-icc.gc.ca/publications/orderpub-commanderpub-eng.aspx)

# THE STATE OF THE ART IN CULTURAL PROPERTY RISK ANALYSIS: REFLECTIONS ON THE LISBON 2011 INTERNATIONAL SYMPOSIUM AND WORKSHOP ON CULTURAL PROPERTY RISK ANALYSIS

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*Abstract.*—This paper reflects upon the state of the art in cultural property risk analysis. It is based upon an overall review of the presentations given at the 2011 International Symposium and Workshop on Cultural Property Risk Analysis. Symposium papers provided a diversity of case studies, method and risk model critiques and developments, and reports of initiatives related to climate control, risk, and sustainability. A risk management maturity model specific to cultural property risk analysis is proposed and used to evaluate the state of the state of the art in cultural property risk analysis as revealed by symposium presentations.

## INTRODUCTION

This paper reflects upon the state of the art in cultural property risk analysis. It is based upon an overall review of the presentations given at the 2011 International Symposium and Workshop on Cultural Property Risk Analysis. This event, organised by the Universidade Nova de Lisboa Faculdade de Ciências e Tecnologia, VICARTE, and Protect Heritage Corporation, was sponsored by the Society for Risk Analysis and in association with the International Council of Museums—Committee for Conservation, and was held in Lisbon 14–16 September 2011.

The first day of the symposium included 33 presentations (Macedo and Waller 2011). It will not be possible to include in this paper much content from each symposium presentation. I extend my apologies to authors for my concise referrals to their work. Their presentations, taken together, provide a good overview of the situation regarding practical case studies, risk assessment method and model development, issues of preservation and sustainability, and issues of management and training. In this paper, a risk management maturity model specific to cultural property risk analysis is proposed. This model is used to place symposium papers in context of an overall evaluation of the state of the art in cultural property risk analysis.

## RISK MATURITY MODEL

The field of risk management is increasingly employing a risk maturity model to describe the degree to which risk thinking is integrated into an organization. This model is used here as a general structure for evaluating the state of the art from three perspectives: the heritage preserving institution as an enterprise, the collection care function within that institution, and the conservation field as a whole. The last perspective is given as that of the conservation field because that is the collection care subfield which has been most involved in risk management in recent years.

Risk maturity models characterize within five (or four) steps the capability of an organization to apply and benefit from a risk management process (Table 1). These models are adapted from and have evolved from the Capability Maturity Model for Software developed by Software Engineering Institute Carnegie Mellon University (Paulk et al. 1993). Of the five examples given in Table 1, the levels and definitions of Marks (2011) seem most suited to the purposes of this review.

Table 1. Examples of level titles given in Carnegie Mellon University's original Capability Maturity Model and several risk maturity models.<sup>a</sup>

Level	Capability maturity model	HM Treasury	Project risk maturity model	Aon ERM maturity model	Marks 2011
1	Initial	Awareness and understanding	Naïve	Initial/Lacking	Ad hoc
2	Repeatable	Implementation planned and in progress	Novice	Basic	Preliminary
3	Defined	Implementation in all key areas	Normalised	Defined	Defined
4	Managed	Embedding and improving	Natural	Operational	Integrated
5	Optimizing	Excellent capability established		Advanced	Optimized
	Paulk et al. 1993	HM Treasury 2009	Hopkinson 2010	Aon 2012	Marks 2011

<sup>a</sup> Abbreviations: HM, Her Majesty's; ERM, enterprise risk management.

Mark's (2011) definitions of the five levels are given in Table 2. Level 1 is the starting point for any organization beginning to address risk assessment and management. Presently, Level 5 is aspirational for virtually all organizations.

Interpretations of these and intermediate levels for the three perspectives being considered are given in Table 3. The majority of effort in cultural property risk assessment and management is currently within levels 1–3.

Higher levels in the risk maturity model involve more coherent approaches throughout an organization, but are not intrinsically better for all purposes. Some problems requiring a risk assessment solution are of a scale, or have time constraints, that demand an ad hoc approach. Many conservation challenges require timely responses to issues of limited scale and these might require a level 1 approach. Just as important as the development of sophisticated, integrated, and optimized risk assessment models and processes is the exploration and learning about diverse level 1, ad hoc, approaches. Fortunately, the symposium provided us with a rich diversity of level 1, 2, and 3 approaches to cultural property risk assessment. Most presentations took the form either of case studies or method/model development papers. In reality, however, practically all case studies involved some method development and in turn, the method/model development papers included some information from actual cases. Still, papers 14–16 that were primarily case studies will be described first, followed by papers that primarily addressed method and/or risk model development.

Table 2. Risk Maturity Model level definitions (Marks 2011).

Level	Name	Description
1	Ad hoc	Undocumented; in a state of dynamic change; depends on individual heroics.
2	Preliminary	Risk defined in different ways and managed in silos. Process discipline is unlikely to be rigorous.
3	Defined	A common risk assessment/response framework is in place. Organization-wide view of risk is provided to executive leadership. Action plans implemented in response to high priority risks.
4	Integrated	Risk management activities coordinated across business areas. Common risk management tools and processes used where appropriate, with enterprise-wide risk monitoring, measurement, and reporting. Alternative responses analyzed with scenario planning. Process metrics in place.
5	Optimized	Risk discussion is embedded in strategic planning, capital allocation, and other processes, and in daily decision-making. Early-warning system to notify board and management to risks above established thresholds.

Table 3. Risk Maturity Model for cultural property protection: descriptions for five levels from three system perspectives.

Name	Perspective		
	Heritage-preserving institution	Collection care function	Conservation field
1. Ad hoc	Singular efforts to consider risks in simple, isolated situations.	Singular efforts to consider isolated risks to objects or parts of collections.	Informal risk-based analysis conducted to address a specific issue.
2. Preliminary	Risk assessments are occasionally made in response to external demands (i.e., audit, insurance).	Assessments done primarily in response to external demands (i.e., loans, facility project).	Some effort made to link evidence and research with preservation predictions.
3. Defined	An enterprise risk management process is in place.	A comprehensive assessment of risks to collections completed and used to set preservation management priorities.	Conservation assessments are based on risk predictions and research is expected to provide information to support risk assessment.
4. Integrated	Coordinated risk management processes, scenario planning engages all parts of the institution and incorporates risk to cultural property.	Risk assessment model communicates effectively with other collection management systems (use, development) and other functions (i.e., facility management, fundraising).	Conservation field effectively communicates with political and technical fields regarding quantitative risks (i.e., emergency preparedness organizations, material scientists).
5. Optimized	Risk management is embedded in all policy and planning processes and effectively communicated to the board level.	Risk management is embedded in all collection-related processes and activities and seamlessly integrated with all related institutional systems.	All relevant political and technical fields maintain an awareness of risks to cultural property and instinctively communicate and coordinate with conservation about emerging concerns.

## CASE STUDIES

A fine example of a level 1 approach presented at the symposium was the work of Jennifer Teper (2011) on planning for disaster recovery in high-density, high-bay library storage. In this work, risk modeling was applied to understand expected distribution of water damage in the event of a fire suppressed by a water sprinkler in a high-bay library storage facility. This kind of risk modeling allows conservators and others involved in emergency response to virtually experience a unique emergency situation and learn from that virtual experience.

Several case studies provided examples of risk assessments that could be seen as either level 1 or 2; that is, ad hoc, preliminary, or intermediate between those levels. Verberne-Khurshid (2011), Antunes (2013), Bernath (2013), and Neykova (2013) all provided good examples of this kind of assessment. Bernath demonstrated how identification and simple scoring of a few major risks could provide sufficient supporting documentation for a risk mitigation project already being planned. Neykova described how a ranking of the relative importance of agents of deterioration (Canadian Conservation Institute 2009) could be used to galvanize and motivate staff to achieve substantial improvements to an exhibit hall. Verberne-Khurshid described the use of a risk management framework to facilitate planning and oversight of a major collection move project. Antunes presented a

risk level assessment of buildings at risk in a seaside architecture setting. Due to the importance of current building condition for assuring the resistance of buildings to weathering, in this case, current condition could be used to a large extent as a predictor of future risk.

Pinheiro et al. (2013) provided a 5-year update on a risk analysis in a Portuguese archive, which was at an intermediate level between the preliminary (2) and defined (3) levels. Risks were systematically, although possibly not comprehensively, identified and quantified. Case studies such as this, which repeat an assessment, and retrospectively consider the validity of the first assessment, are especially valuable to the conservation field as a whole because it endeavors to develop its ability to formulate and support risk assessment processes at levels 2, 3, and 4. Lee and Castles (2013) provide another case study of a collection risk assessment at the Royal British Columbia Museum repeated after 5 years. This assessment, together with those of Southward et al. (2013) and Elkin et al. (2013), being both systematic and comprehensive, are at a level 3 with respect to the collection care function. Due to institutional or conservation field constraints, they may, however, only achieve level 2 from the institution and field perspectives (see Table 3 for relevant level descriptions).

#### METHOD DEVELOPMENT

Taking the view that the best way to achieve institutional investment in collection preservation is in a university library setting, Ogden (2012) proposed direct integration of the collection risk assessment with the university's enterprise risk management (ERM) system. This has the advantage of automatically merging collection preservation priorities with university-wide priorities. It will face challenges, such as ensuring that the granularity of risk identification (how finely risks are subdivided) is both fine enough to give meaningful assessment of preservation issues and coarse enough that identified risks rank within the range of other institutional risks. It is clearly a level 3 initiative from the perspective of the heritage-preserving institution and intends to strive to be level 3 from the perspectives of both the collection care function and the conservation field. Collins et al. (2011) described the (UK) Natural History Museum's Collections Standards Project. This project takes a benchmarking approach to evaluating the degree and quality of implementation of a large variety of collection management practices. This characterization of the state of collection management could contribute to modeling risk to collections. It is very broad in reach, and consequently, for now is limited to being a level 2 (preliminary) from all three perspectives.

Karsten et al. (2011) discussed adaptation of their risk-reduction recommendations scoring system to incorporate cost effectiveness of proposed risk reduction measures. In another example of risk assessment method development, Brokerhof et al. (2011) discussed the application of risk assessment to a contemporary art installation. In this situation, very diverse senses of value together with consideration of maintenance activities that included routine replacement of parts had to be considered. An alternative to estimating loss in value due to hypothetical changes in state brought on by exposure, Leijonhufvud and Broström (2011) investigated estimating risk by considering restoration costs for treating climate-induced damage. Paupério et al. (2011) sought to establish improved risk quantification for catastrophic hazards by adapting building engineering risk assessment models to both heritage buildings and their contents. That work is of great importance both for informing heritage property risk assessment and for establishing links between the fields of building engineering and moveable heritage

preservation. Chien et al. (2012) and Gonçalves and Esquetim (2011) also developed heritage risk management approaches founded on building- and risk-engineering approaches.

Although most of the papers at the symposium adopted a deliberative, forward-planning approach to risk assessment and management, Frame (2013) discussed the requirement for pragmatic and adaptive assessment and management of risks at the Historic Royal Palaces. The five royal palaces are major heritage attractions attracting over 3.8 million visitors annually. Experiential visitor programs are planned rapidly and dynamically. Consequently, deliberative advance planning is limited to the setting of key performance indicators. Risk management in this situation requires many real-time, pragmatic decisions. In this situation, the best overall result is achieved by empowering front-line staff to make on-the-spot risk management decisions without being unduly constrained by detailed advanced plans. Similarly, Hawks and Waller (2013) encouraged linking, at the working level, the collection preservation and health and safety systems to achieve benefits of synergy with little or no added cost.

Spawning diverse approaches to cultural property risk analysis is highly desirable at this early stage in the development of models and methods (Harford 2011).

#### RISK MODEL DEVELOPMENT

Several papers addressed issues of comprehensiveness and correctness of any risk model. Taylor (2012) discussed the problems that can arise when a simplistic scheme of identifying risks with agents of deterioration is employed. He showed how a single event categorized within one agent of deterioration can cause damage to a collection that could be attributed to a variety of agents, as well as how several agents can work synergistically to cause a single form of damage. An example of the former is an earthquake leading to not just physical damage but also to fire, water damage, looting, and so on. An example of the latter is the combined effect of pollutants with elevated temperature and relative humidity levels leading to corrosion of sensitive objects. Ashrafi (2011) presented an argument for including risk to intangible values as well as to the physical integrity of heritage property. Along similar lines, Espinosa (2011) discussed social, political, and economic factors contributing to risk to the cultural heritage of the Huichol indigenous people of Mexico. Bullock (2012) addressed the issue of value quantification in general. She highlighted the difficulty in marrying the free, expansive style necessary for capturing a full sense of significance with the need for clear, succinct value concepts required for quantitative expressions of changes in value.

Linden and Smith (2011) described progress made by the Image Permanence Institute in relating measured levels of temperature and relative humidity in collections to risk of damage (e.g., mold risk factor) and deterioration (e.g., time-weighted preservation index for chemical decay). These are important steps in building a quantitative risk model. An excellent example of more detailed technical risk modeling was provided by Di Pietro et al. (2011) to describe how pollutants and interrelated factors contribute to eventual physical damage in libraries and archives. The exhaustive evaluation of research requirements regarding material interactions with pollutant, temperature, and relative humidity levels by Thickett and Lankester (2012) represents an important contribution to our understanding of how to include those risks within our overall risk model. Improving the comprehensiveness, quality, and clarity of our risk models is essential for moving the risk maturity of the conservation field from level 2 (preliminary) to level 3 (defined).



### CLIMATE CONTROL, RISK, AND SUSTAINABILITY

Apart from the case studies and method/model development papers described above, several papers dealt with the issue of climate control, risk, and sustainability, with particular focus on temperature and relative humidity levels and variations. All of the presentations on this topic contribute to building level 3 capacity in the conservation field. Bell (2011), from the perspective of recent efforts to develop the British Standards Publicly Available Specification 198 (PAS 198; British Standards Institution 2012), discussed the overall availability of, and current efforts towards establishing, research results sufficient to support the collection risk consequences of environmental specifications. Thickett and Lankester (2012) provided an exemplar review of knowledge gaps in our understanding of the effects on archaeological materials of pollutants, temperature, and relative humidity levels, and variations of these three factors. He was able to use a risk assessment perspective, combined with a thorough literature review to establish clear priorities for conservation research needed to predict the behaviour of archaeological collections as a consequence of their environment.

Linden et al. (2012) described research being conducted by the Image Permanence Institute (IPI) and its partners to evaluate the possibility of libraries reducing operating costs through scheduled shutdowns of heating, ventilating, and air-conditioning systems. Although some cost implications are given, the paper concentrates on identification and mitigation of risks associated with the shutdown procedure. In particular, it emphasizes the importance of systematic, step-wise screening to determine whether mechanical system shutdowns could first be considered, then be tried in a carefully monitored experimental fashion. Lev-Alexander (2012) described the experience of the Library of Congress in working with IPI on a program of experimental mechanical system shutdowns. The experimental program is seen to be at once complex, achievable, and promising.

Cultural property risk analysis is not, and never will be, an exact science. It must account for individual and collective human preferences to avoid one kind of damage or loss over another kind of damage or loss. Further, many players, often from diverse backgrounds, should be involved in risk assessment, and even more so in risk management. Deciding upon appropriate climate specifications to best balance preservation, building situation, costs (including opportunity costs), and commitments to sustainability, involves a complex communication challenge. Ankersmit (2011) provides a guide through this challenge in his recent publication *Klimaatwerk* (Ankersmit 2009).

### CONCLUSIONS

The presentations that comprised the 2011 International Symposium and Workshop on Cultural Property Risk Analysis reflect considerable diversity among topics, approaches, and presenters' professional backgrounds. In addition, initiatives at each of the first three levels of risk maturity further reflect a healthy and appropriate diversity of effort. Still, all presentations were unified by a common goal: to reduce the risks of damage and loss to cultural property. This ability to organize and unify our preservation and preservation research efforts is a great benefit of adopting a risk assessment and management approach.

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# RESEARCH ON ENERGY SAVINGS IN COLLECTIONS ENVIRONMENTS: A CASE STUDY OF YALE UNIVERSITY'S STERLING MEMORIAL LIBRARY

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*Abstract.*—The specific research question investigated in this project is whether institutional sustainability efforts, specifically the reduction of energy usage in collections storage environments, can be aided by carefully monitored and risk-managed shutdowns of air handling units (AHUs) without compromising the quality of the preservation environment. This paper is a case study of the methodologies and promising early results of the investigation that concentrates on, but is not limited to, Yale University's Sterling Memorial Library (SML), one of the research partners for the project. Subsidiary research questions include the identification and selection of the candidate research space, the tools needed to measure energy use and the effects of environmental changes on collections preservation, and the procedures and processes for collaboration among facilities and library/preservation staff. The paper also discusses lessons learned in the research process, unexpected findings, and the potential impact in cost savings of these practices.

This 4-year experiment is funded in the United States by the Institute for Museum and Library Services (IMLS), and conducted by the Image Permanence Institute (IPI) at the Rochester Institute of Technology, in Rochester, NY, and their partner Peter Herzog, principal of Herzog/Wheeler & Associates, a Minnesota-based energy consulting firm.

## INTRODUCTION

Strategic shutdowns of air handling units (AHUs) during unoccupied hours have long been recognized as a viable option for achieving energy savings in buildings managed primarily for human comfort. However, the specific requirements of collections preservation environments have made such strategies difficult to enact in cultural institutions. Research has shown that environmental conditions, in particular temperature and relative humidity, are the most significant factors not related to handling and use that impact the lifespan of collections materials held by cultural institutions. Mechanical systems designed to create and control these conditions typically run constantly, providing a steady volume of conditioned air to a particular storage area, in order to maintain the specified environment; and the energy required for that operation is often disregarded. The possibility of altering those environmental conditions in the name of energy savings has traditionally been a risk that collections managers, preservation professionals, and conservators have been hesitant to take.

The Image Permanence Institute (IPI), a nonprofit research laboratory based at the Rochester Institute of Technology, in Rochester, New York, is currently in the third year of a 4-year research project on AHU shutdowns in collections environments, which is funded by the Institute of Museum and Library Services (IMLS). Yale University's Sterling Memorial Library (SML), in New Haven, Connecticut, is one of five test sites being studied by IPI and its energy-consultant partner, Herzog/Wheeler & Associates, LLP. Other partners and test sites for this research include the Library Annex at Cornell University in Ithaca, NY, the main stacks at the Birmingham, Alabama, Public Library, the Bryant Park Stack Extension at the New York Public Library (NYPL), and the Southern Regional Library Facility and Young Research Library at the University of

California, Los Angeles (UCLA). Although this current research takes place in library collections, the methodology and findings have potential application in any cultural institution with the mandate to preserve cultural, scientific, or historic materials in a sustainable manner.

This article will discuss the methodology and current findings of the project, with specific attention paid to SML. A talk related to this article was originally given at the 27th Annual Meeting of the Society for the Preservation of Natural History Collections held at Yale University, New Haven, Connecticut. SML was chosen as the case study both because of its association with the host institution as well as for the evidential value of the project's experience there. Specifically, the purpose of the project is to test the hypothesis that energy usage in cultural institutions can be significantly reduced through carefully monitored and risk-managed shutdowns of AHUs without compromising the quality of the preservation environment. To lessen the impact on human comfort, the aim was to conduct the experiment during unoccupied hours in selected spaces.

#### DEFINING THE NEEDS

The end goal of this research is to determine the viability, in terms of energy and preservation, of altering mechanical system operation in order to save energy in collections environments, as well as to define a methodology by which individual institutions can test the impact of shutdowns on preservation environments. The first step is to define what the experiment is trying to achieve and why, and what potential risk that change poses. As a basis for comparison, information is needed on the current state of the preservation environment, the typical operation of the mechanical system, and the amount of energy the system uses to create the environment.

The potential for saving energy in collections environments has a natural correlation with the broader "sustainability" needs of modern cultural institutions. Shutdowns have the potential to fit seamlessly with "green" efforts to reduce an institution's carbon footprint or reduce dependency on fossil fuels—turning off an AHU is the most effective way to save the energy that it uses. However, the need for sustainable efforts in maintaining collections preservation environments goes far beyond the contemporary desire to become greener. Cultural institutions in general are faced with increasing energy costs and shrinking budgets; maintaining preservation environments while disregarding the energy used to create them, particularly when it is fossil-fuel based, is both irresponsible and infeasible. The sustainable solution—a method of mechanical systems operation that can be reasonably continued until better strategies or options are found, of which system shutdowns can be a part—has to be found, while weighing the simultaneous needs of collections preservation and reduced energy expenditure.

#### *Preservation*

For the purposes of this research, the preservation environment is defined as the temperature and relative humidity of the collections storage space that is a candidate for an AHU shutdown, measured and analyzed over time. As determining factors in two types of collections decay/degradation that are most significant to the experiment, namely the chemical deterioration and mechanical shape change of objects, the alteration of temperature and relative humidity through a shutdown (or any other operational change to an AHU) has the potential to decrease the preservation quality of the environment.

Whereas other environmental factors, such as light exposure and pollutants, contribute to the overall quality of the preservation environment on a macro-level, their impact on

collections is not significantly affected or altered by a system shutdown. Lighting in spaces is typically controlled separately from AHU operation, and the shutdown does not directly influence when the lights are turned on or off, or the amount of light exposure collections materials might receive. However, when lighting is turned on, it can contribute to the heat load and mechanical system operation in the given area. Each light bulb in a space, whether incandescent or fluorescent, is rated in watts, or energy consumed, and gives off a certain amount of heat energy in BTUs (British Thermal Units). In a cooling season, the mechanical system must then use more energy to remove the heat generated by the lighting. Essentially, lighting is often paid for twice – in the electrical energy to power the light, and in the cooling needed to remove the heat. Filtration of pollutants introduced from the outdoor environment is, in many regards, aided by system shutdowns. The majority of outdoor pollutants in a preservation environment are introduced from the outdoor environment through the outside air intake on the AHU. Shutting the system down reduces the quantity of outdoor pollutants that must be removed.

To protect against chemical deterioration and mechanical decay, traditional environmental guidelines for the preservation of cultural materials call for conditions at 21°C (70°F) and 50% relative humidity (RH), with minimal fluctuation. However, research in the past 15 years has shown that cooler temperatures and lower relative humidity slow the rate of chemical deterioration (Sebera 1994, Reilly et al. 1995), and that many materials can experience elastic shape change in RHs fluctuating between 30% and 60% without suffering permanent mechanical decay (Ehrhardt et al. 1995; Mecklenburg 1999, 2007). These advances in understanding have influenced changes in standards and expectations—such as the National Archives and Records Administration’s Directive 1571, which now calls for paper storage at a maximum temperature of 18°C (65°F) and effective RHs between 30% and 50%—and recent discussions surrounding environmental conditions and museum loans at the 2010 Rethinking the Museum Climate roundtable held at the Museum of Fine Arts, Boston, Massachusetts (AIC 2010).

Using temperature and relative humidity data gathered from a space, it is possible, using IPI’s Preservation Metrics™, to quantitatively assess the quality of the preservation environment for both chemical and mechanical decay. The preservation index (PI) metric uses a set of temperature and relative humidity values at a given point in time and evaluates their effect on the chemical decay rate. The time-weighted preservation index (TWPI) integrates temperature and relative humidity values over time into an estimate of the cumulative effects of the environment on chemical decay. In both cases, the lower the number is, the faster the rate of chemical decay; the higher the number is, the slower the rate of decay and the better the environment. The percent dimensional change (%DC) metric indicates the amount of physical shape change that an object is likely to undergo based on its maximum and minimum equilibrium moisture content over time. Generally speaking, the cooler the temperature (while maintaining a moderate range of relative humidity), the slower the rate of chemical decay will be. Likewise, that moderate range of relative humidity will be beneficial to minimal dimensional change or mechanical decay because the object never experiences very dry or very damp conditions.

The need, in terms of experimentation with shutdowns, is to establish baseline rates of chemical and mechanical decay with no shutdowns in place to allow comparison with those figures when shutdown patterns are introduced. The Yale University Library Preservation Department has been monitoring the preservation environment in the SML

storage area, a tower consisting of 14 floors of book stacks, for the past 7 years. These historical data provide the necessary baseline to understand the normal preservation environment. During that time the temperature in SML has remained steadily between 18°C (65°F) and 20°C (69°F) year round, with an average of 19°C (67°F). The relative humidity fluctuates seasonally between approximately 30% during the dry winter months and 60% in the summer months. The result is an environment with a TWPI of 51 to 54 between 2005 and fall 2010 (result varies by floor). The working assumption of the experiment is that temperature and relative humidity set points for candidate spaces have been chosen to match the institution's desired or achievable level of preservation given the use of the space and the capability of the mechanical system. The goal, therefore, is not to alter mechanical system operation to improve preservation, but to improve energy savings without reducing the preservation quality of the environment.

### *Energy Savings*

Institutional goals for energy savings and quantifiable sustainability measures are not unusual in today's landscape, and sustainability activities within cultural institutions are not difficult to find. However, as time progresses, and energy costs rise, institutional mandates for energy savings and carbon neutrality have had a greater impact on actual environmental conditions and mechanical equipment operation within collections spaces. It is not uncommon to find some variation of a "set back" (typically a change in set point on nights or weekends) or a system shutdown already in place in a storage environment, sometimes taking the needs of the preservation environment into account, and sometimes not.

The past two decades have seen significant changes in the way institutions care for collections when it comes to environmental conditions. Flat-line control of temperature and relative humidity conditions, gas-phase filtration, and upgrades to ultra-modern mechanical systems have all been sought after as "best practice" for collections preservation. Some of the leading guidelines recommend constant air volume, continuously-running systems to maintain temperature and relative humidity conditions in collections areas where preservation is a priority (Wilsted 2007, ASHRAE 2011), often without regard to energy consumption aside from using more energy-efficient equipment when possible. Collections managers, preservation professionals, and conservators have worked for decades to achieve "appropriate" preservation environments; unfortunately these environments are also often among the most costly to produce.

In an age of increasing energy costs and decreasing budgets, this model is no longer sustainable. One example, given at the Rethinking the Museum Climate meeting held at the Museum of Fine Arts in Boston, Massachusetts in 2010 (AIC 2010), compared one institution's total operating budget and utility costs in 1999 and 2009 to several projected possibilities in 2019. In 1999, utility costs comprised 1.3% of the total budget; in 2009, they were 3%. The future projection was for a 33% decrease in total budget from the 1999 figure, with an optimistic projection of utility costs at 7.3% of that total budget in 2019. Another model (dependent upon crude oil prices) placed the potential utility costs as high as 28% of that decreased budget (Rogers 2010). Although this particular example was for a large museum, the trends hold across all cultural institutions; in another example, the per-unit steam price for heating paid by a library in Washington, DC has risen by approximately 500% since 1989.

### *The Goal*

The implication of these competing priorities is clear: cultural heritage organizations must work toward reconciling preservation needs with the cost of energy used to create

collections preservation environments. The idea of an “optimal preservation environment,” or one that achieves the best possible preservation of collections, with the least possible consumption of energy, and is sustainable over time, is the new goal. Any number of strategies can have bearing on the definition of what “optimal” might be in any particular institution, from altered preservation conditions, to optimized system operation, to more energy-efficient heating, ventilation, and air conditioning (HVAC) equipment. This experiment tests one of those strategies: the feasibility of shutting down mechanical systems, in this case the library storage in the SML tower, without harming the preservation environment.

#### METHODOLOGY: CANDIDATE SPACE SELECTION

Gathering data on the viability of mechanical system shutdowns as energy-saving strategies in collections storage areas with sensitive temperature and relative humidity needs requires a sample set that is not only manageable in scope, but also representative of the various climatic conditions and types of building construction found throughout the United States. Project parameters meant that IPI and Herzog/Wheeler were restricted to selecting no more than five partners from a group of volunteer institutions. The final selection criteria included:

- Geographic location;
- Institution type;
- Storage model—traditional stacks, high-density modules, individual rooms;
- “Interior” and “exterior” wall and roof exposure;
- Single or multiple identifiable air handlers serving the space;
- HVAC zone dedicated to collections storage; and
- Level of human occupation during the day.

These factors provide a variety of starting conditions and a range of challenges to the successful implementation of a preservation risk-managed shutdown. SML is located in New Haven, Connecticut, on the New England coast in the United States. The seasonal outdoor climate presents dual challenges to maintaining the preservation environment: hot, moist summers consisting of temperatures reaching above 32°C (90°F) and dew points that can peak above 21°C (70°F) place a burden on the AHU’s ability to dehumidify and cool effectively, whereas cold, dry winters with below-freezing temperatures and low moisture content require heating and humidification. These outdoor conditions are the primary influence on the indoor environment through two separate avenues. Fresh air, taken in by mechanical systems in order to meet human health requirements, drives the moisture content of collections environments, necessitating moisture control, and likewise requiring heating or cooling to maintain the stacks’ temperature set point. In addition, heat gain and loss through the exterior building envelope create an indoor “load” that mechanical systems are designed to correct.

Completed in 1931, the SML tower was designed to house 3.5 million volumes of general collections, and is comprised of 16 levels of mixed-use space, with the majority being publicly-accessible collections storage (Fig. 1). Roughly every-other level of collection storage is open to another on the perimeter, creating, in effect, a series of large spaces several levels high, as opposed to a series of individual enclosed floors. Approximately 75% of the collections storage area is exposed to an exterior wall or roof, with the majority being a combination of granite, brick, and terra cotta construction, and with many of the original exterior windows having been replaced





Figure 1. Yale University's Sterling Memorial Library includes 14 stack levels served by six different air-handling units. The shutdown experiment involves turning off all six units for 8 hours each night.

with new, better-insulating frames and glazing. The upper floors of the structure have a history of seasonal moisture transfer through the envelope, leading to problems of efflorescence on the interior brick and plaster walls.

These factors begin to define the degree of potential “risk” to the collections space and building structure from shutdowns. Older, relatively uninsulated buildings, with a large proportion of collections storage area exposed to exterior surfaces, could be more susceptible to temperature fluctuation when AHUs are turned off, with the primary concerns being heat gain in the summertime and heat loss in the winter. There is also the possibility of an internal gain or loss in moisture content during shutdown, either due to internal moisture sources or negative pressure within a space during shutdown, which can further aggravate the efflorescence problem. Conversely, spaces with little to no exterior wall exposure, or spaces surrounded by other conditioned spaces, are less likely to be influenced by outdoor conditions. The realization that such buildings are often among the most intense energy consumers, particularly when they are controlled to relatively



narrow bands of temperature and relative humidity, serves as a counterpoint to the potential risk, and makes the testing of system shutdowns an important exercise.

The layout of library storage, the location of storage within a building, and the actual space utilization all have an impact on the creation and maintenance of the particular environmental condition, and, in turn, on the reaction to a shutdown experiment. Large, traditional library stack structures such as those at Yale and Birmingham Public Library often have a much smaller volume of collections compared to air volume in the space than do purpose-built high-density storage areas, such as the spaces at Cornell and UCLA. In high-density storage areas there is a greater possibility that the collection, once at equilibrium, could exert some influence by serving as a heat sink and moisture buffer during mechanical system shutdowns.

Typical preservation environments created for publicly accessible general collections storage, such as at SML, are often maintained at temperature and relative humidity set points that are closer to human comfort levels than storage facilities meant to only house collections, such as those at NYPL, Cornell, and UCLA. This factor greatly influences the design and operation of the mechanical systems that serve the collections storage area, especially concerning their ability to control moisture. Dew point, or the temperature at which a particular volume of air, containing a specific amount of water, becomes saturated, is often used as a way of expressing the level of moisture control that is possible. The ability of a mechanical system to either lower the dew point of air moved through it (dehumidify) or to increase the dew point of the air (humidify), serves as a key indicator of the purpose of its original design—human comfort or collections preservation—in this context. The SML storage is both an example of, and an exception to, that “rule”: the temperature set point of 20°C (69°F) is typical of a human comfort environment, but moisture control, from the maintenance of a roughly 9°C (48°F) dew point through their summer months to the ability to humidify in winter to a minimum RH of 30% or higher, is far better than typical human comfort conditions, which often do no better than a 11°C (52°F) dew point in summer and might not have any humidifying capability at all.

One of the requirements for the research partner sites was that each test space be served by one or more identifiable AHUs. Although most of the test spaces for the study are served by a single AHU that operates alone to create the specified preservation environment, there is a series of six separate air handlers that create the preservation environment in the SML tower, serving both collections storage areas and several associated spaces. In addition to the air-handlers, a perimeter hot water heating system serves the exterior of the space in colder months, protecting against condensation on exterior surfaces and contributing to the overall heating of the space. In the interest of controlling the variables that could affect the feasibility of the shutdowns, the initial goal was to conduct the experiment on AHUs that served easily definable zones (the physical area for which the unit creates the environment) dedicated to collections storage. Mixed-use zones, which include both collections storage and office space or other public areas, were avoided as much as possible in order to remove the influence of human comfort concerns from the experiment in the event that systems were unable to quickly recover from temperature fluctuation due to the shutdown. Ultimately, two spaces, SML and the Birmingham Public Library stacks, were selected that were open to the public. The project team estimated the timing of peak human activity in each test space and sought to schedule shutdowns during low-activity periods, typically at night.

The six systems and their zoning in the SML tower present a particular challenge to the study due to the arrangement of the zones. A common arrangement in a situation such as

this might be to have a single unit serve a predictable section of the space—perhaps two entire levels, or a vertical section throughout the tower. In the case of the SML, the six units, due to their placement on the roof and in the basement, and their different airflow capacities, serve an unpredictable, although documentable, portion of the tower. Four of the units (R-1 through R-4), each providing a different cubic feet per minute (CFM) airflow capacity to the space, are located in a penthouse on the roof, and two larger units (SB-1 and SB-2) are located in the subbasement of the building. With the exception of the two lowest levels, which are served exclusively by SB-2, every level of the stacks is served by at least two of the AHUs, with the top eight levels receiving a blend of air from four different AHUs. Although the various zones that each AHU serves are definable by the temperature and relative humidity sensors on each level, the reality is that the environment is controlled as one large space. The averaged readings from each unit's sensors drive the supply air conditions from that individual AHU, resulting in a series of “blended” areas where zones meet.

#### METHODOLOGY: DATA COLLECTION

Successful analysis of the ability to use system shutdowns to save energy without negatively affecting preservation quality requires the availability of measured temperature and relative humidity data from both the collections storage area and the mechanical system. The goal of data collection within the space is to gather baseline information about the preservation environment. This allows for a quantitative comparison of existing conditions, without shutdowns, to new conditions that include the system shutdown schedule. The Preservation Department's history of environmental monitoring meant that there were already dataloggers present in some portions of the collections spaces. In order to gain a balanced view of how the six AHUs interacted with one another, and whether there was any variation in environmental conditions in each zone throughout a level, IPI and Herzog/Wheeler deployed an additional 26 PEM2® dataloggers throughout the SML tower and in the adjoining Music Library, which AHU SB-1 also serves. Beyond the possibility of temperature or RH variation on each floor, there is also the potential for significant vertical stratification throughout the SML tower, both from natural heat rise as well as from differences in exterior exposure (the lower stack levels are surrounded by other conditioned spaces). Once those data are available, IPI's Preservation Metrics™ are used to quantify the preservation quality in terms of chemical and mechanical decay of each storage space. Analysis of these collected data also identifies how quickly conditions within the space change when conditioned air is not constantly provided, whether or not a previously unidentified source of heat or moisture exists in the storage area, or whether the collection itself might be exerting any control over temperature and relative humidity—a possibility to consider when all others have been examined.

Calculations of the impact of shutdowns on energy consumption are based on data typically logged at five points within an AHU, depending on system type. The systems in the SML tower are all configured in an arrangement known as “subcool and reheat,” where, for purposes of dehumidification, the cooling coil comes before the heating coil in the airstream so as to subcool the air to the desired dew point before reheating it back to the desired supply air condition. In these systems, dataloggers are typically placed in the outside air intake; the return air from the space; the mixed, outside, and return air streams; the cooled and/or dehumidified air; and the heated/reheated supply air. The humidifiers on the systems in the SML tower are located in the mixed air chamber, ahead

of the filters. The difference in the RH of the mixed air and cooled air during winter operation showed whether or not the humidifiers were operating. These datasets are compared to one another to determine the amount of work done by each component within the AHU, allowing for the calculation of energy saved by not running the heating or cooling coils during the shutdown period.

In addition to strict temperature and relative humidity collection within the unit, the amperage used at the supply fans of each AHU in the SML tower is logged in order to measure the rate of energy consumption by these devices. A current transducer (CT), which is attached to an amperage logger, was secured to one leg of the three-phase electrical supply, typically after the emergency disconnect and before the variable frequency drive (VFD) and the fan motor. This positioning allows for two processes to be monitored: the energy consumption of the unit, controlled by the VFD (which controls the speed of the motor), and the confirmation of the actual shutdown of the equipment according to the designated schedule. A unit that is shut down should register no electrical energy draw.

In addition to IPI's PEM2 dataloggers, space monitoring in the SML tower is also accomplished with the original PEM<sup>®</sup>. Logging in the mechanical systems is primarily done with the PEM2, whereas Onset's HOBO<sup>®</sup> loggers are used to collect electrical data and ACR<sup>™</sup> loggers are used in condensing environments.

#### METHODOLOGY: EXPERIMENT DESIGN

IPI worked with the research partner team at Yale to develop the experimental shutdown schedule for the SML tower. The actual shutdown design at each research partner site considered several factors:

- The need to limit the number of variables;
- Recognition of the general trends of outdoor conditions;
- Respect for human comfort requirements in the space;
- The need for accurate comparative data;
- A desire to achieve meaningful energy savings; and, most importantly, the protection of collections from any undue risk.

As a result, IPI and Herzog/Wheeler settled on a number of guidelines for experimentation that was relatively constant for all research partners. At each location the project teams gathered 3 to 6 months of baseline environmental data from both the storage space and the AHU. In the case of the SML tower, the experiment was fortunate to have the previous 5 years of space data from the Preservation Department; this, combined with the additional 6 months of baseline data gathered at the new logging points throughout the space, provided "as-is" operational data for initial analysis and later comparison. Initial analysis of these space data and the control system showed that the current and historic conditions in the space were not so harmful as to make the shutdown experiment an undue risk to preservation, and that the AHUs' normal operation was controllable, with no indication that a shutdown would adversely affect that ability to control that operation. If the quality of the preservation environment had been too poor at the outset, or if the system was not controllable, the data review would have required us to cancel the experiment at SML and seek a replacement partner.

The SML baseline data actually included preexisting systems shutdowns that had been put in place several years before in the interest of energy savings. Two of the rooftop units, R-2 and R-4, which primarily serve the core of the tower, were alternately shut

down for several days at a time. Although the Preservation staff knew that there was a shutdown in place, they were unaware of the actual units and schedules, and had never noticed a corresponding trend in the preservation environment. These alternating shutdowns were discontinued for the final portion of the baseline data-gathering period and for the entirety of the experimental data-gathering period.

Once baseline data were collected and reviewed, IPI and Herzog/Wheeler conducted a 1-month shutdown test period, between November and December 2010, designed to identify any potential system or environmental problems with the shutdown parameters before the shutdown experiment began. The test period was used to determine if the AHU could handle the shutdown without experiencing a mechanical failure, if the shutdown pattern was correctly programmed into the controls system, and whether drastic changes in space conditions from unforeseen heat loss or gain due to outdoor conditions might occur. The SML tower completed both the baseline data collection and experimental shutdown period without complication. Space conditions showed a maximum gain of 1°C (roughly 2°F) in fluctuation, with about 4% fluctuation in RH levels (these fluctuations were also influenced by the perimeter heating system, which did not cycle off with the AHU shutdown), and there were no mechanical complications with the AHU or the controls.

The goal was to experiment with 7 to 10 hours of total shutdown time for each 24-hour period at each test location, generally conducted overnight. Conducting the shutdown from 11:30 PM to 7:30 AM in the SML tower, mostly hours when the space is unoccupied, provided the greatest potential for energy savings, while minimizing the likelihood of human comfort complaints. In addition, by conducting the shutdowns during nighttime hours, the possibility of drastic swings in environmental conditions due to outdoor conditions and the construction of the stacks tower were dramatically reduced. The nighttime shutdowns do miss out on one potential energy savings opportunity—the demand charge portion of the institution’s electrical bill. The demand charge is a surcharge that is essentially based on the peak demand of the building or institution, as opposed to the commodity charge, which accounts for the actual amount of energy used. By conducting the shutdowns during unoccupied nighttime hours, savings are possible on the commodity charge, but likely not on peak demand, which typically occurs during daytime hours.

Once the 1-month shutdown test period was successfully completed, the SML tower moved on to the full 24+ month experimental period. Preservation Department staff at Yale gather and review the data approximately once per month during this period, and with greater frequency in spring and during other seasonal transitions.

#### METHODOLOGY: ADMINISTRATION

Previous field research has taught us that administration of the project at each partner institution requires a primary contact and “champion” for the experiment. The primary contact at Yale is the Preservation Field Services Librarian, who had previously partnered with IPI in the IMLS-funded Web-Based Environmental Risk Assessment (WebERA) project (2007–2009) and had extensive knowledge of IPI’s research methods and tools. Due to the nature of the experiment—adjusting the operation of the mechanical system while protecting the collections—IPI and Herzog/Wheeler are operating within multiple administrative structures in most institutions, and therefore need the input, commitment, and cooperation of all individuals and departments involved. When carefully considered, the breadth of concerned parties with a potential

stake in either collections preservation or systems and energy can be considerable, including multiple departments within a library, several different facilities functions, and the administration related to both of those areas. In addition to the Field Services Librarian at Yale, IPI and Herzog/Wheeler are also working closely with the Director of Preservation, the Director of Building Operations and Security for the Libraries, and a Facilities Operations Systems Engineer in charge of the mechanical system controls. The successful conduct of the experiment at Yale has required the cooperative participation of both collections and facilities staff, as well as the approval and commitment of the administration.

The members of Yale's project team worked with IPI and Herzog/Wheeler to develop the specific project design and methodology for the SML tower, including the initial selection of the candidate space and AHUs. Their knowledge of Yale's administrative structure ensured that the project team was working through the proper channels to make adjustments to the mechanical systems, and their knowledge of the stacks and the associated AHUs provided a strong initial understanding of the potential risks and complications, both to the experiment as well as to the spaces and systems. They have successfully worked with IPI and Herzog/Wheeler and among themselves to finalize the work plan for data gathering and analysis, and understand each person's role within the project. As a result, the Preservation staff knows whom to contact if they find that the experiment schedule is not taking place, and the Facilities staff know to contact the collections staff if there is a malfunction or planned maintenance that will create a departure from the experiment schedule.

#### EARLY RESULTS

The final shutdown schedule for experimentation in the SML tower was put into place in early December 2010. Through spring 2012, the results of the shutdowns have been generally positive. The experiment is finding expected fluctuation in the collections spaces during the shutdown, with the system recovering to its set point a short time after being turned back on. There have been several occasions where the systems have lost the shutdown schedule for unknown reasons; those instances were corrected without any significant loss of experimental data.

Analysis of representative space and AHU conditions and operation during summer and winter months indicates the effects of the shutdown experiment. Figure 2 shows a temperature graph of two datasets during August 2011, a typical summer month. The plot for "IPI SB-2 Supply Air T°C" (widely fluctuating line) shows the condition of the supply air from AHU SB-2 to the collection space during the period, whereas the plot for "IPI SB-2\_3M\_26N\_1\_2 T°C" (minor fluctuation) shows the recorded air temperature in °C from one recording location within SB-2's zone in the SML tower. The plot for the supply air, which fluctuates extensively, provides two pieces of information. First, the fluctuation is representative of the shutdown schedule being in place, with the valleys in the plot representing the "on" periods, and the spikes the nighttime "off" periods. Second, the high spikes most likely indicate that the heating coil in the unit is not valving off during the shutdown—no air is circulating through the unit, but some water is still circulating through the coil. This will have a minor effect on the total energy savings during the shutdown, but there is no negative effect on the collections space. The fact that the lesser fluctuating plot—the temperature felt in the space—shows temperature variation of 1–1.5°C (2–3°F) with no cumulative increase in space temperature over time, indicates the potential viability of the shutdown procedure in this space. With no

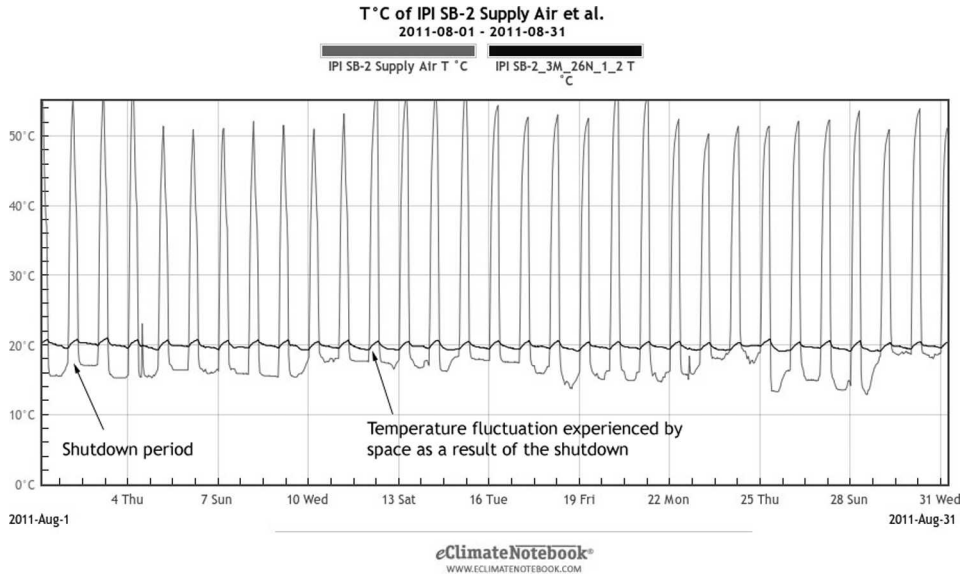


Figure 2. Temperature plots of supply air and space conditions from AHU SB-2 in August 2011. The supply air plot clearly shows the shutdown pattern, with little fluctuation in the space temperature.

cumulative increase in temperature, and minor fluctuation during the shutdown itself, the off-period is having a minor impact on the preservation quality of the space, and energy is being saved during each shutdown period. The dew point in the space varies by less than 1°C (2°F) during the nightly shutdown (typically rising slightly, as expected), leading to RH variation of roughly 1% each night during the shutdown period.

Figure 3 presents another set of temperature plots from the experimental period, this time of two datasets during January 2012, showing winter operation in the SML tower, which, due to the influence of the perimeter heat, presents a more complicated picture for analysis. The plot for “IPI R-4 Supply Air T°C” (widely fluctuating line) shows the condition of the supply air from AHU R-4 to the collection space during the period, and the plot for “IPI R-4\_4M\_50N\_7\_2 T°C” (nearly flat line) shows the recorded air temperature in °C from one recording location in R-4’s zone in the SML tower. As above, the plot for the supply air temperature—the widely fluctuating line—calls attention to the active nightly shutdown schedule. In most cases, the peaks of the supply air graph would indicate the system’s “on” period, but because R-4 is actually in cooling mode during this period due to the influence of the perimeter heating system on the space conditions, it is the flat valleys that represent the “on” period, and the spikes that indicate the shutdown period. Figure 4 illustrates this cooling behavior by comparing the mixed air temperature (which is the blend of the return air temperature with the incoming temperature of the outside air, and shown in this graph as the plot with the downward spikes during the shutdown period) with the supply air temperature (upward spikes during shutdown). As a note, the mixed air plot shown for AHU R-3 in Figure 4 is the same air condition that AHU R-4 receives. Both R-3 and R-4 receive mixed air from the same unit that blends outside air and return air. The mixed air temperature at R-4 is warmer than the space temperature shown in Figure 3, indicating that the blended return air temperature gets enough heat gain from the perimeter heat that the incoming cold outside air is not enough



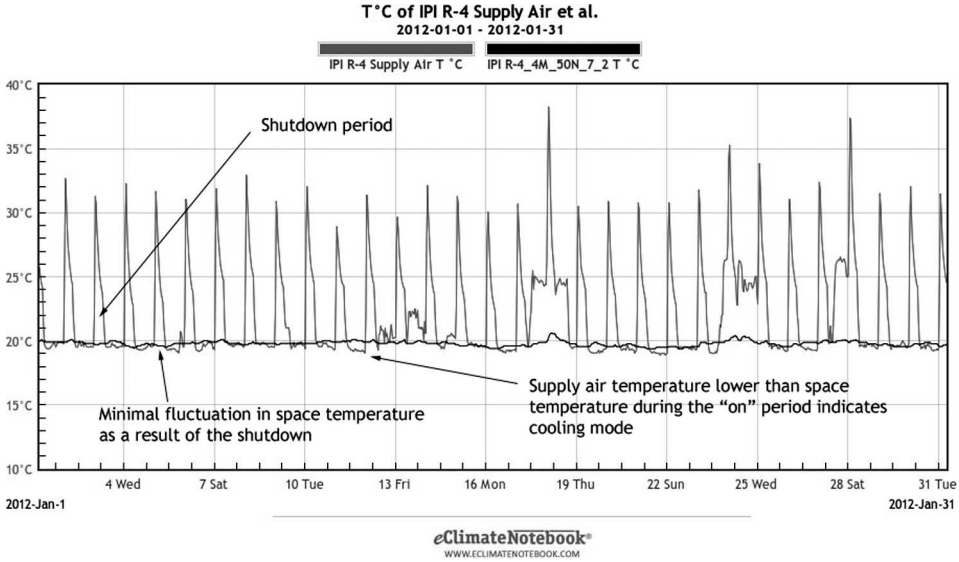


Figure 3. Temperature plots of supply air and space conditions from AHU R-4 in January 2012. The supply air plot indicates the shutdown pattern and the cooling operation, atypical for the winter season. The space temperature shows very little fluctuation as a result of the shutdown.

to overcome it; the resulting warm mixed air condition requires the unit to cool even in winter operation in order to overcome the heat gain from the perimeter hot water system.

Returning to Figure 3, the plot of the space temperature (the nearly flat line) shows the actual effect of the AHU shutdown on the space conditions—less than 1°C (roughly 2°F) in variation during the “off” periods. The heat added by the perimeter hot water system

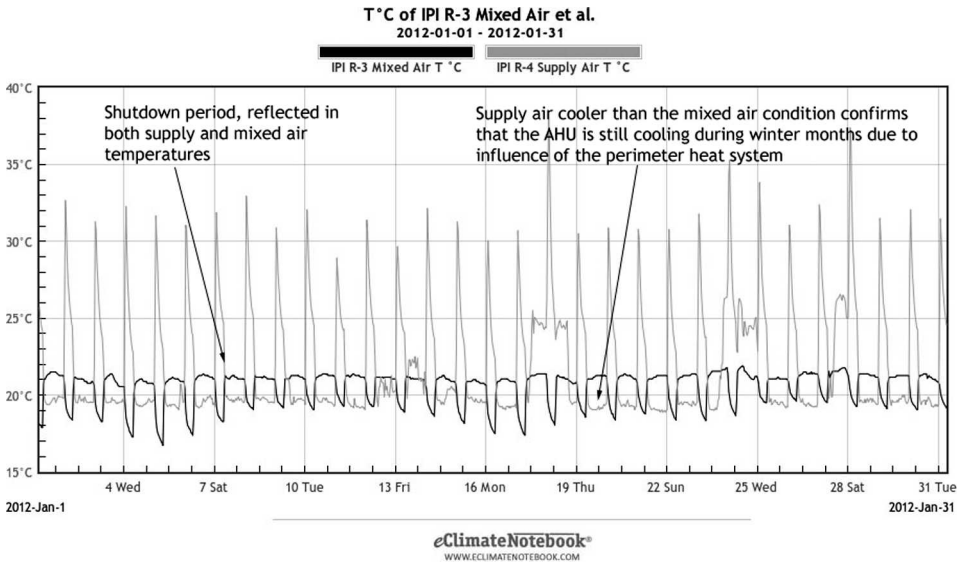


Figure 4. Temperature plots of the mixed air at AHU R-3/R-4 and supply air at AHU R-4. The cooler condition of the supply air during the “on” periods compared to the mixed air temperature indicates that the system is still cooling during winter months.

ensures that there is no overall drop in space temperature due to outside influence during the shutdown period; in fact, because the system is cooling, a slight heat rise would be expected during the AHU shutdown as the perimeter heat gained control over the space. That rise, at least in this particular location, is not present. This particular dataset illustrates that the blending of the zones and perimeter heat influence means that no single datalogging location is sufficient to fully analyze the system behavior. Comparing other datalogging locations in the tower shows that there is a 3.5–4°C (roughly 8°F) variation in “on” period space temperatures, depending on the AHU zone and tower level. Some of those show no variation at all during shutdown periods, while others show up to 1–1.5°C (2–3°F) in temperature variation during the shutdown. Combined with RH variation that ranges from less than 1% due to the shutdown in some spaces to others that experience up to 6%—some of which is due to temperature variation in the shutdown, and some of which is typical variation—there is a sense of the influence of the shutdowns on the Sterling stacks preservation environment in winter. Conditions from zone to zone and tower level to tower level can vary due to the blending of the AHU and the perimeter heat system to create the environment; the effect of the shutdown is nearly imperceptible in some spaces, and greater in others, but the overall effect appears minimal, and temperatures recover to their normal operating conditions during the daytime “on” hours.

The ability to use IPI’s Preservation Metrics™ to quantify rates of chemical degradation can give us some idea of the overall impact. The measured TWPI on SML tower level 3M for the month of August 2010, with no shutdowns in place, was 43. The measured TWPI for that same floor for August of 2011, with a shutdown in place, was 43 as well. Comparing space conditions on the 4th tower level from January 2010 with conditions from the same location in January 2012 is more difficult—average conditions in 2010 were 19.5°C (67°F) and 37% RH, but 2012 had an average temperature of 19.6°C (67.2°F) and an average RH of 47%. The difference between the 2010 TWPI of 65 and the 2012 TWPI of 50 is almost entirely due to those differences in humidification levels, which were the result of changed control set points as opposed to the shutdowns. The lesson is that, although direct comparison of conditions from one year to another is an inexact process due to differences in outdoor weather and normal variations in mechanical operation, an inspection of the preservation environment conditions, and their root causes, can help determine which effects are due to the shutdown procedure and which are not.

These operational examples show the opportunity for energy savings due to shutdowns in both the summer and winter seasons (when there is the greatest risk of fluctuation in the preservation environment) in the SML tower. Minimal temperature fluctuation due to the shutdowns, recovery to the system set points the following day, and the slow rate of moisture equilibration for many collections materials mean that the shutdowns should have little effect on the overall preservation quality of the environment.

#### POTENTIAL BENEFITS

Carefully managed shutdowns of mechanical systems that serve collections storage areas have potential benefits for both preservation and energy savings. In locations with a seasonal cool or cold climate where the typical system operation is to add heat to the airstream in order to maintain a set point, there is the possibility that shutdowns could lead to a slightly decreased rate of chemical decay due to lower temperatures during the shutdown period. Although the current operation of the perimeter radiation system



negates this possibility in the SML tower, a better-insulated building without that constant heat source could potentially support cool/cold weather shutdowns of longer durations, presuming careful observation and no concerns for human comfort, and provided that relative humidity could be kept within reasonable bounds.

The potential for energy savings as a result of system shutdowns is both real and meaningful—shutting equipment off is arguably the most effective energy-saving action possible. For most systems, the potential savings come primarily from three different areas: electrical consumption at fans or electric heating, chilled water consumption at a cooling coil, and steam or hot water at a heating coil. The amount of electrical savings related to energy used at supply or return fans is often nearly directly proportionate to the length of the shutdown. For example, if the daily shutdown of a system was 8 hours, or one-third of the day, the electrical savings from fan operation would be around 33%. Different factors can influence the actual percentage—in nighttime shutdowns where the demand charge is not affected, the result can be savings slightly less than 33%, but still significant. Savings at cooling and heating coils varies with each system and location, depending on how the system was designed to operate, and how much each component runs during different seasons. Nonetheless, each hour the AHU is turned off is an hour's worth of energy that a particular component might not be using. In the case of the SML tower, the summer shutdown represented in Figure 2 would save energy at the supply and return fans on the system, at the cooling coils that do the subcooling for the dehumidification, and at the heating coils that bring the air to the necessary supply condition.

Normally, a shutdown in the winter operation illustrated in Figures 3 and 4 would only save energy at the fans and at the cooling coil (the system is supplying cooler air to the space). However, a comparison of the mixed air, cooled air, and supply air conditions at R-4 during January 2012 shows that the system was actually still subcooling and reheating. Instead of simply cooling the air to the necessary set point, the system was cooling below the necessary condition, and then using the heating coil to bring it back to the desired supply condition. In that scenario, the shutdown actually saves additional energy, not only at the fans and cooling coil, but also the excess energy used in subcooling and reheating the air. This behavior also illustrates an excellent point about the side effects of the research. Although the point of the research is to enact system shutdowns and measure their effects without making any other systematic changes, the process of data gathering in the spaces and AHUs often exposes inefficiencies within the system. These inefficiencies, which must be considered part of the “normal” operation of the system, are documented as part of the project and will be reported to the partners as part of the final project data so that they can be remedied.

Data collected within the AHU, and detailed information about billing and energy rates, allows IPI and Herzog/Wheeler to calculate the energy savings for the systems worked with at each partner institution. Additionally, the data allows for the determination of whether or not certain energy usage patterns are present. One particular concern regarding the value of shutdowns in energy management has to do with the question of whether the system has to use extra energy in order to recover its original set point when it is turned back on. If so, the extra consumption would negate some of the savings gained during the shutdown. Although there is no evidence of this in the examples presented here, datasets from several institutions in the project do show a slight “catch up” effort when turned on that represents energy used in excess of what the unit normally would use. In the cases that IPI and Herzog/Wheeler have identified so far,

the excess energy used has not been more than 10–15% of the total energy saved during the previous night's shutdown, meaning that there is still a significant net positive energy savings. The datalogger deployment in the mechanical systems allows the measurement and analysis of those patterns when they are present, and final energy calculations for the project will incorporate their effect into the net energy savings for each AHU and site. In the same vein, there was concern at the beginning of the experiment that the constant shutting down of the systems could place undue stress on the motors and belts. IPI and Herzog/Wheeler determined with the help of facilities personnel that most of the motors were capable of "soft" starts, often with VFDs, and after further discussions with facilities partners and observations, have seen no mechanical breakdowns or attrition that can be attributed to the shutdowns.

#### LESSONS LEARNED TO DATE

There are several unexpected variables and developments that will influence how IPI and Herzog/Wheeler approach the conclusions regarding the success of the methodology for this research. It was expected, and has proven true, that communication and cooperation between collections staff, facilities, and administration is crucial to the success of the project. In one instance—not at SML—a system that was to be part of the experiment was never placed on the final experimental shutdown schedule due to a simple miscommunication with the facilities operator in charge. The mistake was caught, but it was not until several months into the project, thus reducing the amount of data that are available for that particular system.

A system shutdown seems like a relatively straightforward proposal until work starts with the control systems that operate AHUs; holding to the schedule can be harder than expected. Systems have fallen off the schedule, including AHU's R-2 and R-3 in the SML tower, due to emergency maintenance, holiday shutdowns that reset all AHU controls to pre-experiment defaults, and equipment malfunction. The experience shows that it is not enough to monitor the conditions within the space; the system itself has to be monitored regularly to ensure that the desired operating schedule continues.

IPI and Herzog/Wheeler suspected from the onset that shutdowns would not be appropriate for every space, season, or climate. Although the experiment does not yet have a full set of data to analyze for the project, it is likely that some spaces and systems might not be able to hold reasonable conditions during an 8-hour shutdown during hot, humid summer months, and that such operation, while beneficial in terms of energy savings, might prove unwise for collections preservation. Further experimentation could be needed to determine if there is any appropriate length of time—perhaps 2 to 3 hours instead of 8 hours—for those locations.

Conversely, several sites do show potential for the shutdowns to be successful in year-round energy conservation without negatively impacting the preservation environment, including the high-density storage sites at Cornell and UCLA. As national and international planning for shared or individual high-density storage modules moves forward, it is worth considering potential energy usage and savings as factors when making decisions about geographic location and building construction—energy savings could be a key difference between two otherwise similar sites. The more cultural heritage professionals document and learn about the optimization of storage environments, the easier it will be to incorporate those lessons into future planning and design, encouraging the use of locations with more favorable outdoor climates to allow for reduced operation of mechanical systems, and the construction of buildings whose envelopes are designed to support such "passive" control.

The preliminary data analysis conducted here for the SML tower seems to indicate that the potential gain in energy savings from a systematic, risk-managed shutdown is worth the minimal impact that it has on the preservation environment at that location. The final decision of whether to continue with the shutdowns after the completion of the experiment ultimately lies with the preservation, facilities, and administrative functions of the Yale University Library.

#### CONCLUSIONS

Although it is too early to draw final preservation and energy conclusions at this stage of the research, the methodology and its application to the collections storage in Yale University's Sterling Memorial Library tower does provide a clear picture of what it takes to design an appropriate experiment and what it is likely to take to implement these practices in a practical manner in the future. The project goal—to determine whether monitored, risk-managed shutdowns can reduce energy consumption without negatively affecting the collections storage environment—supports a key component of IPI's research and education mission: enabling cultural institutions to define, achieve, and maintain an optimal collection storage environment. Appropriately applied shutdown strategies have an important place in that equation, and determining their feasibility and the methodology needed to practically apply them will bring IPI, Herzog/Wheeler, and the entire profession closer to that mission.

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# EFFECTIVENESS OF ENTOMOLOGICAL COLLECTION STORAGE CABINETS IN MAINTAINING STABLE RELATIVE HUMIDITY AND TEMPERATURE IN A HISTORIC MUSEUM BUILDING

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*Abstract.*—Maintaining a stable environment is critical to long-term preservation of museum collections. The objective of this project was to determine how well storage cabinets buffer conditions in an environment with highly fluctuating relative humidity and temperature. Storage cabinets in the Insect Collection housed at the Smithsonian Institution's National Museum of Natural History were evaluated during a 6-mo study. The Smithsonian's Museum Conservation Institute (MCI), in collaboration with the National Museum of Natural History (NMNH) and the Office of Facilities Engineering and Operations (OFEO), collected environmental data within six randomly selected museum cabinets, as well as the ambient conditions in the three building zones in which they were located. Staff used an ultrasonic leak detector to identify potential leaks (sites for air exchange) and Elsec 764 dataloggers to monitor interior relative humidity (RH) and temperature (T) for each cabinet. OFEO engineers supplied the building's environmental data, collected via ethernet Veriteq (now Vaisala) monitors in all three zones and compiled monthly. The data from the ambient conditions were compared with readings from the cabinet interiors. Although T remained relatively stable, ranging from 21°C to 23°C in both the ambient environment and inside the cabinets, ambient RH ranged from 10% to 60%, while the RH inside the cabinets averaged from 38% to 45%, with the exception of one cabinet that was slightly out of the range. This demonstrates that cabinets can be highly effective in protecting collections from large fluctuations in RH.

## INTRODUCTION

Architecturally complex and historic buildings such as the Smithsonian Institution's National Museum of Natural History (NMNH) building (hereafter NHB) often present challenges in maintaining stable environments for the storage and long-term preservation of museum collections. The central part of NHB was completed in 1910, while the East Wing and East Court additions where the National Insect Collection (NIC) is housed were completed in 1962 and 1999, respectively. Consequently, these building expansions resulted in a patchwork of environmental systems that have been upgraded at different times over the years.

In the present study we surveyed environmental conditions inside storage cabinets of the NIC in response to concerns that the building did not provide optimal stability of conditions for collection storage. Depending on the type of collection, high or low relative humidity (RH) can lead to pest problems and can cause physical deterioration of natural history objects. The Smithsonian Institution has adopted collection environment target ranges of 37–53% RH and 20–25°C for collections (Erhardt and Mecklenburg 1994, Mecklenburg et al. 2004, Michalski 2007).

This study was a two-phase project, first initiated in 2008 and completed in 2012. Phase I (initiated by two of the coauthors: Furth and Mecklenburg) focused on characterization of the ambient environment in the collection ranges and preliminary evaluation of cabinets based on their structural characteristics. With that objective in mind, 12 cabinets of differing construction and vendors were selected and monitored over a 2-mo period from mid-August to mid-October 2009. Relative humidity and temperature (T) were recorded from inside the cabinets and in the ambient collection ranges. The results of Phase I demonstrated large fluctuations in RH in the ambient environment, ranging from 15% to 60%, and minor fluctuations, ranging from 40% to 45% inside all tested cabinets, regardless of cabinet type. The T, however, remained nearly constant at 21°C during Phase I testing. The findings of Phase I then served as a guide in selecting cabinets and cabinet range locations for a more systematic and controlled study undertaken in Phase II. In this second phase, we evaluated the performance of six carefully selected storage cabinets to determine their effectiveness in buffering RH fluctuations compared to the ambient environment.

In addition, each cabinet was also tested using an ultrasonic leak detector to evaluate each cabinet's air tightness and possibly explain any discrepancies in a particular cabinet's ability to maintain stable relative humidity and temperature. Ultrasonic leak detection has been utilized since 1998 for testing air tightness of gaskets and effectiveness of clean rooms, but its application in the museum field is relatively novel. Consequently, there are no established standards about what degree of deviation from a baseline reading is considered acceptable or unacceptable for natural history collection cabinets. Air exchange ratios for storage cabinets and display cases, however, have long been considered as playing a role in maintaining desired internal environments for preserving collections (Calver et al. 2005; Thickett et al. 2005, 2008). These authors emphasized not only the need to prevent the external environment from affecting the stability inside the cabinets, but also the need for a small amount of air exchange to prevent the potential build up of damaging products resulting from offgassing inside the cabinets. Recent research on air exchange rates for museum cabinets suggests that a rate of one exchange every two to three days provides a good enclosure that aids in maintaining stable conditions without being so tight that it jeopardizes collections via internally generated pollutants (Calver et al. 2005).

## MATERIALS AND METHODS

### *The Building*

Two air-handling zones within the NHB, representing three different locations of the NIC, were monitored in Phase II of this study: 5<sup>th</sup> floor East Court (5EC), 6<sup>th</sup> floor East Court (6EC), and 5<sup>th</sup> floor East Wing (5EW). None of these locations or any of the air-handling zones employ intentional seasonal humidification as part of normal building operations. The RH and T data were continuously collected via a real-time Vaisala monitoring system, recording data at 30-min intervals from 1 August 2011 to 1 February 2012. This monitoring is part of the building management system operated by OFEO, and the loggers used in this phase of the study are permanently mounted in the collection ranges. Data were downloaded via ethernet connection and then compiled and graphed monthly using Vaisala's proprietary software, viewLink.

### *Storage Cabinets*

For this study, six metal cabinets were selected in different building zones based on Phase I data for potential zone RH fluctuations beyond the acceptable Smithsonian



Figure 1. Typical entomological cabinetry in the National Insect Collection. Cabinets in the East Court of the Natural History Building are mounted on moving compactor storage compactors (left) to maximize storage capacity, whereas those in the East Wing are stationary and arranged in aisles (right).

standard range. Three of the cabinets were double-door cabinets, and the remaining three were single-door cabinets (Fig. 1).

Besides the obvious differences in number of doors and capacity, the double-door cabinets have recessed door handles with a rotating circular back plate (Fig. 2), whereas the single-door cabinets have a different kind of nonrecessed handle that does not have a similar back plate. All cabinets selected for Phase II had intact gaskets around the door seals, so there was reasonable expectation of a good seal between the ambient and internal environments of all cabinets.

Each cabinet contained an equal number of collections drawers (14), which are made of coated wood with a tight fitting glass top. Inside each wooden drawer were various sizes of archival unit trays with insects pinned into a polyethylene foam substrate (Fig. 3).

#### *Monitoring Instruments*

The Smithsonian's Museum Conservation Institute (MCI) provided 12 Elsec 764C dataloggers, manufactured by Littlemore Scientific, for monitoring of the internal environment of the cabinets selected in Phases I and II. Elsec dataloggers record RH and T, among other environmental parameters, and are favored for their small size, reliable monitoring (given proper calibration), and relatively long battery life. Two dataloggers were placed in each cabinet, one in the top and another at the bottom of the cabinet to detect any potential within-cabinet variation. Data were collected at 1-hr intervals over the 6-mo period from 1 August 2011 to 1 February 2012. Recorded data were downloaded at the end of the project via an infrared reader that connects through standard computer USB port. The results were graphically produced in RView, Elsec's proprietary software, and then exported as Excel data files for further analysis.

To test for areas of potential air exchange between the ambient and interior cabinet environments, cabinets were analyzed with a portable, SDT 170 ultrasonic leak detector, provided by the NMNH Collections Program. Ultrasonic waves are generated by an SDT





Figure 2. Cabinets marked after testing with an ultrasonic leak detector, which records “leaks” as dBmV readings of sound escaping from various parts of the cabinet. The sound was produced by an ultrasonic emitter placed in each cabinet. Readings were recorded directly on the cabinets using a wax pencil.

200 nW bi-sonic transmitter that was sealed inside each cabinet prior to deployment of the Elsec dataloggers. Ultrasonic waves are beyond the range of human hearing ( $>20$  kHz), so the SDT 170 converts them to corresponding audible sounds and measures them as decibels (see SDT International 2012). The decibel level is reported on an LCD and manually recorded. A reference “baseline” was established by measuring ultrasonic waves that passed directly through the solid metal areas of the cabinet doors where no cutouts or fixtures were located. The flexible sensor permitted measurements in corners, near the door handles and near the hinges. During this process, the decibel readings were recorded directly onto the surface of the cabinet using a wax pencil (Fig. 3). The principle behind this testing is that the decibel levels correspond to air leakage from the cabinets, identifying possible sources of air exchange between the cabinet interiors and the environments in the surrounding spaces.

## RESULTS

### *The Building Environment*

On the basis of our findings in Phase I, we anticipated large fluctuations of RH in the building environment. Over the 6-mo period of measurements, there were major fluctuations in RH in all three collection locations (Fig. 4).

The maximum-recorded value of RH in all three areas remained within a range of 50–60% over most of the 6-mo period, dropping below 50% in December 2011 and January 2012 for 5EC and in January 2012 for 6EC, and exceeding 60% in August 2011 for 5EW.



Figure 3. Pinned entomological collections are typically stored dry in foam-bottomed unit trays that are themselves housed inside tightly sealed glass-topped wooden drawers that are arranged in cabinets.

However, significant drops in minimum values of RH were noted in all three areas starting in October 2011 and continued until the end of the monitoring period. Average RH levels tended to fluctuate greatly, regardless of location, with high standard deviations (Table 1; Figs. 5–7). In contrast, temperature remained nearly constant across all locations, remaining between 21.6°C and 22.5°C throughout the same period (Table 1; Figs. 5–7).

#### *Storage Cabinets*

Average RH levels remained within a range of 37.6–44.8% with relatively low standard deviation (Table 1). With the exception of cabinet no. 4 located in 5EW, all of the cabinets maintained RH within the ranges prescribed by Smithsonian standards (Figs. 5–7). Interestingly, RH remained fairly high inside the cabinets relative to the ambient RH in the collection ranges, even when the ambient RH declined at the end of the study. Dataloggers inside the storage cabinets recorded very stable T, between 21.3°C and 22.7°C (Table 1; Figs. 5–7).

While the RH remained relatively stable within most of the cabinets, cabinet no. 4, located in 5EW, showed the greatest fluctuation in RH (24–44.5%) and an unusual decline in the RH in the last months of the trial period, mirroring declines in the ambient RH (Fig. 6).

Examination of the ultrasonic leak detector results (Table 1) demonstrated that cabinet no. 4 had a much higher degree of air movement from and to the cabinet due to larger openings in the cabinet (50 dB, at some sites), which was higher than that of the other cabinets. The baseline reading of 20 dB for cabinet no. 4 is much higher than that for the other cabinets, possibly reflecting a general difference in the gauge of steel used in construction of the cabinet. The average overall readings for cabinet no. 4, at  $32.0 \pm 8.1$  dB, is higher than that for the other cabinets as well. The level of air movement for all cabinets was greatest in the areas of the hardware, such as door handles and door label holders, not along the door closures and gaskets (Table 1).

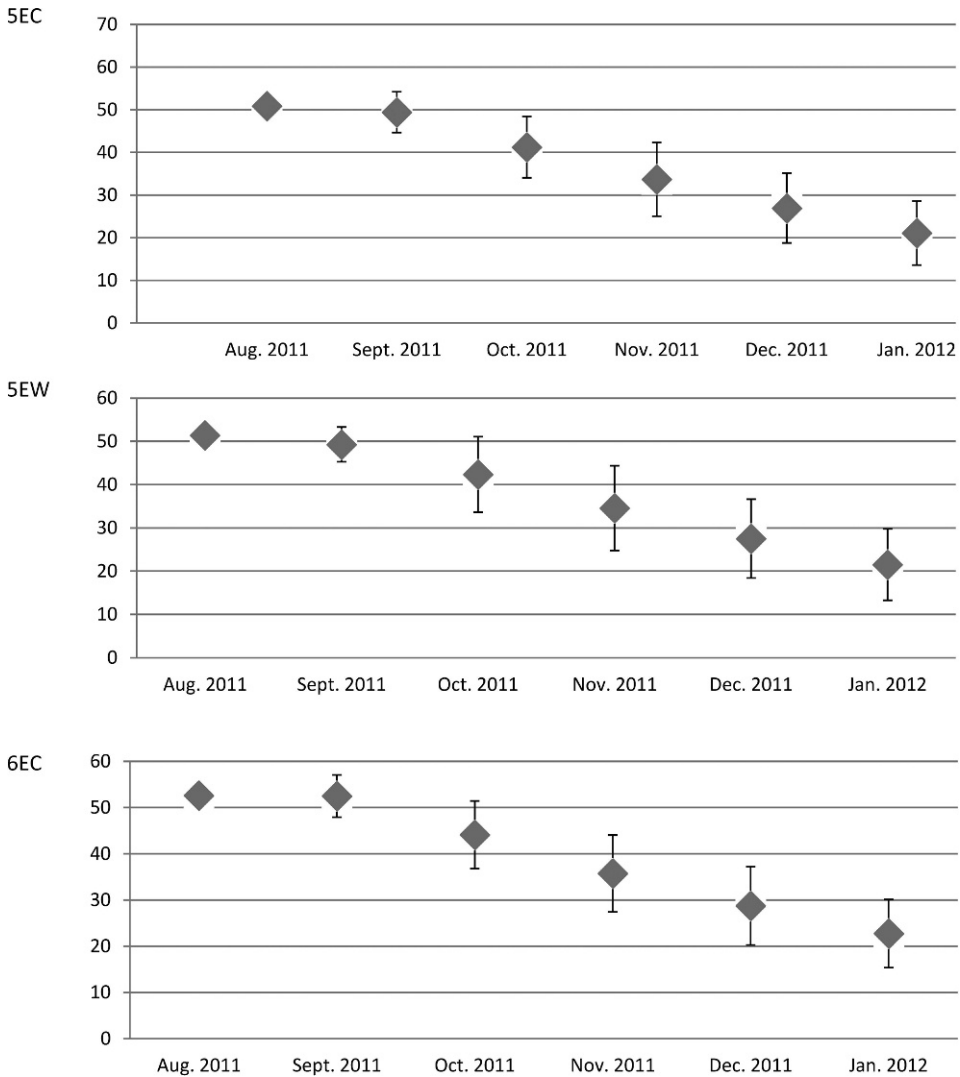


Figure 4. Monthly average relative humidity ( $\pm$  standard deviation) in the three monitored zones of the Natural History Building, during the 6-mo period of this study.

## DISCUSSION

The effectiveness of storage cabinets in maintaining a stable internal RH despite fluctuating ambient RH was clearly demonstrated over the 6-mo period of Phase II. Despite unusual fluctuations in one cabinet (no. 4), potentially linked to more sites of air movement based on the results of the ultrasonic detector, the internal environment in each of the cabinets was still decidedly more stable than the ambient environment. Based on these results, we can reasonably conclude that storage cabinets are useful for protecting biological collections in large historic buildings where the building architecture and air-handling systems may offer a limited degree of humidity control. In the single case where a cabinet failed to provide a stable RH compared to the ambient environment (cabinet no. 4), ultrasonic leak detection provided clues suggesting that the higher degree of fluctuation in that cabinet might be due to the construction of the cabinet.

Table 1. Sample cabinets selected for this study, including their location in the building zones, the data from each Elsec 764C datalogger units in the cabinets, where those units were located within the cabinet and the average relative humidity (RH) and temperature (T) in the cabinets and in the ambient collection ranges; data from Phase II. Finally, the results of the ultrasonic leak detector testing (a relative measure of air exchange) are also shown for each cabinet, expressed in dBmV.

Cabinet	Location	Elsec location	Cabinet			Ambient			Ultrasonic detector		
			Average T (°C ± SD)	Average RH (% ± SD)	Average T (°C ± SD)	Average RH (% ± SD)	Range (baseline)	All average (dBmV ± SD)	Hardware average (dBmV ± SD)		
1	5EC	Top	22.5 ± 0.5	44.8 ± 0.9	22.5 ± 0.6	36.2 ± 13.0	10–40 (10)	19.9 ± 6.7	29.0 ± 9.5		
		Bottom	22.3 ± 0.5	44.1 ± 0.7							
2	6EC	Top	21.7 ± 0.4	38.7 ± 1.2	21.5 ± 0.4	38.3 ± 13.2	15–47 (13)	28.6 ± 9.5	35.6 ± 7.2		
		Bottom	21.5 ± 0.3	39.1 ± 1.2							
3	5EW	Top	21.1 ± 0.3	41.9 ± 1.0	21.6 ± 0.3	36.7 ± 13.5	17–50 (15)	26.3 ± 9.3	26.2 ± 6.5		
		Bottom	20.7 ± 0.3	44.2 ± 0.5							
4	5EW	Top	22.7 ± 0.7	37.6 ± 2.8	21.6 ± 0.3	36.7 ± 13.5	20–50 (20)	32.0 ± 8.1	25		
		Bottom	21.2 ± 0.3	39.4 ± 3.8							
5	5EW	Top	22.7 ± 0.9	38.0 ± 0.9	21.6 ± 0.3	36.7 ± 13.5	18–20 (11.5)	19.3 ± 1.2	NA		
		Bottom	21.8 ± 0.4	40.4 ± 0.8							
6	5EW	Top	22.5 ± 0.7	37.6 ± 0.6	21.6 ± 0.3	36.7 ± 13.5	16–23 (14)	18.3 ± 4.0	16		
		Bottom	21.6 ± 0.4	39.8 ± 0.7							

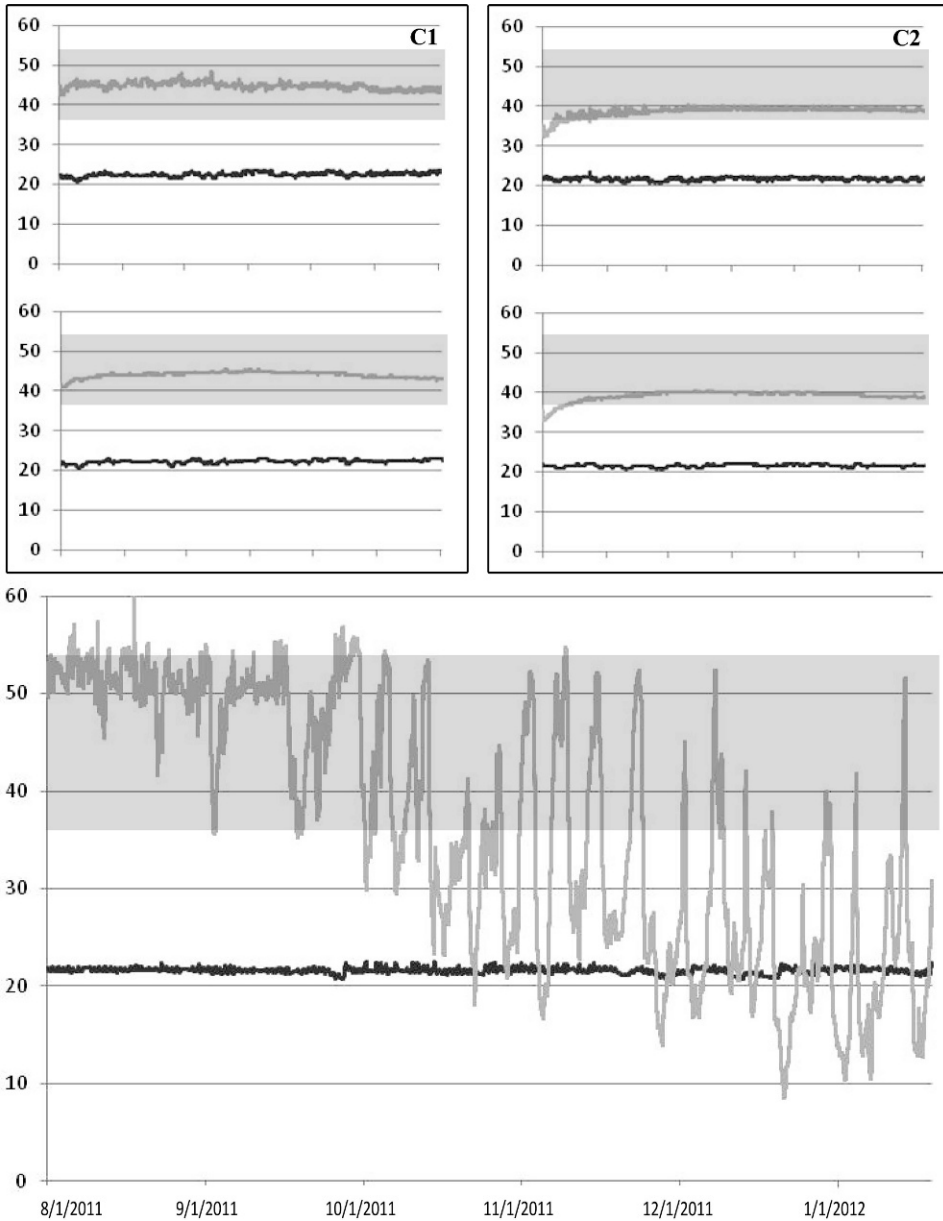


Figure 5. Temperature and relative humidity measurements from the ambient environment of the East Court of the Natural History Building over the 6-mo testing period (lower graph). Upper graphs show the conditions inside the cabinets in that zone (C1 and C2) during that same period. Uppermost graph displays data from the Elsec monitor placed in the top of the cabinet while the lowermost graph displays data from the one placed in the bottom. Gray bars = Smithsonian target range for relative humidity ( $45\% \pm 8\%$ ).

Not surprisingly, on the basis of the results of Phase I, we found that the building systems were much more effective at maintaining a stable temperature during Phase II as well, with temperatures in the collection ranges and the cabinets not differing and remaining relatively stable at  $\sim 21^{\circ}\text{C}$  during the 6 mo of testing. Unfortunately,

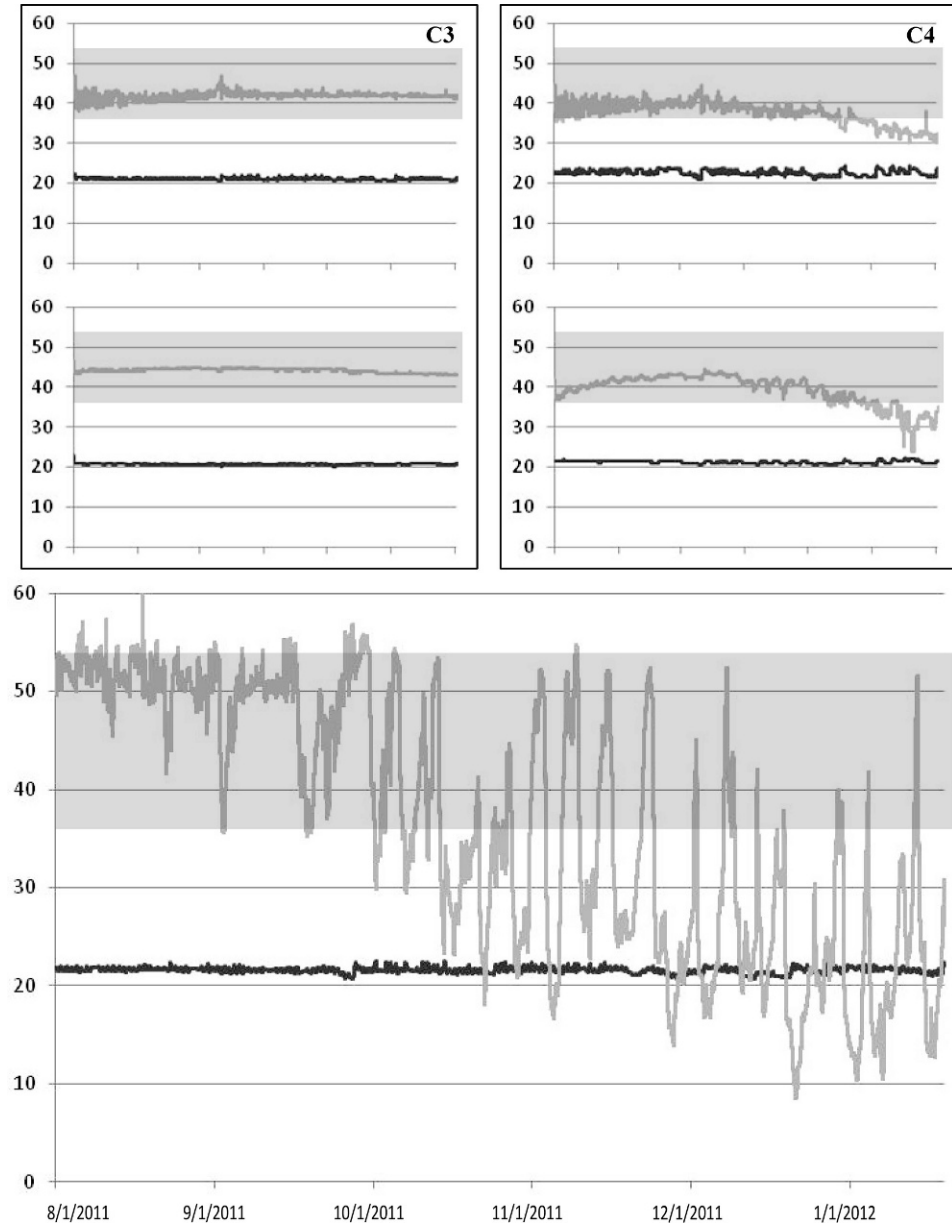


Figure 6. Temperature and relative humidity measurements from the ambient environment of the 5<sup>th</sup> floor of the East Wing of the Natural History Building over the 6-mo testing period (lower graph). Upper graphs show the conditions inside the cabinets in that zone (C3 and C4) during that same period. Uppermost graph displays data from the Elsec monitor placed in the top of the cabinet while the lowermost graph displays data from the one placed in the bottom. Gray bars = Smithsonian target range for relative humidity ( $45\% \pm 8\%$ ).

because there were no detectable differences between the ambient and the internal environment of the cabinets in Phase I or II, it is impossible for us to draw any conclusions about the ability of entomological cabinetry to buffer fluctuations in temperature.



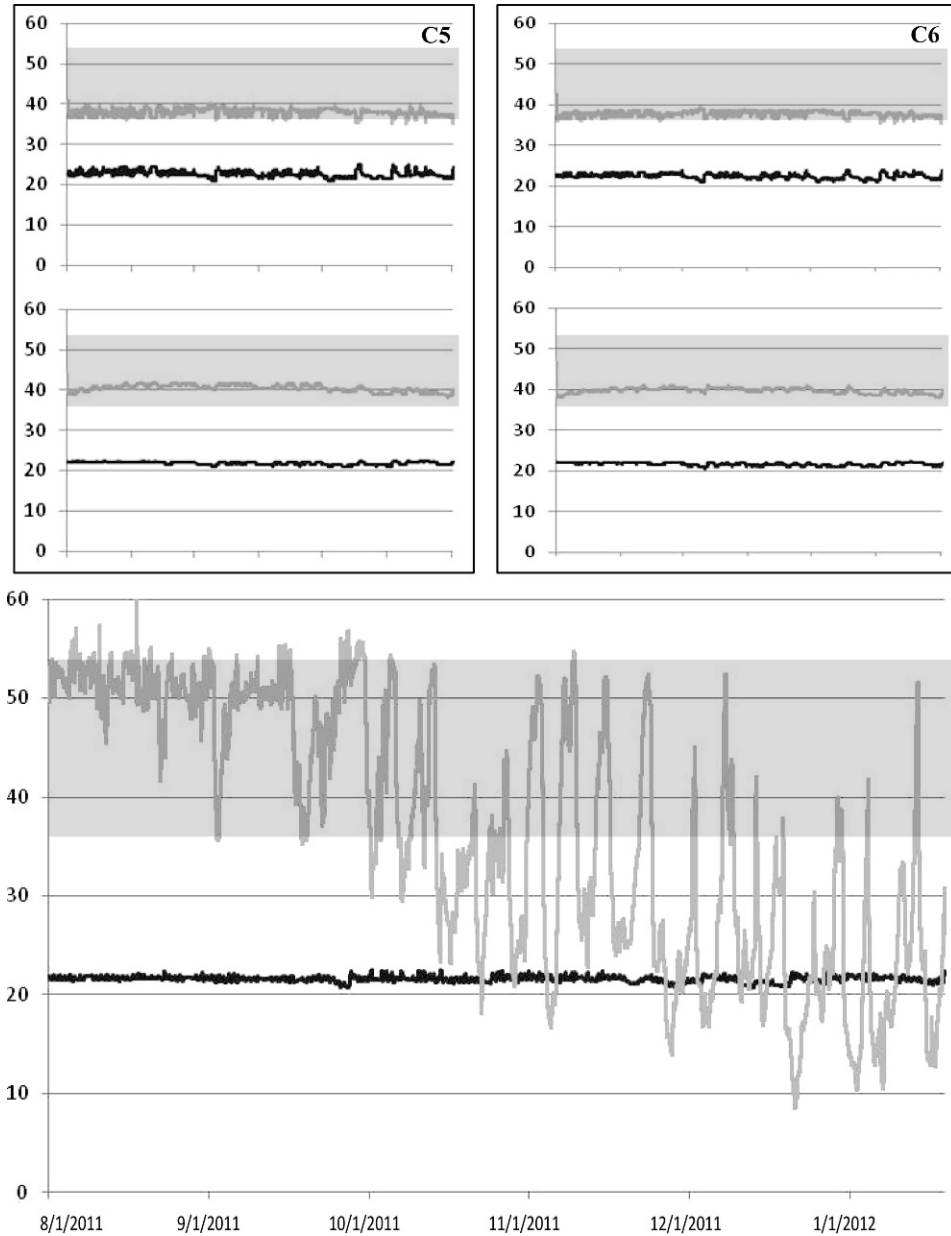


Figure 7. Temperature and relative humidity measurements from the ambient environment of the 5<sup>th</sup> floor of the East Wing of the Natural History Building over the 6-mo testing period (lower graph). Upper graphs show the conditions inside the cabinets in that zone (C5 and C6) during that same period. Uppermost graph displays data from the Elsec monitor placed in the top of the cabinet, and the lowermost graph displays data from the one placed in the bottom. Gray bars = Smithsonian target range for relative humidity ( $45\% \pm 8\%$ ).

Overall, our findings support the NMNH's commitment to providing modern cabinetry for natural history collections, helping manufacturers improve cabinet designs and cabinet seals, requiring manufacturers to provide data on air exchange rates, and monitoring temperature and RH as major factors in protecting sensitive natural history

collections. Most important, our data demonstrate that additional buffering of collections is not necessary to maintain stable relative humidity as long as they are housed in reasonably well-sealed entomological cabinets.

#### ACKNOWLEDGMENTS

This project relied on successful collaboration between four different units within the Smithsonian Institution: the MCI, the NMNH Department of Entomology, the NMNH Collections Program, and OFEO. Exclusion of six storage cabinets from use for 6 mo was necessary to prevent corruption of data collection, and we thank the Department of Entomology staff for their patience during this testing period. We also thank the two anonymous reviewers who offered many helpful suggestions on an earlier draft of this manuscript.

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# MICROFADING: THE STATE OF THE ART FOR NATURAL HISTORY COLLECTIONS

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*Abstract.*—Microfading is a powerful tool for assessing the risk of light damage in collections. It is an accelerated light exposure method for rapidly and nondestructively estimating the fading rates of colorants on real objects that relies on measuring the early response of a submillimetre spot of colorant exposed to megalux levels of light.

While the main benefit is better identification and protection for the most light-sensitive elements of a collection, it has also been shown to have very significant access, financial, and operational benefits. The basic equipment is suitable for routine screening by a trained conservator in a museum. Alternatively many institutions' needs may be met using a contract service. This paper provides an up-to-date review of the technique's development, and how it is used as a tool for collection management and research.

## INTRODUCTION

The essential dilemma faced by museums in exhibiting potentially light-sensitive materials is neatly summarised as “seeing versus saving” (Michalski 2011). Striking a balance between display and the inevitable and irreversible damage caused to light-sensitive objects is very difficult without specific fading rate data. The problem with published information, where it exists, is that for reasons discussed below it may not accurately or in some cases even approximately reflect the behaviour of the particular objects in question. Importantly, this is true even if the identity of the pigment or dye is known. Restricting display according to the most conservative interpretation of published data or past experience—the usual fall-back position—has serious access and financial implications that create their own organisational and logistical problems. This is the problem that the accelerated light exposure technique known as microfading was developed to address.

As discussed in this paper microfading was developed by Whitmore et al. (1999) at Carnegie Mellon University, and a similar *in situ* microspot fading test was independently developed by Pretzel (2000, 2008). Whitmore's instrument focuses a submillimetre spot of very intense visible light on an object and tracks the resultant (visually undetectable) colour change in real time using reflectance visible spectroscopy (Fig. 1). It is rapid, virtually nondestructive, and specific to the object tested.

It has three unique advantages over other forms of accelerated light ageing. Firstly, because it is essentially nondestructive, colorants on real museum objects can be tested. Secondly, it is not necessary to have identified or know anything about a colorant, and finally the method is rapid, with typical fading runs of less than half an hour. Using the technique it is possible to evaluate the fading behaviour of two or three moderately complex coloured artefacts or works of art, including data interpretation, in a day.

The essential components consist of a UV and IR filtered xenon arc light source, optical fibres, and a series of lenses for delivering and focusing the light on to a small area (less than 0.5 mm diameter) of the object being tested. The light reflected from the object is directed to a reflectance spectrometer, through a second set of optical fibres and lenses. The spectrometer tracks reflectance change in real time as the colorant responds to the test illumination.



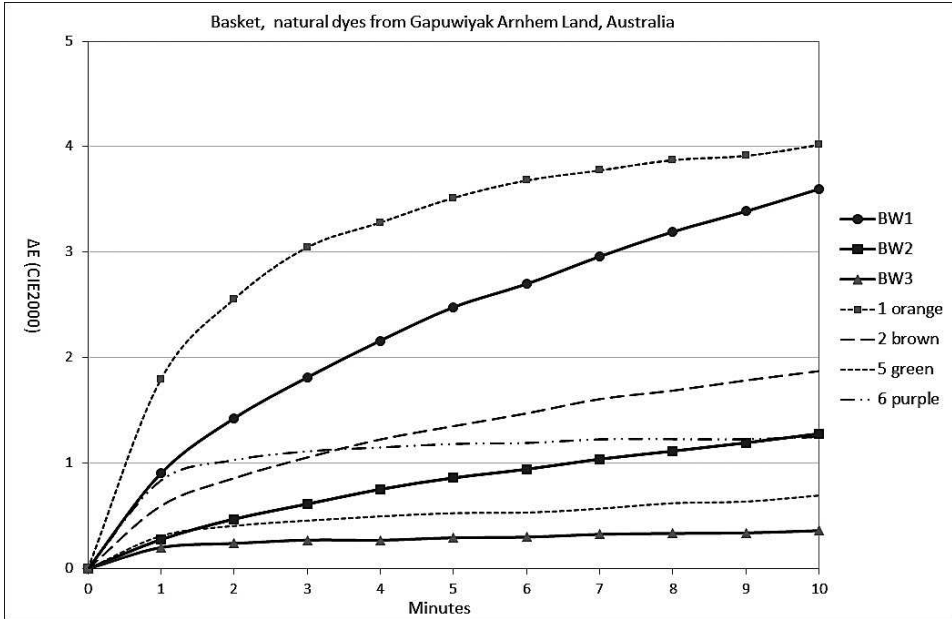


Figure 2. The (micro-) fading curves of natural dyes on an Australian Indigenous basket. Note the large spread of fading rates. The vertical axis is color change, the horizontal axis is minutes of microfading at approximately 6 Mlx.

and limitations of the method and practical hardware and data analysis issues are discussed.

“Fade” and “fading” are used throughout as a shorthand; however, not all light-induced color changes involve a loss of chroma, darkening, or lightening—the usual understanding of the terms.

### WHY MICROFADING?

Why fade-test individual objects instead of using published fading rate data for typical colorants? Before considering this question it is worth stating that because it is unlikely that most museums will acquire a microfader, improving the range and quality of fading rate data in the literature through publication will be an important role for those who do. Initiatives like the Canadian Conservation Institute's Light Damage Calculator (Canadian Conservation Institute 2012) will become even more useful as a wider range of data from both microfading and traditional accelerated ageing is entered into it.

The first problem with published information is that dyes and pigments' identities are usually unknown, particularly outside the niche areas of well understood—mainly European—historical graphic, fine art, and textile traditions. This is certainly the case for the mid-19<sup>th</sup> century on, a period when color technology exploded. As already stated identification is unnecessary for microfading although, conversely, the spectral and fading rate information from microfading may assist with identification. This is dealt with in more detail below. Specimens in natural history collections in particular contain biopigments for which we have little or no reliable data but that contain important scientific information about animal and plant nutrition, communication, camouflage, thermal regulation, and sexual selection as well as being a source of pleasure to museum visitors and researchers alike.

Even where pigment identification is possible, real colorant systems' responses to light depend crucially on specific physical, chemical, technological, and ageing properties that cannot be easily or economically inferred even using sophisticated analytical methods. A related problem is that published data are usually based on the results of accelerated ageing of freshly prepared surrogate or made-up samples that cannot in principle replicate real objects with their complex histories and compositions.

In addition to the obvious dependence of fading on the chemical identity of a particular dye or pigment, the physical disposition of colorants within the substrate—for example, whether they are molecularly dispersed, clumped together, or (in the case of textiles) reactive dyes—is thought to play a primary role in their fading (Baxter et al. 1957, Gupta 1999).

Prior fading and tint strength also lead to variations in the fading rate of a given colorant of as much as one to two blue wool steps (Michalski 1997, CIE 2004).

Fading is almost never unimolecular, and the chemical environment (substrates, mordants, photochemical catalysts, antioxidants) can play a significant role. Indigo, for example, is much more lightfast on wool than cotton (Padfield and Landi 1966). A similar effect is apparent in the very different stabilities of iron gall inks on parchment and paper in the example in Figure 3. This may be because although photooxidation is the most common fading mechanism, photoreduction also occurs in air, usually where the substrate is more easily oxidised than the colorant as is sometimes the case for proteinaceous substrates (Giles et al. 1972).

In an example of unexpected catalysis, Doll et al. (1998) found that the photo-fading of certain ink jet dyes could be significantly accelerated by contact with other colors in areas where they were printed together, an effect that would not be predictable even if their individual identities and fading rates were known.

Manufacturing idiosyncrasies including particle size, washing, paper finishing methods, the number of dye bath applications, and the botanical or biological origin of dyes further undermine predictions based on surrogate studies.



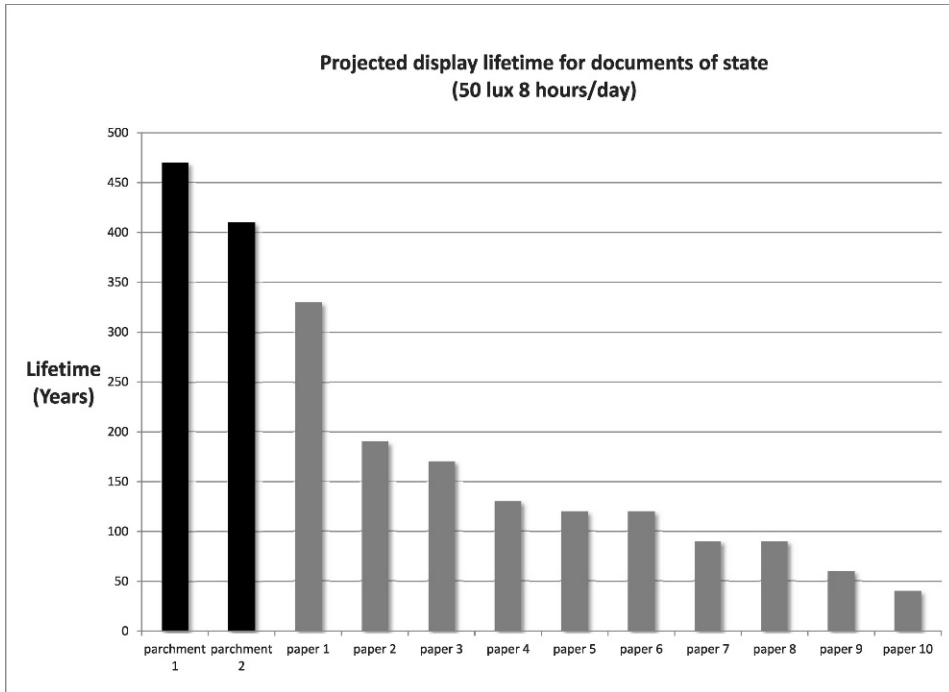


Figure 3. Years exposure to one just noticeable difference ( $JND = 1.6 \Delta E_{00}$ ) for a set of important mid-19<sup>th</sup>-century state documents intended for display. Ten JNFs are considered to effectively end a document's display lifetime.

Finally, fading rates are influenced by environmental factors such as relative humidity and components that act as humectants, as well as the availability of molecular oxygen where fading is due to photo-oxidation, an effect that low oxygen display mechanisms attempt to exploit (Beltran et al. 2012b).

#### LIMITATIONS OF MICROFADING

The usefulness of accurate fading information is obvious to anyone who has had to make exposure decisions, particularly for rare or high-value material. Microfading has significant advantages over generalised fading rate data for the reasons given above, but what are the uncertainties associated with it and what limitations do they place on the interpretation and use of microfading data?

Before examining this in more detail, it is important to realise that nearly all of the uncertainties that affect the predictive value of microfading are common to conventional accelerated light-ageing methods as well. The differences, where they exist, are those of magnitude rather than kind.

Whitmore et al. (2000) originally developed microfading as a method of rapidly locating dyes and pigments likely to fade rapidly under gallery lighting conditions, rather than predicting what something might look like after 20 or 200 yr on display. However, he found that conservators and conservation scientists were seeking more predictive information, probably responding to the increasing use of lighting guidelines based on cumulative exposure and maximum fading targets (Colby 1992, Ashley-Smith et al. 2002, CIE 2004). In considering this question, having identified a range of factors that

potentially limit the accuracy of microfading as an absolute predictive method, he concluded that “[t]he accurate prediction of the fading of different colorant systems is an elusive, perhaps unachievable goal.”

The factors Whitmore identified include the effect of the geometry of the test area on color measurement at such a small scale, the spectral distribution of the light source, and situations where microfading—which measures only photochemical change while the object is under illumination—cannot replicate other factors that affect color especially in the long term. Nonphotochemical changes to optical properties may be particularly important in natural colorant systems where appearance is almost invariably related to structures vulnerable to natural polymer degradation and biological attack. Alterations to texture, gloss, and transparency—including the deterioration of structures responsible for interference colors—may be as important or more important agents of color change than the light fading they are often mistaken for. These may usually be distinguished from fading by examining the spectral changes recorded at intervals during test fading.

Simulated before and after digitally altered photographs (Morris and Whitmore 2007), or the estimated color changes provided by the Canadian Conservation Institute’s (CCI) light damage calculator (Canadian Conservation Institute 2012) based on fading data are excellent demonstration and decision-assisting tools, but probably not to be taken too literally when applying them to individual objects. Michalski (2010) has commented that the dose response data for the BWS referred to above—which underpin both the CCI’s light damage calculator and absolute lightfastness calculations based on their use as internal standards for microfading—have a potential uncertainty as large as  $\pm 1$  BWS step. At the time of writing, both the CCI and the Getty Conservation (GCI) are conducting research to correlate microfading and conventional accelerated light-ageing dose responses for the BWS and to reduce this uncertainty.

Two areas that appear to be of particular concern in relation to the predictive value of microfading and the interpretation of results are reciprocity “failure” and the measurement of color change itself.

### *Reciprocity*

Reciprocity is the assumption that fading depends only on total exposure; that is, 100 lx exposure for 5 yr in a museum case is equivalent to 1,000 lux for 6 mo or 15 min microfading at 6 Mlx. This is also the basis of lighting guidelines that allow for cumulative exposure budgets to be “spent” in any way so long as they are not exceeded within the budget period (e.g., Ashley-Smith et al. 2002). “Reciprocity failure” is a term derived from photography but now commonly used in accelerated light-ageing studies where this quantitative relationship does not—or appears not to—hold at much higher intensities than museum lighting. Theoretically this might be where a bottleneck in the progression of reactions leading to the destruction of a chromophore sometime after the absorption of a photon becomes rate determining—for example, the diffusion of reactants (oxygen) or intermediates to a reaction site. In practice this would be difficult to distinguish from an apparent nonlinearity, which has nothing to do with light intensity per se, but local temperature rise and dehydration perhaps (Feller 1994). Feller gives a few examples of situations where he would expect reciprocity failure to be significant for accelerated light ageing in general, and Michalski (1987) cites studies in which reciprocity holds for textile dyes, food dyes, and the yellowing of epoxy. The most expansive literature review on the reciprocity law is that of Martin et al. (2003), who included within

his study experiments in photography, photoconductivity, photo-medicine, photobiology, and polymer photodegradation. The last category is the one most germane to microfading, and here slightly more than 60% behaved fully in accord with reciprocity, while another 23% slowed with higher exposure intensities. This left 17% reported as “reciprocity failures.” Martin et al. proposed his own model to account, among other things, for this apparent bottleneck in the reaction rates with higher intensity, but his solid-state model remains somewhat controversial.

Underlying much of the speculation and some of the very limited research into the ubiquity and extent of deviations from reciprocity at microfading intensities is the expectation that the phenomenon will cease to be a problem at some yet to be determined but still accelerated light intensity. This may be the case; however, as Whitmore points out, the causes and magnitudes of reciprocity failures (where they occur) are likely to depend on factors particular to the physical and chemical properties of the colorant system under test rather than as a simple function of light intensity or the identity of the colorant.

In principle it is relatively easy to test for reciprocity effects using microfading by attenuating the illumination beam with a neutral density filter and extending the exposure duration. In practice the drop in intensity is typically limited to about an order of magnitude by a combination of the fading rate of the colorant and instrument drift. However, Liang et al. (2011) were able to lower the effective detection limit to 1% of full power in some cases using an innovative automated recalibration process. Del Hoyo-Mendez and Mecklenburg (2011) determined that for some very fugitive natural dyes demonstrating reciprocity over the first order of magnitude does not necessarily mean reciprocity holds at lower levels.

Some microfading reciprocity results have been published, and many more unpublished tests have been conducted; however, as yet there has been no published large scale systematic microfading investigation of the phenomenon or an agreed upon test protocol that would ensure comparable results. This is important because observed reciprocity effects depend not only on the variables mentioned above, but also on procedural issues like the cumulative light dose used. This can affect results because rapid early fading tends to magnify differences that are not as apparent in the longer term. Whitmore et al. (1999) has published data for a few colorants that illustrate equivalence between microfading and conventional light box ageing as well as demonstrating reciprocity over the test intensities he used, and Liang et al. (2011) from Nottingham Trent University have found reciprocity held for a majority of painted-out samples on paper of fine art pigments tested, including some over two orders of magnitude, but the same team also reported reciprocity breakdown for the pigments Prussian blue and orpiment (Lange and Liang 2011). Del Hoyo-Mendez and Mecklenburg (2011) found that the most stable colorants they tested obeyed reciprocity, but that materials of lower light-fastness exhibited greater apparent deviations.

### *Colorimetry*

Color measurement itself is a source of uncertainty. The relationship between color change, which is an estimate based on models of how the “average observer” perceives reflectance differences and pigment concentration changes (the physical reality), is complex and nonlinear. Liang et al. (2011) argue partly for this reason that spectral change in the absorption region ( $\Delta R$ ) is a better measure of sensitivity; however, the relationship between reflectance change and colorant concentration, described by the

Kubelka Munk equations, is itself far from straightforward in real situations (Johnston-Feller 2001). Bacci et al. (2004) have shown that  $\Delta E$  does not reflect photochemical damage as accurately as  $\Delta R$  within the dominant absorption region, and it is possible to speculate that some apparent reciprocity deviations might even disappear if the latter were used. On the other hand, it may be argued that precisely because the relationship between pigment concentration and perceived color change *is* nonlinear—and changes in appearance really are the issue— $\Delta E$  is the most relevant metric.  $\Delta E$  is also prevalent in the conservation literature and advice on fading (for example, CIE157), it has the advantage of being widely understood by conservators, and it is easily calculated from colorimetric data produced by spectrometer software. In reality, for practical exhibition risk management purposes, the choice is probably inconsequential.

Several different perceptual models are used to calculate color difference ( $\Delta E$ ) from spectral change, and they do not necessarily agree (Kuenhi 2008). Two iterations of the CIE equations widely used in industry and almost exclusively in conservation—the first produced in 1976 (CIELAB) and the latest in 2000 (CIE2000)—differ by as much as a factor of two in their respective estimations of  $\Delta E$  for blues (including the ISO Blue Wool Standards) for the same exposure, and even more for some high chroma yellows. The CIE2000 color space is the most perceptually uniform of the two; however, CIE76 is widely encountered in the conservation literature. For comparative purposes it is probably better to report both.

Scaling up the measured color change of a single pigment or dye to its appearance in the context of a whole object presents another set of challenges. Estimates of how much fading ( $\Delta E$ ) is required to produce a JND vary over nearly an order of magnitude according to the observer and the effects of lighting, contrast, adjacent colors and other aspects of the complex visual context (Richardson and Saunders 2007, Brokerhof et al. 2008). A figure somewhere between a  $\Delta E_{00}$  of 1 and 2 (where the subscript designates the color space) seems to be the generally accepted compromise (e.g., Pretzel 2008).

#### RISK ASSESSMENT USING MICROFADING

Given these uncertainties, how is one to use microfading data? It is useful to distinguish between absolute and comparative fading rates. Microfading's ability to predict exactly what a real object's color will look like in 50 yr is unproven (but not necessarily inaccurate) and is likely to remain so for some or all of the reasons outlined above. This is true for any accelerated method. In a general sense the limits to its predictive accuracy will naturally become better understood as fading in real time under known conditions (e.g., Ford 1992) is compared to accelerated results, particularly in well-defined technological or natural fields. At the J. Paul Getty Museum in Malibu, California, the microfading results for particularly vulnerable tinted albumen photographs were followed up with direct colour monitoring. At the end of 26 wk of direct monitoring it was estimated that the first detectable visual change would occur in 110 wk of continuous exhibition, and while other objects might not respond so predictably, this was generally what microfading had predicted when considering the uncertainty ranges that Brokerhof et al. (2008) and Richardson and Saunders (2007) had estimated for establishing a JND on a work of art (Miller and Druzik 2012) as well as the BWS dose-response uncertainties referred to above.

When microfading is used to directly compare fading rates, as opposed to estimating long-term behaviour under museum lighting conditions, higher precision may be assumed. This is where the method is used to select the most lightfast objects from a

range of alternatives for exhibition or loan. Information of this kind is particularly useful at the exhibition design stage. It may also be used to probe the effect of environmental conditions, for example, testing the fading rate of pigments in a painting under different oxygen concentrations to assess the value of low oxygen encapsulation.

Microfading data are most useful when it is used in conjunction with the kind of risk management framework (lighting guideline) that sets limits on the amount of color change the museum can tolerate over a given period. This approach has been described by Colby (1992) at the Montreal Museum of Fine Arts and Ashley-Smith et al. (2002) at the Victoria and Albert Museum and Michalski (2011) on the Canadian Conservation Institute Caring for Collections website. These lighting guidelines really only reach their potential with the kind of specific data microfading provides, and Ford and Smith (2009) have described the use and benefits of microfading data in this context (see below).

Most collection risks cannot be precisely quantified with the available data; however, something like order-of-magnitude estimates are still considered useful. In this context the predictive uncertainties in relation to microfading data and their interpretation are not unusual. Although fading rates within the “high responsivity” category in CIE (2004) span more than an order of magnitude, the recommended exposure, based on an average lightfastness for the range, is only 15,000 lx-h/yr (typically a few weeks). The range is so broad precisely because of the lack specific fading data to locate colorants within it, and it is a serious problem for many museums because a large proportion of their collections fall within that range. The value of microfading lies in being able to clearly distinguish between the top, middle, and bottom of this range (3–4 Blue Wool steps) and set relative exposure limits accordingly.

In considering whether to adopt microfading at this stage of its development and given the uncertainties, it is interesting to examine the hypothetical consequences of using microfading data that proves to be wrong or a lighting guideline that turns out to be insufficiently conservative. Consider the case where a museum’s tolerance for fading is predicated on a 500-yr displayable lifetime—the “survival” target chosen by the Victoria and Albert Museum. If in 20 yr it were determined (by the next generation of conservators) that today’s data, or interpretation thereof, had overestimated the lightfastness of a colorant by a factor of two, it will to a first approximation have faded an unintended extra 10 yr of its target lifetime over that 20 yr. This would still leave a remaining service lifetime of 480 instead of 490 yr. Actually, for relatively pristine and rapidly fading colors—for which initial fading is often much more rapid than the rate averaged over the entire period—the early damage may be much more consequential. This is, in fact, an argument in favour of microfading in order to identify such colorants (Whitmore’s original aim) since a completely uninformed decision is likely result in even worse overexposure.

#### COLLECTIONS MANAGEMENT

Conservators are usually in the uncomfortable position of recommending restrictions on display duration and light levels without really knowing if they are proportionate to the risk of light damage in any particular case, and sometimes in the face of serious pressure to relax them, a role Michalski (1990) referred to as the “lighting police.” With microfading this particular dynamic can be avoided, and on the much rarer occasions when disruptive restrictions really are found to be necessary, the data tend to be the focus rather than the roles and authority of curators and administrators and conservators.

Figure 3 gives the individual display periods to 1 JND ( $\Delta E_{00} = 1.6$ ) of a set of mid-19<sup>th</sup>-century state documents held by a national archive, as assessed by microfade testing.

The first two—the documents most visitors come to see—are written in iron gall ink on parchment, and the rest are iron gall ink on paper. They all date from 1840. The entire set of documents has been the centrepiece of a permanent exhibition for just over 20 yr; however, the display conditions are currently under review as part of a plan to rehouse them in a new and more publically accessible location. The archives recently received advice from an expert in conservation lighting to restrict all of the documents to 6 wk/yr (15,000 lx-h) as a precaution based on their being of potentially “high responsivity” to light. As it happens, this advice was almost exactly what the microfading results for the least lightfast documents (9 and 10) would indicate; however, applying that restriction across the board would have made it extremely difficult to design a satisfactory exhibition. The two most important outcomes of microfade testing for the archive were to confirm that an acceptable exhibition strategy could be built around the two most important documents (from the public’s perspective) because they are suitable for something like permanent display, but that to continue to display all of the documents together, even at very low light levels, would shorten the legible lifetime of the most fugitive, which fade 10 times faster, to an unacceptable degree for such important state documents.

In a similar example, microfading was carried out by the Canadian Conservation Institute for the Canadian Museum of Nature to select pages from a collection of pristine scrapbooks by Catharine Parr Traill so they could be safely displayed. Because of the value of the collection and light-sensitive elements in the scrapbooks, such as natural dyes and pigments in pressed plants and insects, there was a temptation to keep the whole collection from being displayed. Microfade test results allowed conservators to knowledgeably choose pages that were less sensitive, instead of limiting access to the whole scrapbook out of fear. In addition, the fading data for different plant species helped conservation staff when choosing similar plants for other long-term exhibitions (Tse et al. 2011).

The flip side to identifying and better protecting the most vulnerable artefacts is having the confidence to relax restrictions on less fugitive objects. This not only allows for increased access and more flexible lighting options but also can result in significant financial savings, particularly for collecting organisations with long-term or permanent exhibitions whose preventive conservation programme includes periodically rotating light sensitive material off display to limit cumulative exposures. The National Museum of Australia had for some years used a lighting guideline that restricted items in the “high responsivity” range to 2 yr per decade (Ford and Smith 2009); however, the estimated cost of each replacement—on the order of \$1,000/object taking into account curatorial time finding and interpreting replacements, registration and conservation activities, and installation—had become unaffordable. This is not an isolated example; for example, the Netherlands National Museum of Ethnography has reported the same problem (Reuss et al. 2005). The use of microfading to make distinctions within the high responsivity range on an object-by-object basis, together with a lighting guideline that additionally prioritised object replacements on other grounds, led to an estimated 70–80% reduction in light-driven replacement costs (Ford and Smith 2010). Conservation benefits included increased protection for objects with colorants assessed as more fugitive than average for the range; fewer objects unnecessarily exposed to the hazards of preparation, transport, and exhibition involved in routine proactive object replacement; and freeing up time from routine object substitutions for other conservation activities.

## RESEARCH

Microfading is continuing to play a role in research as well as collection management. One of the earliest studies using microfading was carried out *in situ* on known



biocolorants in lepidoptera by one of the authors (Druzik) almost 10 yr ago at the GCI. The work, unpublished, showed that phorcabilin, sarpedobilin, papiliochrome II, papiliochrome M, papiliochrome R, and ommatin D were all highly light sensitive. The GCI and the University of California (UCLA) have collaborated on research into the fading of feathers using microfading (Pearlstein and Keene 2010, Pearlstein et al. 2011). They reported that the “benefit of microfading [lies] in the ability to perform accelerated aging and color measurements on the same location, avoiding the variability introduced by the feather’s movement and repositioning” (Pearlstein et al. 2011, p5). Ford and Smith (2011) have published a survey of the fading rates of materials used in Australian Indigenous objects including feathers, natural fibres, and natural dyes and resins. The Tate Gallery (Lerwill 2011), the GCI (Beltran 2012a, 2012b), and the Smithsonian (del Hoyo-Meléndez and Mecklenburg 2010) have all investigated aspects of anoxic storage and display, where in addition to its speed, specificity, and the small sample area of the technique, the ability to test materials (including real works of art) through glass is a major advantage. Lavédrine (2011) has measured the relative fading rates of colored starch grains in the Lumière Brothers’ autochrome transparency process using a microfader modified to operate in transmission mode through a microscope objective. Tse et al. (2010) at the Canadian Conservation Institute have investigated the effect of aqueous treatments and calcium phytate on the light sensitivity of iron gall inks, Stenger et al. (2010) used microfading to assess the fading rate of lithol red as part of a larger project to characterise the pigment and its deterioration, and Connors et al. (2005) have studied the light sensitivity of Japanese wood block prints.

The ability to swap illuminants or otherwise shape the spectral power distribution of the source (see below) will allow the rapid evaluation of the damage associated with new exhibition light sources such as LEDs or potentially less damaging triband sources (Cuttle 2000). The use of tuneable filters for the source allows the microfader to be used to determine the wavelength bands most responsible for the fading of specific pigments (Lerwill et al. 2008), which may lead to the development of selective filters for exhibition lighting designed to remove them (Getty Conservation Institute 2010).

Some of the ongoing research into the technique itself (for example reciprocity) has already been mentioned, and the continuing development of instrumentation by various groups is covered in a following section.

#### PIGMENT IDENTIFICATION

A good deal of pigment identification, which is an expensive and time-consuming operation that often involves physical sampling, is carried out with the aim of determining the fading risk; however, there are other reasons to identify pigments. A microfader may also be used as a fibre optic reflectance spectrometer (FORS), a method that has been used to help identify pigments, dyes, and inks (Leona and Winter 2001, Bartol 2008, Biscula et al. 2008, Neevel and van Bommel 2008). With appropriate filters and a xenon source, reflectance spectra from just below 400 nm to about 1,000 nm are possible using the Newport microfader where the choice of spectrometer options allows measurement of that range. The fading pattern itself may also assist with identification, for example, the characteristic darkening of vermilion. Visible spectra themselves are not necessarily diagnostic; however, in combination with handheld XRF, for example, the method is very useful, particularly where the range of possibilities is constrained by technological or historical happenstance.

### HARDWARE, SOFTWARE, AND TRAINING

The choice of intensity, spot size, and various elements of the hardware are a compromise between often opposing requirements; for example, for the method to be suitable for routine lightfastness screening it needs to be rapid; however, the megalux levels required to shorten test times may increase the probability and extent of reciprocity failure. Likewise tiny test spot sizes are necessary to achieve high fluxes, minimise the test-faded area, and allow fine features like ink strokes to be measured, but they also result in increased measurement variation due to inhomogeneity at the scale of the test area. There will never be a “perfect” microfader, only instruments with different strengths and weaknesses according to their cost and the purpose for which they are designed.

There are many conceivable variations on the hardware theme, several of which have been realised in practice (Lerwill et al. 2008, Druzik 2010, Liang et al. 2011, Łojewski et al. 2011), and some of them have been evaluated side-by-side (Druzik and Pesme 2010). They all share similar fundamental characteristics: that is, a maximum IR and UV filtered visible light output of between about 3 and 16 Mlx (or approximately 2–10 mW in radiometric terms) within a test spot size of less than about 0.5 mm. IR filtering minimises heating of the test area; however, there are differences in reported temperatures with Lerwill et al. (2008) and Ford (2009a) measuring rises of about 5°C and Whitmore et al. (1999) more like 25°C for similar light intensities. UV filtering can (in principle) be tailored to approximate gallery lighting conditions; however, it requires modifications to the equipment (below). As mentioned, Lavédrine adapted the instrument to work in transmission rather than reflectance mode to probe the relative lightfastness of early transparencies.

The most popular form of Whitmore’s basic design, available as a complete unit from Newport Corporation (Stratford Connecticut), currently consists of an Apex xenon fibre illuminator that incorporates the lamp power supply, xenon bulb, and focusing optics in single relatively compact unit (Fig. 4). This is coupled with a Control Development (South Bend, Indiana) PDA-512 spectrometer with a measurement range of 200–1,100 nm depending on choice of slit width and resolution, and the optic fibres, filters, and lens assemblies. An alternative lens assembly holder that incorporates a camera mount (Fig. 5) is available from another supplier (Four Hour Day, Towson, Maryland). The whole setup costs less than \$15,000 at today’s prices. The argument in favour of the “standard” Newport equipment is that its performance is reasonably well characterised, and interlaboratory results are relatively consistent (Ford 2009b, Druzik and Pesme 2010); however, this is not an argument against the development and use of different instruments that may be cheaper, more compact, or better approximate real lighting conditions (below) or have some other advantage. The aim is to deliver a uniform spot of high-intensity light to the surface of an object and record the changing reflectance spectra, and it does not much matter how this is achieved, so long as it works.

The spectral power distribution (SPD) of the source depends on the nature of the illuminant and additional filtering; for example, Whitmore used a colored filter to reduce the correlated color temperature of the xenon source from 5,500 K, which is a reasonably good simulation of sunlight through UV-filtered window glass, to 2,850 K approximating incandescent lighting (Whitmore et al. 2000). Although the lower color temperature results in significantly slower fading rates for some colorants at the same intensity, most users employ the higher color temperature because it provides a built-in safety factor by generally overestimating responses expected of artificial lighting. As already mentioned Lerwill et al. (2008) have fitted a tuneable bandpass filter to the source. White LED and

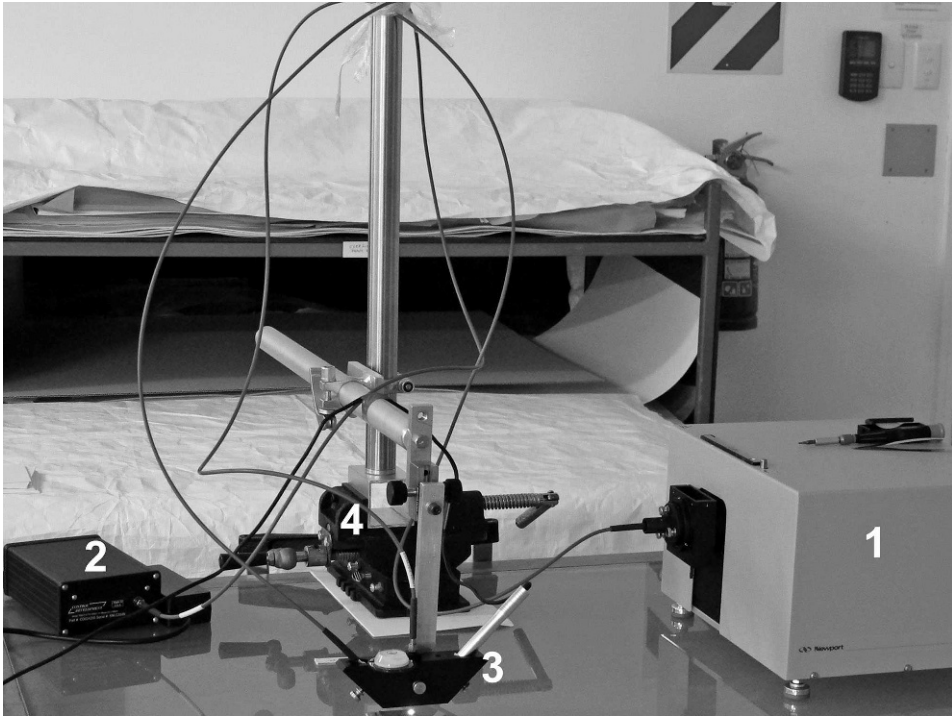


Figure 4. Portable Newport Oriel Microfade Tester. (1) Apex xenon fibre illumination lamp; (2) Control Development PDA 512 USB UV-Vis spectrometer; (3) measuring head; (4) X-Y translation stage and support armatures.

halogen sources have been substituted for xenon (Łojewski et al. 2011, Druzik 2012), and while at present they deliver lower fluxes, the situation will undoubtedly change (Fig. 6). Whitmore and Tao (2010, Tao and Whitmore 2010) have recently replaced the glass condenser and collimating lenses in a Newport Apex xenon lamp with parabolic mirrors overcoming spectral power distribution (SPD) reproducibility problems associated with chromatic aberration of the condenser and allowing measurement into the near-UV, thereby replicating daylight through unfiltered window glass.

Other modifications such as autofocus (Liang et al. 2011) are optional rather than essential or have drawbacks. For example, a version in which the light is delivered to and received from the test area directly through a bifurcated optical fibre (Fig. 6) without lenses (McGlinchey 2008, Druzik 2010) delivers minor gains in portability and ease of setup; however, the modification sacrifices key advantages of Whitmore's design, most notably the focal length (about 12 mm), which allows the measuring head to stand off the surface being measured, thereby avoiding physical contact with the object, the ability to use a camera to easily locate and record the exact area under test, and testing through glazing.

Microscope boom stands can be easily adapted to provide a support for the measuring head and controlled movement across artworks and other large objects. Mounting the measuring head support on an X-Y or X-Y-Z translation stage with motorised (Lerwill et al. 2008) or manual control (Ford 2009a) (Fig. 4) significantly improves the instrument's useability and avoids the need to move the object under test. Like

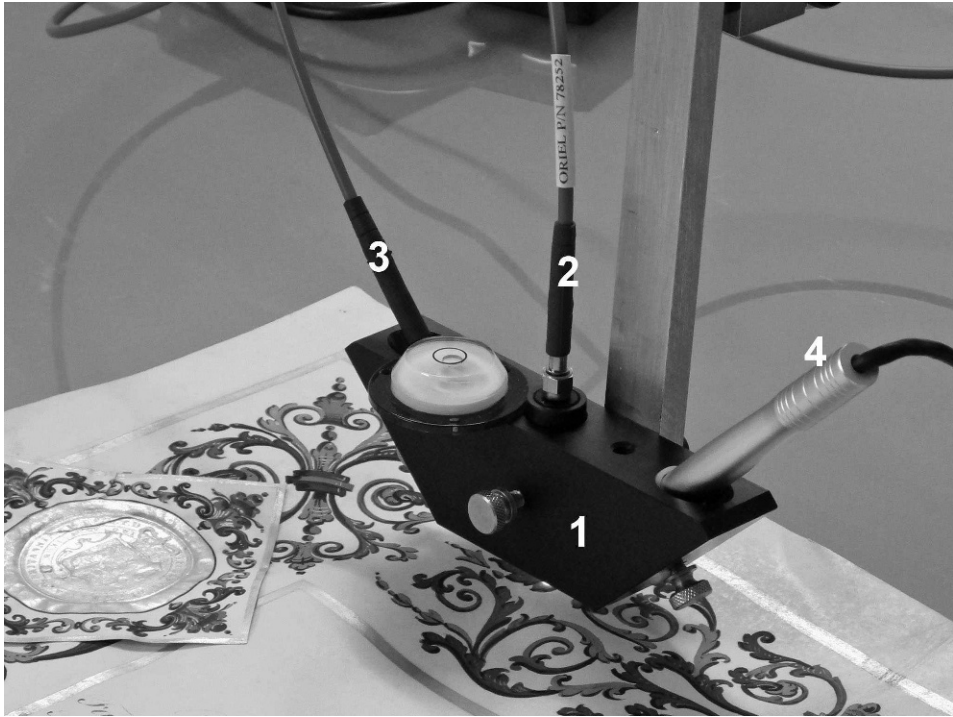


Figure 5. Probe detail. (1) 4 Hour Day probe block; (2) illumination fibre and lens assembly; (3) spectrometer fibre and lens assembly; (4) USB microscope camera.

micrography, with which it shares optical stability and focus requirements, good stability of the supporting structure for the measuring head is critical, a requirement that tends to work against portability, however small the light source or spectrometer.

In principle any fibre optic visible spectrometer is suitable; however, in practice the option to continuously monitor live  $\Delta E$  using supplied software is not common. This capacity, which is a minimum requirement for microfading, is important for monitoring the progress of a test so that in (the rare) cases where there is a risk of perceptible damage, it can be terminated. Live  $\Delta E$  can be added to most spectrometers via third party data acquisition and instrument control software such as National Instrument's Labview; however, the programming required is a specialised skill.

Data acquisition, analysis, and reporting are probably the biggest impediments to the efficient use of microfading as a rapid screening tool for most users. GCI Spectral Viewer™, a free program written specifically for the Control Development spectrometer data files for microfadometry by Lionel Keene (Getty Conservation Institute), is very useful; however, it stores data in a proprietary format that is unlikely to be readable into the future and has limited data analysis and presentation options, and extracting data for further analysis requires cutting and pasting by hand. The use of macros in spreadsheets like Microsoft Excel allow the automation of data acquisition from any spectrometer data file and subsequent data post-processing and visualisation in a form that can be easily exported to report templates in Microsoft Word or PowerPoint with live update between them.



Figure 6. Prototype mini- microfade tester, GCI. (1) LED illuminator; (2) bifurcated lensless probe; (3) variable LED power supply; (4) spectrometer.

A question for institutions with a need for more accurate fading rate data is whether to purchase the equipment and develop the necessary skills and knowledge in-house or to contract in microfading services. At the time of writing, there is at least one contract microfading service available. Most organisations have a short list of important collection items that are always in demand for exhibition or loan and/or are thought to be particularly vulnerable to fading, and for many of these it might be enough to have these assessed. This is likely to be true for archives and libraries with limited exhibition programs. Large museums with diverse collections in which light-driven object replacement programmes are an integral part of their preventive conservation strategy will find it cost effective to acquire their own microfade testing capacity, and it is likely that it will be a standard option for central service laboratories like the Canadian Conservation Institute (who already have it).

As a routine screening tool, the equipment and data interpretation are sufficiently straightforward for a conservator trained in its use to obtain much better and more specific fading data than is available from the literature. There are some manual skills involved in using the equipment, and the flexibility to develop (and validate) measurement methods for different types of objects and surfaces is important, particularly for diverse collections. Acquiring, analysing, and interpreting the data involves using spectrometer software and programs like XL or GCI Spectral Viewer, and the operator needs sufficient background or training to interpret visible spectra and the characteristic patterns of spectral change that accompany changes in the absorption bands of colorants and substrates during fading. Like other scientific analytical techniques such as XRF and infrared spectroscopy that were once purely the domain of specialist scientists, the level of expertise and theoretical understanding required depends on the questions being asked—which at their most basic in the case of



lightfastness testing is which objects are at most risk of fading? At times this might be simplistic; for example, unravelling the role of the different contributions of structural colors and biopigments in animal coloration is difficult even for highly specialised scientists in the area, let alone interpreting changes to those colors. In cases like this the contribution of microfading may be limited to establishing an upper limit to light fading; however, mitigating the risk of unacceptable fading is truly a case of not letting the perfect become the enemy of the good.

#### ACKNOWLEDGMENTS

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# DEFENSIBLE COLLECTIONS: DESIGNING A SAFE EXHIBIT SPACE

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*Abstract.*—A startling number of conservators tell stories about mistreatment of collection material by the public. We used to hear a familiar type of problem: vitrines marred by strollers, glass broken by resting parents, or a pencil falling out of a pocket onto a background. Now, the story is more dramatic: French fries deposited on remote surfaces of large dinosaur specimens. Is an exhibit successful if attendance effectively damages delicate material? This paper provides a broad overview of the risk to exhibited collection material imposed by the visitor. Patterns of damage to collections correspond to specific characteristics of the exhibit spaces themselves. This investigation looks at problems encountered at one large paleontology exhibit and overlays successful concepts drawn from sources outside the museum world.

## DESCRIPTION OF PROBLEM

Despite reduced funding from public and private sources, the American Association of Museums has reported increases in attendance at museums over the last several years in the wake of the global economic recession (AAM 2011). Organizations often tout these statistics as evidence of success, and many seek to build upon this popularity with programs tailored for a newly expanded audience.

Yet as more visitors stream into museums, collections managers and conservators increasingly see a cost borne by material placed on exhibit. Rising attendance has been accompanied by an increase in damage to valuable artifacts, and both published reports and conversations with museum professionals indicate that the problem is getting worse (Drdacky and Galova 2000).

This paper focuses on a single exhibit, Fossil Hall at the Smithsonian Institution's National Museum of Natural History, as a case study of damage to collections caused by visitors. As home to the Smithsonian's paleontology collection, Fossil Hall is an iconic place in the cultural life of Washington, DC, and an eagerly anticipated part of many visits to the Capital. The exhibit, typical of a certain era of design, includes raised decks and platforms for displays, places many specimens within reach of even small children, and sits alongside the Fossil Café. The case study represents an extreme example of visitor behavior. Because it is a feature of one of the most visited museums in the world, Fossil Hall sees more people and therefore confronts a dramatic range of behavior (good and bad). At the same time, this example demonstrates what we have seen at many other museums (Russell 2012).

An unpublished assessment report of 75 out of 475 vertebrate specimens on display in this exhibit was completed in preparation for an ambitious renovation project (Hawks et al. 2010). The survey describes in some detail (Fig. 1) the state of the artifacts, some of which have been on continuous display since the museum opened, and provides a series of recommendations that have shaped the proposed renovation's scope and timeline. Recommended treatment measures relate directly to the age of the mounts, generations of display techniques, and the fragility of the specimens themselves. The collection remains in remarkably good shape given its age and the number of visitors over the years, a testament to the museum's safekeeping over several generations of stewardship.

Exhibit methodologies have a direct connection to observed damage. Artifacts on open display have twice as much mechanical damage and three times as much soil and dirt as

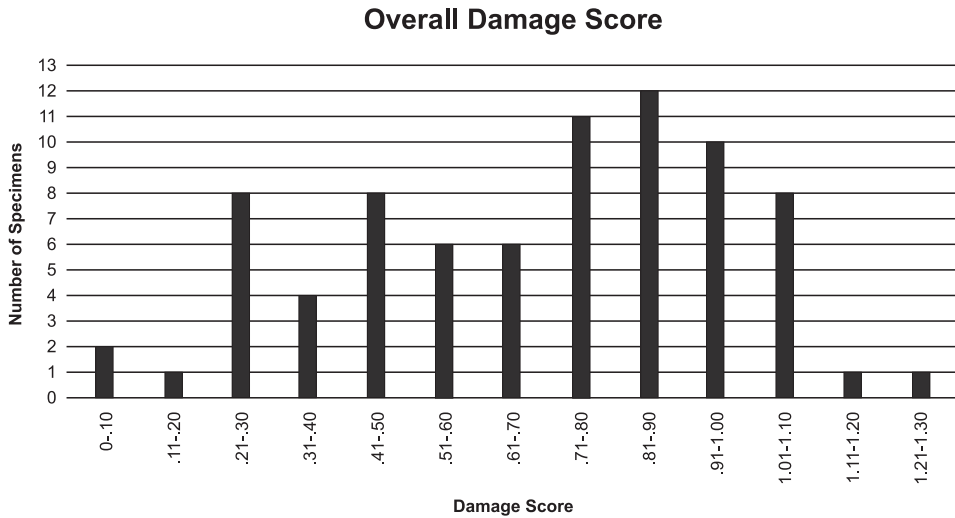


Figure 1. Table indicating damage scores of specimens in Fossil Hall (redrawn from Hawks et al. 2010).

material housed in cases or vitrines. Specimens within reach of the public exhibit more damage than those mounted more remotely. The more accessible items show signs of being touched, and in some cases pieces have been broken and removed. Even specimens mounted overhead have accumulated food residue.

How can this loss be prevented? Exhibiting at least portions of their collections is central to most museums, but so is the preservation of that same material. Understanding how the public display of collections affects the mission of preserving these collections is the focus of this narrative.

#### ACTIVE DAMAGE

Several specimens in Fossil Hall showed signs of damage that could not be accidental in nature:

- Food deposits
- Portions removed (items were taken as souvenirs)
- Discoloration from fingerprints
- Debris within display cases (coins)

The harm to collection material caused by willful behavior—through indifference or vandalism—is active damage. One might assume that this behavior would take place at the margins of the exhibit, out of sight of security guards and museum staff. These incidents might represent an act of opportunity presented by the particular design of the exhibit enclosure.

Mapping the incidents indicates no particular pattern except that noticeable damage clusters around the pedestrian paths through the space. Vandals have not taken advantage of hidden corners or blind spots; most of the incidents were in the open. People seem to have acted without concern for the repercussions of their actions (Figs. 2, 3). One can conclude that wherever there are people, there will be some incidence of damage to the collection. Remedies are difficult to enact because the problem appears to be the audience and not the museum.



Figure 2. Handling exhibited collections is increasingly routine behavior, even among adults. Photograph by Smithsonian Institution.

This report looks to other fields that study behavior at different scales for solutions. A city, for example, has a compelling need for a certain sense of order. Although urban dwellers tolerate some control over their daily lives, they also expect easy and direct access to shared amenities such as parks, plazas, and sidewalks. Why do many urban



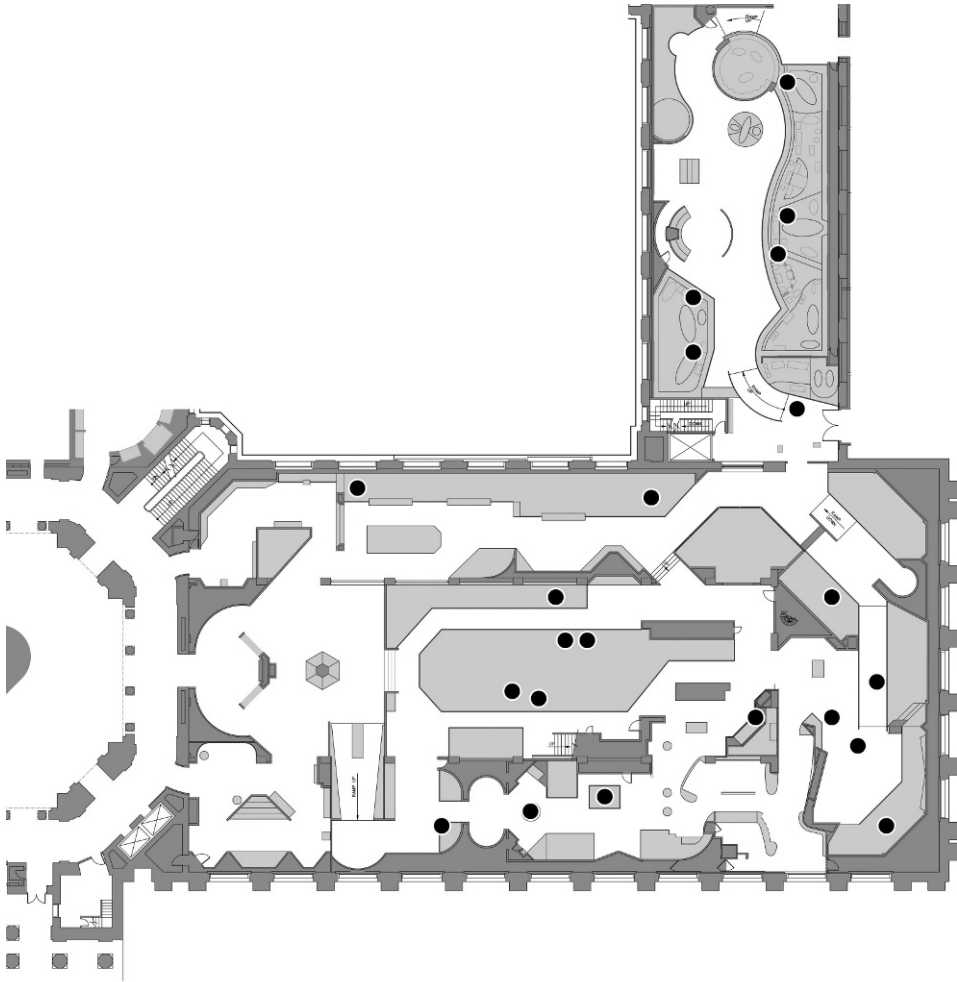


Figure 3. Instances of visitor damage (black dots) to collections range from disposing of trash to contact with specimens. Ironically, repeat damage is highly prevalent in the core of the space despite its high degree of visibility.

spaces thrive even though they are vulnerable to crime and malfeasance? What prevents vandalism in public areas that are monitored to much less of a degree than are museums?

#### BEHAVIORAL DETERMINANTS

Museums are unlikely to consider their visitors to be criminals, yet exploring the causes of crime in the city (a larger scale than a museum) may give museums ideas for protecting their collections. The social sciences offer a variety of models for degenerative behavior, many bound deeply in politics and technical in their analysis of larger socioeconomic forces. This report looks to one example, drafted in 1982 for a general audience, to see whether understanding the structure of urban decay will help explain the underlying factors that contribute to indifference in museum visitors. The scale of the two problems is radically different, but at the root of both is the behavior of people in the public realm.



A seminal article in *The Atlantic*, “Broken Windows,” explains the importance of order and maintenance within the urban conscience. In the face of a dramatic growth in drug use and its related violence, the authors, Kelling and Wilson, suggest that the value of police activity is less about crime prevention and more about maintaining the informal mechanisms within neighborhoods that allow communities to control their environments. Successful communities monitor their spaces and address problems quickly and efficiently (Kelling and Wilson 1982).

The familiar algorithm from this article identifies a broken window as a signifier that group controls have failed. People sense that no one cares, and the neighborhood begins to decline. Police departments lack the resources to replicate the system of controls present in a healthy and vibrant neighborhood; criminals understand this process all too well and take advantage (Kelling and Wilson 1982).

The relevance of this theory is that it looks to the group for the solution. Police watches are unnecessary if a community is functioning properly: families sitting on porches or stoops will report suspicious behavior early, find out what brings outsiders into the neighborhood, and handle nuisance activity quickly. Those closest to the problem are the best agents for correcting it.

As an analogy to the vandalized exhibit, this model suggests that the museum audience can play an important role in maintaining orderliness, joining with security guards, docents, and museum administrators, whose presence has a positive effect on behavior. Visitors outnumber museum staff and are likely to be close by when incidents occur. Can they be asked or even taught to help safeguard a museum’s collections?

#### SPATIAL DETERMINANTS

##### *Defensible Space*

The failure of architects in designing multifamily housing (particularly in New York) in the 1950s and 1960s focused attention on the qualities of effective, secure buildings. The design community enlisted help from the social sciences to determine how safe, livable neighborhoods work. One set of answers came from a research team led by Oscar Newman. *Defensible Space* (1973) explains how the built environment suggests to both an inhabitant and a stranger that an area is under the undisputed influence of a particular group—that a place is controlled by its residents. Certain configurations of space favor the clandestine activities of the criminal, and designing successful places requires the establishment of a clear hierarchy between the public and the private (Fig. 4).

Like the Broken Window theory, *Defensible Space* argues that policing is best done by the people in a community coming together in joint action. Spaces that cultivate safety and vitality include several important features:

- Symbolic barriers
- Defined areas of influence
- Improved opportunities for surveillance.

The implication for museums involves organizing spaces around exhibits to bring the workday of the museum professional alongside the public. Can exhibit spaces be integrated into the fabric of the museum in the way that emulates a small city, with staff and the public interacting on a regular basis? Careful planning creates opportunities for incidental surveillance by museum staff and increases the likelihood of self-policing by the public. Isolating exhibits can leave these spaces untended by staff other than those explicitly tasked with overseeing their goings-on. Our case study, the Fossil Hall (Fig. 5), sits along the main

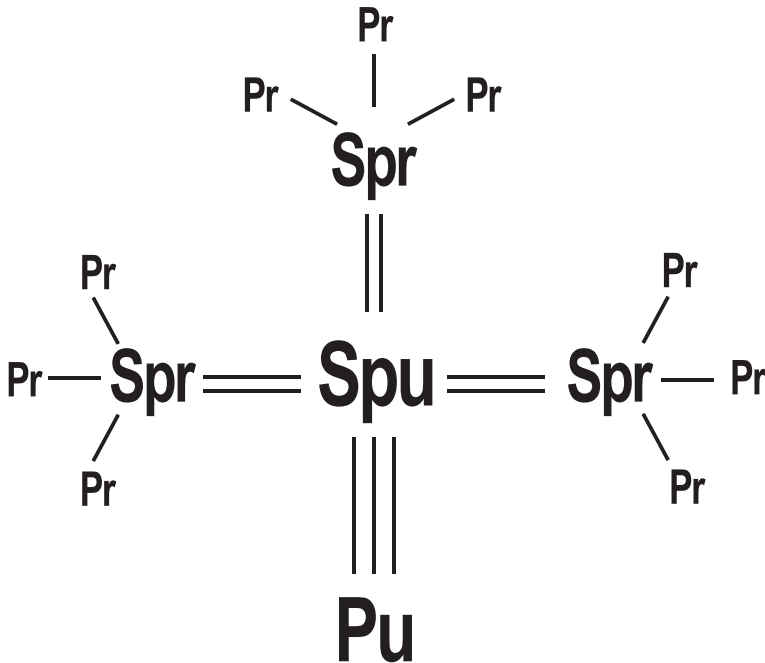


Figure 4. The transition from the public (street) to private (individual dwellings). At each point, ownership of spaces is the clear responsibility of defined groups. For example, several dwellings open onto a stair tower; it is this group's problem to identify suspicious behavior and take action. This group has no responsibility for the elevator lobby in an adjacent dwelling unit (Newman 1973). Abbreviations: Pu, public; Pr, private; Spu, semipublic; Spr, Semiprivate.

entrance to the museum from the National Mall; visitors have immediate access to the exhibit off the Rotunda. The pattern of visitor circulation is clear and direct.

Staff, however, circulate around the space but not typically through it. This pattern is reasonable given the significant attendance levels that the museum enjoys. *Defensible Space* would predict that incidents of vandalism would be reduced if staff were more directly connected to the pattern of visitor circulation. Note that the incidents of vandalism are less frequent in immediate proximity to the FossilLab, staffed by collections managers and trained volunteers.

#### *The Social Life of Small Urban Spaces*

The fact that most museums have (at least somewhat) discreet security systems to protect valuable artifacts is well understood by the public, and yet some treat the collection in ways that are clearly wrong. More obvious monitoring of visitors could further dissuade some vandals, but this strategy could also change the atmosphere of the institution. But is that response necessary? Daily life includes plenty of places where crime is not present, even though the opportunities exist. Many cities have plazas where loose furniture is left overnight, where garbage collects in trash cans and not on the ground, and where things are quiet enough for people to read or even work for long periods of time. Examples are numerous: Market Square in Houston, Bryant Park in New York, cafés along almost every boulevard in Paris. Why are some public places vibrant, orderly, and generally safe for visitors of all ages despite a lack of management—and yet some people show little hesitation mishandling exhibit material?

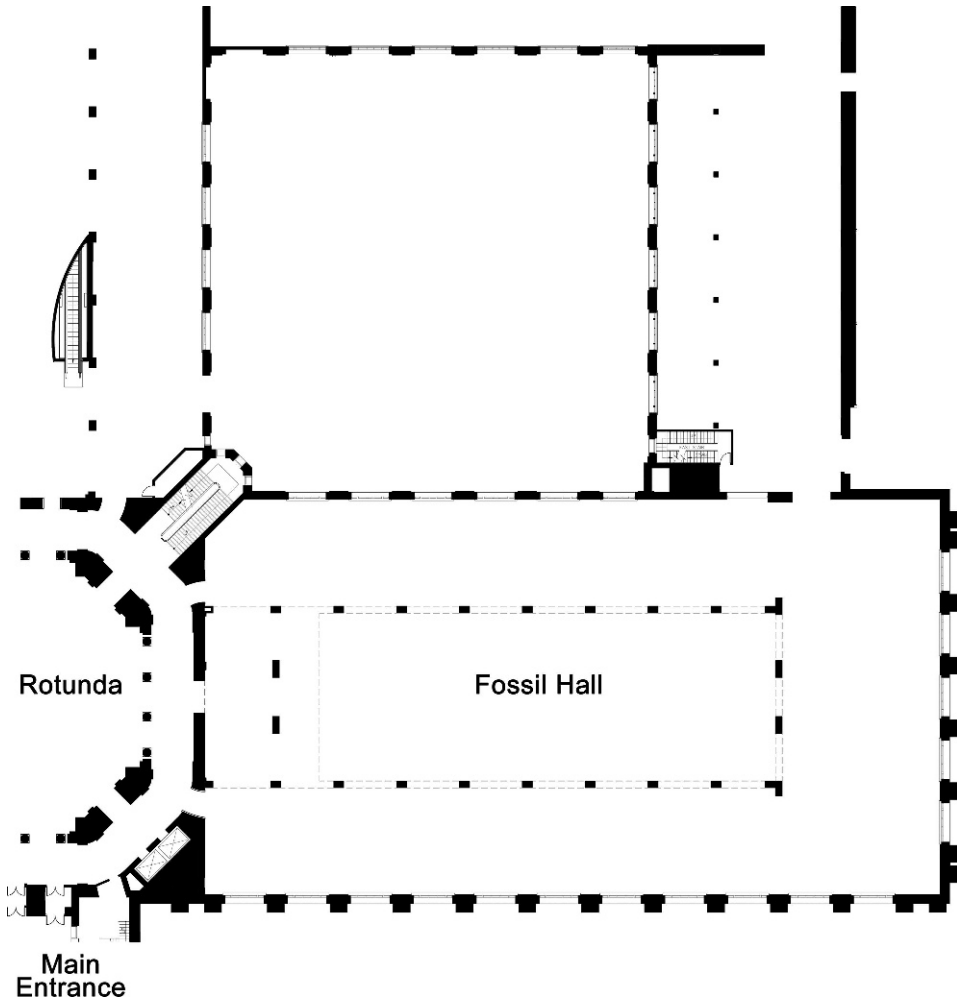


Figure 5. Visitor access to Fossil Hall.

One set of answers stems from research begun in the 1970s by a team of social scientists led by William H. Whyte. The group, now known as the Project for Public Spaces (PPS), observed places over long periods of time. Recording the subtle differences in the quality of street life around large cities, PPS identifies several qualities of successful places that are relevant to museums:

- They are largely self-policing.
- Places can be adapted by their audience (movable chairs and tables are key) to make the space most useful.
- Plazas connect directly to the street; from the pedestrian's point of view the spaces are seamless.
- Street corners are significant places in the life of a city, where people meet, linger, and watch other people.
- Barriers between urban places and the street usually create problems for that space, interrupting its connection to the city fabric (Whyte 1980).

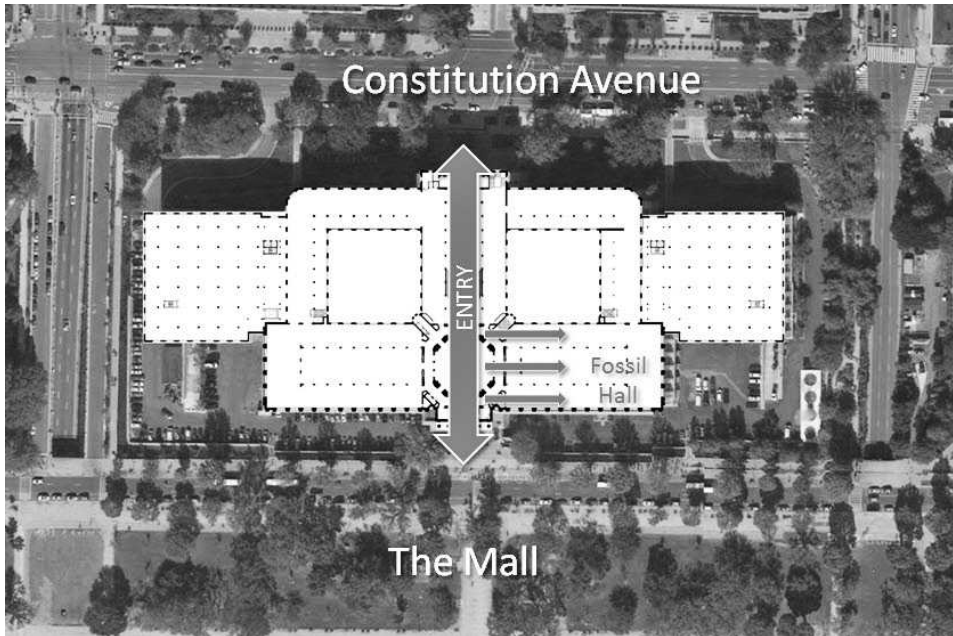


Figure 6. The National Museum of Natural History's building design draws pedestrians from The Mall. Its main entrances and flow of traffic serve as an extension of the sidewalk, pulling visitors into the museum and its main exhibit galleries.

The research suggests that the best way to handle the problem of undesirables who disrupt the peace and quiet is to make a place attractive to everyone else. In city plazas, the solution includes providing amenities such as movable furniture that allow for impromptu meetings. These bring office workers outdoors and into plazas and enliven the space. Orienting plazas along the sidewalk allows activity to flow from the street, so the open space is vibrant whenever the street or sidewalk is active.

Comparisons with urban life are more fruitful for large museums like our case study. The National Museum of Natural History was designed with careful consideration of its place in the District of Columbia (Fig. 6). It connects directly to the National Mall and to Constitution Avenue, continuing the pattern of pedestrian circulation into the building and toward the grand exhibits.

The steps along the Mall and the adjacent Rotunda are lively spaces often filled with people, most of whom will visit Fossil Hall. If the museum were to solicit help from this population, it must provide amenities that encourage at least some people to remain within Fossil Hall. Designing places for people to pause within the exhibit, along the beaten path, ensures that someone will be in the space for more than a cursory visit. Furniture can be particularly helpful in attracting families and the elderly—the people most likely to act responsibly and (maybe) keep an eye on things.

#### PASSIVE DAMAGE

People also represent a risk to the collection even if they do everything a museum professional wants of them. The innocuous harm we inflict on artifacts is passive damage, and this report focuses on two sources: and dust vibration.

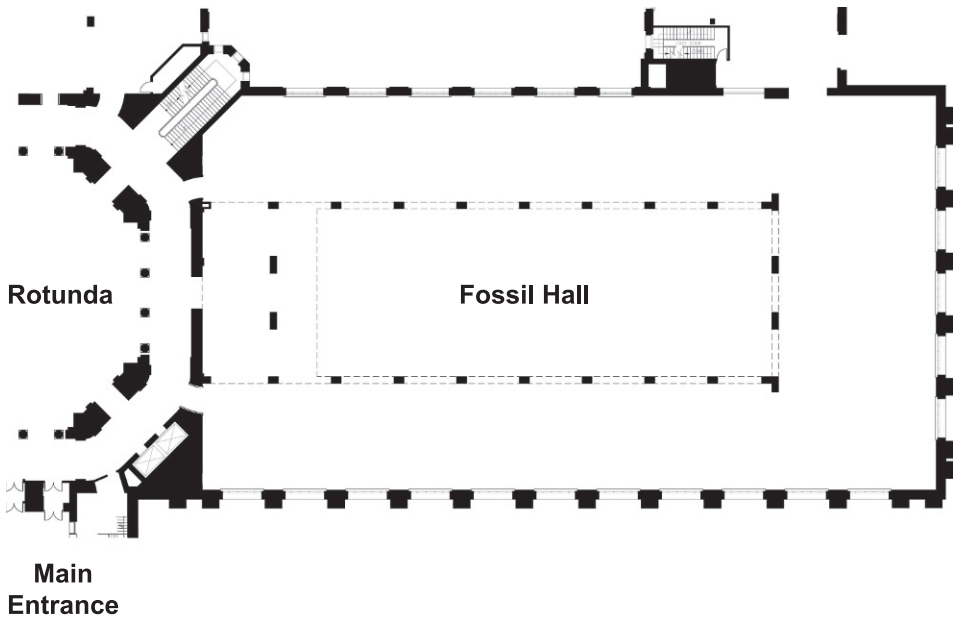


Figure 7. Crowded exhibits like the one at the National Museum of Natural History are at a higher risk to passive damage.

### *Vibrations*

The level of vibrations imposed on collections presents a risk of physical damage from many causes, including abrasion from mounts, displacement of objects from shelves or display equipment, and direct physical damage from accelerations imposed on the objects. Renovation projects can be a time of heightened concern if heavy equipment will be used near the building. Construction activity in one area can produce vibrations that transmit through the building's structural frame and cause problems elsewhere. Institutions will often monitor vibration levels during construction and establish procedures for stopping work in order to limit the exposure of collection material to damage in the event that work exceeds a threshold level of acceleration (Watts et al. 2002). This practice has become fairly commonplace when museum professionals are involved in construction projects.

Everyday sources of vibrations include vehicular traffic, mechanical equipment, and seismic activity. And, yet, the most prevalent source of vibrations that can damage collection material is visitor circulation through a gallery (Thicket 2002) (Fig. 7). A person walking generates a constant force equal to 0.29 kN, creating accelerations of 1.5% ( $a_0/g \times 100\%$ ). The resulting deflection can vary widely depending on floor assemblies and other aspects of the building's construction. Universal standards for allowable vibrations do not exist; requirements instead vary by collection and by institution. By anecdote, many museums have agreed upon limiting the daily exposure of objects to vibration levels based on the construction referenced in Watts and Berry's article (Smithsonian National Museum of American History undated).

Increasing the number of pedestrians in a space has a direct relationship to the accelerations observed (Lloyd and Mullany 1994). Spikes in attendance amplify peak particle velocities within galleries and lead to an accumulated risk to collection material.

House museums pose a particular challenge because these buildings have been typically designed for more lenient structural criteria than is used in the designs of purpose-built museums.

### *Dust and Debris*

The most significant source of dust in a museum is visitors (Yoon and Brimblecomb 2001). Larger dust particles are typically comprised of fibers from visitors' clothing and hair. These particulates are most frequently deposited at the ground level and redistributed along circulation paths by people walking through the exhibit; dust levels fall off dramatically as the distance from visitors increases (Nightingale 2005/6).

Dust is of significance because it damages collection material by soiling and again from the cleaning required for its removal. Although particulates of less than 3  $\mu\text{m}$  in length and width may be a bigger concern in the long term, larger visible particles are noteworthy because they can be managed by janitorial staff and by filters in the building's HVAC system (United States Environmental Protection Agency undated).

The situation is complicated when an institution exhibits fragile material, such as textiles, on open display. Dust distributed on exhibits may be more visible in the dimmed light often required in textile galleries. Exhibit material in this situation needs more frequent cleaning to maintain a sense of appearance and avoid complaints from visitors resulting in further risk to the objects (Nightingale 2005/6).

Both sources of passive damage point to people as a threat to collections without other mitigating factors. Limiting vibrations often requires significant structural interventions in a building. A more cost-effective solution (at least in terms of initial costs) would be to install special mounts within cases or to control the flow of visitors, either by limiting the number or by controlling the rate of access (timed visits). Methods for reducing the potential for dust damage involve regular cleaning of floors and other surfaces and increasing the distance between the collection material and the public. The latter calls for careful consideration during the design of the exhibit in order to integrate collection management into its didactic theme. But separating fragile material from the public promises a more complete solution, since barriers (glass display cases, stanchions or rails, and pedestals and elevated platforms) require no active maintenance to work.

### TOOLS FOR SAFEKEEPING YOUR COLLECTION

Addressing the problem of damage caused by the visitor questions the methods used to exhibit a collection. Passive damage relates more directly to display techniques and may be easier to solve if collection material can be taken out of open display or relocated at a distance from the public. Large specimens, however, may not be so easily rehoused, and exhibit components such as dioramas may be of significance in their own right and not readily altered.

Controlling or managing active damage requires a constant effort on the part of the museum—engaging museum patrons, reorganizing exhibit space, and managing the flow and visibility of visitors.

### *The Exhibit Environment*

The organization of spaces affects how occupants move to and through an exhibit, determines the level of interaction between museum staff and museum visitors, and shapes visitor interactions. It creates possibilities for learning, for discovery, and for fostering a sense of community. At the same time, visitors may see opportunities for



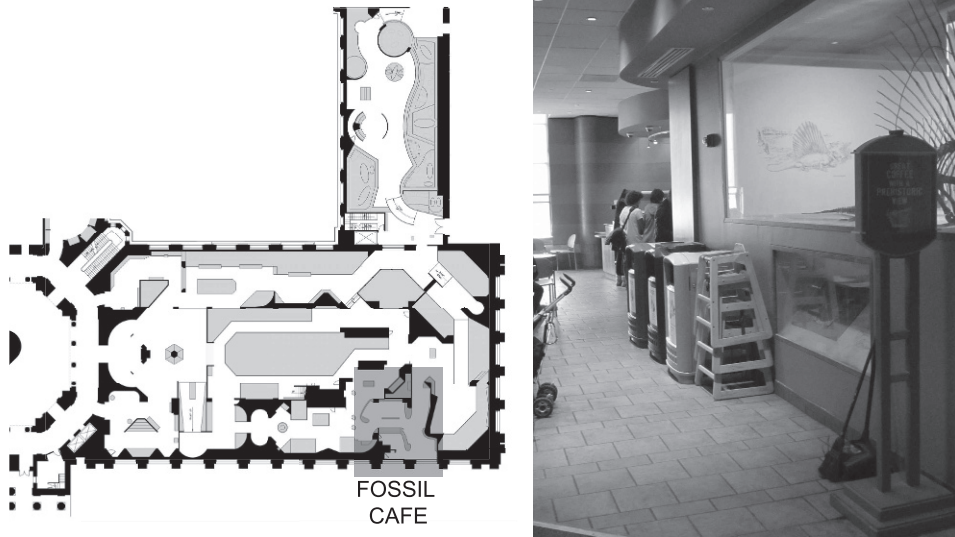


Figure 8. The Fossil Café is so highly integrated into the design of the exhibit that a clear entrance and exit cannot be distinguished. What does this say to the museum visitor?

mischief, for people in crowds use museums in ways that may not have been anticipated in their design. Exploring a few examples from our case study suggests ways of reducing risk to collection materials on display.

### *Boundaries*

Most museums provide a variety of experiences that elicit different types of behavior from people. A gallery may be a place of quiet reflection; a museum shop may be more spirited. Delineating their edges helps reinforce the appropriate etiquette in the different places.

Locating amenities like a museum store near collection material pairs the need to generate revenue with the museum's preservation goals. Damage in our case study at Fossil Hall indicates that the public does not always understand the difference between the commodity and the artifact; conversations with staff reveal that the public frequently believes specimens are not real. An example cited in the collection assessment report describes children tampering with exhibit backgrounds in an attempt to find out if the materials (sand, grasses, and other surfaces) were authentic. Some things are replicas, such as toys on sale in the store within the nearby Mammals Hall. A clear distinction between a store and the rest of the museum would better distinguish the commercial portions of an institution—and the associated behavior of shopping from the presentation of specimens and artifacts.

Things are much worse when the amenity is food service. A good deal of the damage cited in our case study's assessment revolves around the museum's decision to place food service immediately adjacent to the exhibit (Fig. 8). This juxtaposition has been extremely unpopular with collections staff (and is expected to be remedied during a future renovation) as instances of damage frequently occur in proximity to the café. Its design aggravates the problem by blending into the surrounding exhibit, sending an impossibly subtle message about where mess is acceptable and where it is not tolerated. The lack of



Figure 9. The placement of this “Please Touch Gently” sign invites visitors to handle the specimen. Nearby specimens (background) should not be touched.

both an identifiable entrance and exit to the café makes it possible for people to misunderstand the extent of the food service venue. Garbage cans are hidden to avoid being an eyesore, so the public has to decode the interior design to understand where to dispose of trash.

Boundaries help reinforce the limits of certain kinds of behavior, and they are important as natural history museums seek to attract families with young children and first-time museum goers. Museums frequently accommodate these new audiences with tools such as maps to direct people through an unfamiliar venue. Postings of rules related to specimen care are far less common, although a growing number of visitors are unfamiliar with the fragility and importance of artifacts on display. Instead, most institutions rely on subtle messages regarding expectations of audience behavior to avoid offending people who know better. Evidence suggests that museums need to communicate more clearly to help mitigate damage to collections.

The problem of communication rises to a head when exhibits encourage the handling of objects alongside material that should not be touched (Fig. 9). Examples include the display of replica textures and objects intended to give the audience a tactile sense of the artifacts encountered in the rest of the exhibit. Here the rules of behavior depend on a narrative because the physical distinction between “do’s and don’ts” is complex. In our case study, signage describes what can be handled but (almost always) fails to indicate what should not be handled. The distinction is clear only to the museum professional and could be more explicitly presented to visitors.

Spaces such as fossil prep labs or learning centers bring visitors into contact with collection material and demonstrate research methods and equipment. These places are wonderful tools for sharing the work of research institutions with the public, but they require an explanation of the care museums take with collections material and the work required in preserving it for display and for research. Without this effort, the demonstration space may convey a sense of messiness without revealing the skill required to do these tasks properly. In other words, the connotation may be that orderly behavior may not always be necessary within exhibit halls.

### *Acoustics*

Spaces filled with people, particularly excited children, can be extremely loud. Perhaps the added volume is a necessary by-product of success. The public comes to your building and enjoys itself—so what if there is an uproar? The problem is that the noise is more than just an annoyance—high sound levels change people’s behavior, and not usually for the better.

High noise levels make learning extremely difficult, reduce visit times, and change the aesthetic planned for the space (Shield et al. 2010). This problem is exacerbated at natural history museums because of the number of school visits the typical museum hosts, the average age of the visitors, and the tendency to mix exhibit types (for example, it is OK to yell and scream during an IMAX movie, but then the children leave and head for a static exhibit).

Noise and aggression have a direct relationship—increasing ambient sound levels leads to more aggression in people predisposed to that type of behavior. In response to noise, people will focus their attention and oversimplify their surroundings, distorting their perceptions of complex social relationships. The result is that increases in sound levels are concomitant with decreases in interpersonal sensitivity. People become less concerned with being polite and less sensitive and caring about their social situation (Cohen and Spacapan 1984).

Increased sound levels contribute to an environment where people see no consequence in damaging public property. The noise does not cause the vandalism, but it makes people more likely to act on miscreant thoughts. In contrast, quietness is an effective psychological indicator that unruly behavior is inappropriate. In our experience, art galleries are seldom as loud as our case study. Instances of vandalism in art museums do occur but are often of a different nature: people making a personal or political statement (Russell 2012). Reducing sound levels in natural history museums requires careful thought in their design and can be expensive to solve after the fact. Moreover, museums are social places where communities may expect to have a conversation about art, science, and history. Despite this, reducing sound levels should be considered as a means of controlling marginal behavior and protecting the collection without compromising access to collections.

### *Collection Display Methods*

How the collection is presented to the public has a significant influence on its safekeeping. The conditions assessment of Fossil Hall indicates material stored in exhibit cases has fared better than items on open display; however, even the cases show signs of tampering as coins are frequently found in several vitrines. What appears to be the best indicator of collection safety is the distance of the object from the public.

The progression over time in the display of the model *Stegosaurus* in Figure 10 indicates a move away from a formal presentation of the artifact toward its placement



Figure 10. *Stegasaurus* model display through time at the National Museum of Natural History, Smithsonian Institution. Photographs by Smithsonian Institution.

within a composed environment. Located close to the public, the replica has been damaged due to mishandling.

Setting aside other, valid exhibition goals (e.g., connecting people to your collection, outcome studies), exhibit design should consider the following (Nightingale 2005):

- Barriers around items on open display
- Bases at least 30 cm high
- Positioning fragile items away from entrances.





Figure 11. Historic photo of Fossil Hall, National Museum of Natural History, Smithsonian Institution, from the early 1900s. Photograph by Smithsonian Institution.

These suggestions are rooted in the goal of reducing exposure to dust and debris, yet they also protect material from vandalism and require no active maintenance to work.

An example is found in early photographs of Fossil Hall (Fig. 11). Artifacts are presented as sculpture, on pedestals, and with adequate space alongside for circulation to accommodate large groups. This arrangement satisfies many of the qualities of safety deemed important by the Defensible Space theory: clear views of the space allow museum staff to observe the activity, while stanchions serve as symbolic barriers between the circulation space and collections. Finding a modern interpretation of this type of presentation of specimens would move some of the collection material on exhibit farther away from people—or at least the most fragile pieces.

These design gestures require careful planning and some explanation to the public as to why certain material is displayed differently or at a distance.

Collection display methods should also take into consideration routine maintenance. Vitrines and display cases protect specimens, but if the surrounding interior architecture inhibits access to the case for custodians, the area will not be cleaned on a regular basis. Trash and dust will eventually accumulate, providing a subtle cue that the area is not under control and may invite misbehavior (a problem predicted by the Broken Window theory).

### *Museum Operations and Program*

One might excuse younger visitors' behavior and lack of understanding of the consequences of actions, but evidence at Fossil Hall shows that adult behavior can be even more egregious. One account details a mother lifting her child over a stanchion so that he could break off a fossil to take home as a souvenir. Other stories indicate a great deal of the public believe the specimens are fake, a problem often exacerbated by the use of handling collections and the mixing of these collections with real specimens. Dispelling this preconception requires the museum to be transparent about its research, the science within exhibits and the effort required to preserve fragile collections.

### *Educate Your Audience about Conservation*

We assume the person snatching the fossil knows very little about the effort required to discover and preserve it, and meeting this lack of understanding head-on offers a way of

connecting a museum's education and preservation missions to increase public awareness and to solicit help. Exhibits that include a focus on conservation can engage the public as a partner in preservation. Free museums like the one in our case study can use this message to foster a sense of ownership and responsibility to the public. A knowledgeable audience is more likely to police its environment.

This type of exhibit can take many forms. Bringing curatorial staff onto the exhibit floor is a key component of many learning centers, and the public enjoys hearing stories directly from the experts. Extending this idea to conservation connects the museum's education and preservation goals; it also places demands on staff that may not be practical in this economy.

Other methods of introducing the public to conservation make use of technology to reach the museum's youngest visitors. The Museum of Liverpool (undated) employs an online game that allows users to play detective to determine the root causes of deterioration to specimens by reading clues. Introducing the value of preservation and exposing children to its science creates life-long advocates—and may help reform parents.

### *Clarify Signage*

Signage must play a more central role in the preservation of collection material. Our case study identifies the conundrum of subtlety—inviting people to handle portions of an exhibit can be interpreted as an open-ended opportunity. Museums need to be candid and direct about their expectations of how visitors should interact with the collection (and behave in general).

Language greatly influences the resulting behavior. A survey by Mt. Ranier National Park has tested several different types of signs within hundreds of miles of open trails. The first sign type states “off-trail hikers may be fined.” The second sign, an ethical appeal sign, states “stay on paved trails and preserve the meadow.” Other signs included a symbol without text and a humorous message. While all signs were effective in reducing hiking off-trail, the first sign indicating “off-trail hikers may be fined” was by far the most effective, by nearly 25% (Johnson and Swearingen 1992). Though taking such a hard line may seem overly aggressive (and we do not suggest fining wayward visitors), careful consideration of the text is needed to protect the most precious specimens in a collection.

### *Manage Crowd Sizes*

Peak visitation is a time of increased risk to the collection from both active and passive sources of damage. More people generate more vibrations from foot traffic, more dust and debris, and (maybe) more opportunities for mischief. Lower attendance levels may reduce the risk to the collection, but museums are unlikely to turn away revenue by limiting the number of visitors. A more palatable method of reducing risk is to time visits in order to spread the occupant load over a longer period of time. Integrating this idea into the exhibit requires amenities such as plaza-like spaces alongside the exhibit for people to pause before entering. Giving these spaces a clear boundary would reinforce the difference in appropriate behavior between the queuing space and the exhibit. This strategy would reduce the peak vibrations imposed on the structure and could limit noise levels in the galleries.

## CONCLUSIONS

Seven million people visit the National Museum of Natural History a year, making it one of the most visited institutions in the world. If one person in 100,000 vandalizes an



artifact, then the collection endures 70 incidents of damage. The rate could be much higher.

As more people visit museums each year, institutions must take reasonable action to protect their collection material. Our observation is that museums are well versed in preventing passive damage to collections, but the growing threat of vandalism and other forms of active damage has not been adequately addressed. We strongly suggest that institutions solicit help from their audiences in protecting collection material—via a clear dialogue about conservation, and by changing the way that exhibit spaces are organized to encourage appropriate public behavior.

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# APPLICATION OF PREVENTIVE CONSERVATION TO SOLVE THE COMING CRISIS IN COLLECTIONS MANAGEMENT

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*Abstract.*—The 1.8 million known species are represented by 2,500,000,000 voucher specimens in collections; at this rate of accumulation, naming the yet to be described species will produce up to 35,000,000,000 additional specimens. To manage these very large collections of the future new methodologies must be developed based on the application of the principles of preventive conservation, including new designs and standards for storage furniture for maximum efficiency in monitoring specimen condition, control of the storage environment, and the functionality of collection databases to make them better collections management tools. Application of the theory of preventive conservation to the care of very large collections can be used (1) to enhance the stability of the collection storage environment, (2) to improve the quality of specimen tags, labels, containers, supports, and collections storage furniture, (3) to make collection databases better management tools, and (4) to develop more efficient collection storage arrays.

Soon natural history museums will be faced with a problem that is very old, but also very new—how to house, manage, and care for collections larger than we have ever dealt with before. Estimates of the total number of species on Earth range from 3 to 30 million (Yoon 2009). The total number of species named at present is around 1.8 million (Yoon 2009), about half (60%) of the low estimate, or about 6% of the high estimate. Currently taxonomists are describing about 20,000 new species each year, a rate of publication that has been increasing for some time (Wheeler 2010).

Historically, surges in the rate of species discovery have produced some astoundingly large collections. For example, the Natural History Museum of Paris (Muséum national d'Histoire naturelle), founded in 1793, has 60 million specimens (Muséum national d'Histoire naturelle 2012), while the Natural History Museum in London, founded in 1756, has 70 million specimens (Natural History Museum 2012). Housing and caring for collections this size is very expensive. During the last 10 years, the Natural History Museum (London) has added two new buildings for collection storage. Darwin Centre I (Fig. 1A), opened in 2002, houses fluid-preserved specimens; Darwin Centre II (Fig. 1B), also known as “The Cocoon,” opened in 2009 for botanical and entomological collections. Neither of these additions was inexpensive—Darwin I cost approximately about \$2.18 per specimen; Darwin II cost about \$6.25 per specimen (Table 1), and those are just the building costs—they do not include the cost of storage containers, or specimen preparation and cataloging.

The total global systematic collection resource today is estimated to be at least 2.5 billion specimens (Howie 1986; Krishtalka and Humphrey 2000); these specimens are the critical reference material for the 1.8 million species that have been named so far (Reid 2010). Assuming that a reasonable number of the still unknown species can be collected and identified, this will have an enormous impact on collection size and housing costs (Table 2).

Where will these specimens be housed, and who is going to pay for the containers, the cabinets, and the buildings to house them, not to mention the preparation, cataloging, and long-term care and management of this many specimens? If we have learned anything from what we have done over the last 200 years in building systematic collections, it is that large increases in collection growth are not accompanied by similarly large increases

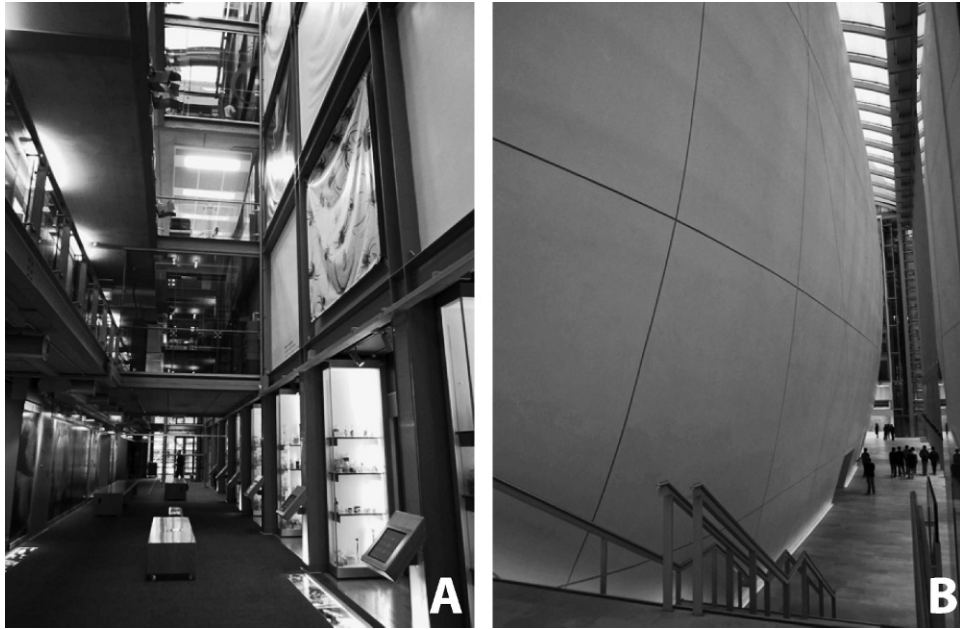


Figure 1. (A) Darwin Centre I housing fluid-preserved specimens, the Natural History Museum, London. (B) Darwin Center II housing dry-preserved specimens, the Natural History Museum, London.

in collections management staff or budgets; thus we must find ways to do more with less. The estimated ratio of collections managers to specimens is about 1 : 200,000 internationally (Howie 1992)—in the future, collections managers will be faced with even larger collections. Museums have four options for coping with growing collections: (1) increase the density of on-site storage, (2) establish off-site storage facilities, (3) cease the acquisition of specimens, or (4) deaccession specimens from the collections to make room for new material. Each of these options has advantages and disadvantages, but even if one or more of these options is enacted, most museum collections will continue to grow as new species are discovered and described.

To manage very large collections, we must develop and implement new methodologies that provide cost savings through economies of scale, but that are based on the application of preventive conservation principles, with particular emphasis on collections storage environments and techniques that more efficiently promote the long-term stability of individual specimens as this is, by far, the most cost-effective way to manage collections. One thing is certain—we cannot continue to manage our collections the way we have in the past. In the future, we must use space and our limited collections care resources much more carefully.

Table 1. Generalized costs of Darwin I and Darwin II at the Natural History Museum.

Building	Contents	Specimens	Storage	Cost
Darwin I	Fluid-preserved specimens	22,000,000	27 km of shelves	£30,000,000 (\$48,000,000)
Darwin II (the cocoon)	Entomology Botany	17,000,000 3,000,000	3.3 km of cabinets	£78,000,000 (\$125,000,000)

Table 2. Estimated collection growth at current proportion of specimens to species.

Number of described species	Number of reference specimens in museums	Estimated cost to house prepared and cataloged specimens (\$)
1,800,000	2,500,000,000	Unknown
3,000,000	3,500,000,000	7,630,000,000–21,875,000,000
30,000,000	35,000,000,000	76,300,000,000–218,750,000,000

### HISTORICAL PERSPECTIVE

Museums have faced similar crises before. The history of modern museums is one of continually outgrowing facilities and somehow managing to find more space. But this new and coming crisis will be at an order of magnitude we have not dealt with before (Table 2). A look back 100 years may help us find a way to cope.

On 18 May 1900, the well-known Egyptologist William Matthew Flinders Petrie (1852–1942) published a paper entitled “A National Repository for Science and Art” (Petrie 1900, Podgorny 2012). Petrie called for the construction of a large—a very large—off-site storage facility for London museums to resolve what he saw as a coming crisis in collection registration, storage, and specimen access. Petrie wrote:

At the end of a century which has so rapidly and greatly changed our very conceptions of the nature of knowledge, and our standpoint for seeing both man and his world, it is well to loosen our old ideas somewhat, and look at things with fresh eyes, so as not to be in bondage to conditions that have already passed away. No one would now think of writing a scientific or historical book on the lines of treatises of 1800 or even 1850. And if that be true of the formal presentation of our new knowledge, how much more is it true of the nature of the materials and evidence on which our books are built. (Petrie 1900:525)

Petrie proposed building an unadorned, purpose-built, fire-resistant facility with extensive collection storage space that was easy to access, could be expanded on-site, and would provide adequate protection for collections as it was then understood. Petrie’s proposed “Sloan Galleries” (to be named for the Sir Hans Sloane [1660–1753], whose collections founded the British Museum), were to be located outside of London on a square mile of space that would be gradually filled with individual, one-storey buildings as museum collections continued to grow for the next 100 years.

Petrie’s essay generated a lot of interest when it was published and was awarded a silver medal by the Royal Society of Arts (Anon 1900). The following month, on 1 June 1900, an abbreviated version of the essay was published in the United States in *Science* magazine, other abbreviated versions were published over the next few years in different publications, and the proposal was discussed at several professional meetings.

Although there was no cohesive theory of preventive conservation in 1900 (Williams 1997, Muñoz Viñas 2005, Applebaum 2010), many of the ideas that Petrie proposed are part of preventive conservation today. For example:

- Petrie’s plan called for carefully planted trees to shade buildings to moderate the internal storage environment. Due to the unreliability and fire danger presented by gas, oil, and electric lighting technology in 1900, Petrie proposed that “The lighting would be by skylight, a quarter of the whole roof area, giving from 18° to 36° of clear sky in different parts” (Petrie 1900:531). Specimens and objects would be housed in closed cabinets within the buildings to protect them from light when the objects were not in use.

- England's notorious relative humidity would be controlled "by a free use of trays of quicklime in all the cases" (Petrie 1900:530), establishing easier-to-control microclimates within the closed storage furniture instead of attempting more costly climate control of the entire building.
- Petrie surmised that objects would be better protected in closed cabinets because he presumed that the rate of interchange of air in cabinets was low; we now know this is true (Michalski 1994; Calver et al. 2005; Thickett et al. 2007).

#### APPLICATION OF PREVENTIVE CONSERVATION

Both on-site and off-site storage facilities should be used as efficiently as possible to control costs while still providing protection and access to the collections. Incorporating the principles and practices of preventive conservation in storage systems can help museums achieve both. Preventive conservation refers to the prevention of deterioration of collections—for example, by establishing appropriate management policies and providing a stable storage environment for the collections (Rose and Hawks 1995). Application of the theory of preventive conservation to the care of very large collections can be used (1) to enhance the stability of the collection storage environment, (2) to improve the quality of specimen tags, labels, containers, supports, and collections storage furniture, (3) to make collection databases better management tools, and (4) to develop more efficient collection storage arrays.

#### *Stable Collection Storage Environments*

Arguably, the aspect of preventive conservation which has had the greatest positive impact on natural history museums since 1985 has been the attention paid to maintaining stable storage environments (Rose and Hawks 1995; Winetraub and Wolf 1995; Fisher 2010). Preventive conservation research has indicated a number of ways in which collections care resources can be used more efficiently. For example, the use of thermal pane windows, storing the collections in interior rooms, ensuring the quality of the building envelope (because buildings have a longer maintenance cycle than environmental control equipment), and using vegetation to reduce the effect of heat islands formed from the absorption of solar energy by hard surfaces (Daniel et al. 2000; King 1993) all help moderate the macro-environment, while the use of archivally stable storage materials and quality storage furniture provides better micro-environments. Further discussions of stable storage environments can be found in Fisher (2010), Simmons (2002), Swain and Buck (2010), and Toledo (2006).

#### *Quality of Specimen Tags, Labels, Containers, Supports, and Storage Furniture*

Another area in which preventive conservation has had a significant positive impact on natural history museums since 1985 is in the use of archival quality tags, labels, containers, supports, and storage furniture (Moore and Williams 1995; Rose and Hawks 1995; Swain and Buck 2010). Information on quality materials and testing methods for tags, labels, containers, and supports is now widely available (e.g., in various issues of *Conserve O Gram* from the US National Park Service and *CCI Notes* from the Canadian Conservation Institute; see discussion in Simmons and Muñoz-Saba 2005).

Although adequate information is available in the literature to make wise choices for archivally stable tags and labels, some museums still implement systems that provide short-term efficiency at the cost of better long-term use of resources—for example, bar

codes. The use of bar codes makes information recording much more efficient and nearly error-free, but it is a technology with a short life span (Mayfield 2002). Much like computer diskettes and compact disks, bar codes require special machines to read the information they contain. When bar code readers are no longer supported by industry, museums will no longer be able to maintain their equipment. Bar code technology is changing rapidly, and many applications are being replaced by RFID (radio frequency identification chips) and other technologies. RFID tags have many advantages for industry over barcodes, some of which are applicable to museums: RFID tags are less prone to physical damage, do not need an unobstructed optical pathway or human manipulation to be read, and can be programmed to carry much more information (Wolff 2001; Nusca 2010; Patel 2010). Museums should carefully evaluate the long-term value of technology-dependent labeling systems before investing limited collections care resources in short-lived technologies. Rather than bar coding a collection (which typically means attaching additional labels with an adhesive that is not archivally stable), museums should consider using archivally stable printing systems to prepare tags and labels that can be read without machines as well as by optical readers or scanner technologies.

An aspect of collections care that can benefit from the application of the theory of preventive conservation is in the configuration of storage furniture. The shapes and sizes of museum storage furniture have long been driven by tradition rather than consideration of efficient long-term preservation of specimens. Typically storage furniture is selected to maximize the use of space without regard to the expenditure of other resources on collection monitoring, particularly staff time. Ideally, storage furniture should both protect the collection and make it easy for specimen condition to be monitored and specimens to be retrieved without having to touch or move specimens. For example, a single row of containers of fluid-preserved specimens on a shelf (Fig. 2A) allows for fast and efficient monitoring of fluid levels and visual aspects of fluid quality, as well as order in the storage array; however, when the shelves contain two or more rows of containers (Fig. 2B) it is necessary to move the containers in the front one-by-one to check the containers behind them for fluid level and collection order, which is time-consuming and carries with it an increased risk of disrupting container seals and misplacing containers. Instead of deep shelving housing several adjacent rows of containers, a more efficient configuration would be many more ranges of shelves that accommodate a single row of containers that could be quickly and easily monitored. Similarly, drawers and cabinets for storing dry specimens should be configured to both protect the specimens from deterioration and allow all specimens to be monitored without having to move one specimen to see another. For example, study skins should be arranged in drawers to make efficient use of space, with the specimens not overlapping one another, with tags and labels visible without having to move the specimens, on a light-colored background (for easier inspection for pest activity) that provides a barrier against the migration of acids or oils (e.g., polyethylene foam or acid-free paper). Large, heavy specimens such as fossils and geosciences specimens should be arranged in a configuration that makes it possible to locate and remove or replace individual specimens without having to shift adjacent specimens.

#### *Collection Databases as Management Tools*

Another aspect of Petrie's (1900) paper that is worth examining more closely, in the context of applying the principles of preventive conservation to managing large collections, concerns registration and cataloging processes. To speed up the slow process



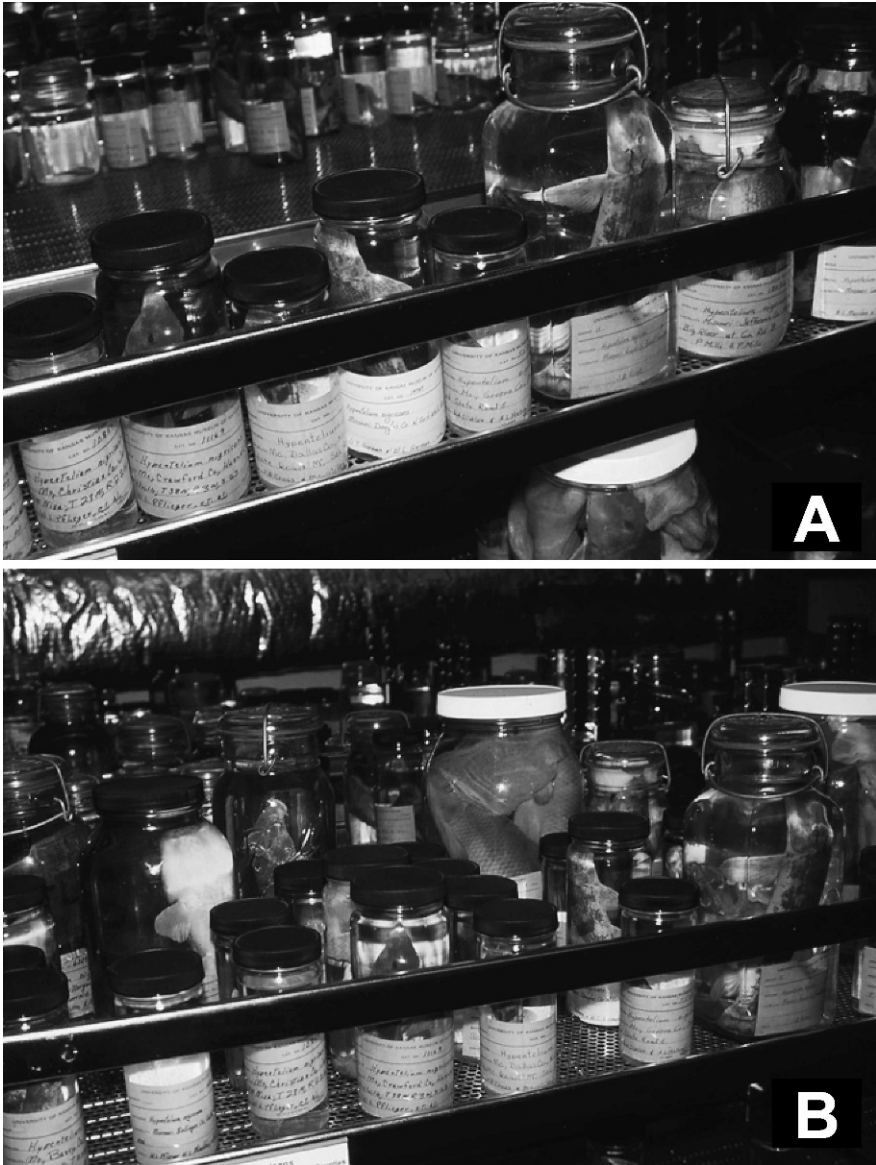


Figure 2. (A) Single row of containers of fluid-preserved specimens on a shelf. (B) Multiple rows of containers of fluid-preserved specimens on a shelf.

of cataloging vast collections, Petrie proposed using photo-documentation instead of having experts laboriously describe each object, which would take advantage of the then new technology of precise, close-up photography. This suggestion could have made a significant difference in the efficiency and effectiveness with which collections were cataloged had it been implemented on a large scale. Today the processes of registration and cataloging have been enormously speeded up by computers and electronic databases. Although we have good collection databases available today, they are still simply memory storage and retrieval systems that make it possible to do what was once done

with paper systems faster and more accurately because database development has been driven by the need to make more use of specimens and data rather than the need to better manage and care for collections. As a result, while we are handling the traditional tasks of accessioning, cataloging, making loans, and so forth quite well, our databases are not yet the useful tools for collections management that they should be. For example, the KE EMu database is described as including “taxonomic definitions, specimen identification, type status, field trips, and a gazetteer” (Sendino 2009:152); the so-called “conservation” component is nothing more than a bookkeeping feature that allows recording and scheduling of object examinations and treatments—the software does not link environmental monitoring data to collection deterioration rates or provide any analysis of factors that might affect the usable life of the specimens (KESoftware.com. 2012). A true collections management database should integrate information on specimen preparation (both in the field and in the lab), collection use, environmental monitoring, specimen inventories, specimen use records, integrated pest management, specimen field notes, and correspondence related to the collection, along with registration data, to be an effective collections management tool.

A more troubling aspect of database use is that museums are greatly increasing the amount of information they maintain in electronic formats—and some are dispensing with written catalogs all together—without consideration of the fact that at present there is no way to reliably preserve electronically recorded information for the future. No available means of preserving electronic data is as reliable as data recorded on acid-free paper with a nonacidic carbon-based ink: tape systems, hard drives, and “the cloud” all depend on magnetized metallic particles embedded in polymer systems that have short life spans (Hedstrom 1998; Tooby 2001; Blue Ribbon Task Force and Rumsey 2010). This means that museums in the future will be confronted with a continual expensive and risky conversion of electronic data as each new generation of hardware and software comes and goes, further diluting limited collections care resources. Unlike traditional archives, digital archives require the preservation of both the recording media and the hardware and software systems necessary to access the data (Hedstrom 1998). Although the problem of the long-term preservation of digital archives is attracting some attention, there are as yet no widely accepted industry standards or viable plans for financing perpetual storage and migration of electronic museum data (Blue Ribbon Task Force and Rumsey 2010).

### *Efficient Collection Storage Arrays*

Another of Petrie’s ideas worth reexamining is that the proposed storage space “shall cost a minimum, compatible with safety. The requisite space being thus cheaper than the labour, the shifting and re-arranging of objects must be avoided as much as possible; and building must be capable of interminable expansion at any point, so as to allow of incorporating large collections without *moving everything else to agree*” (Petrie 1900:528). In practice, this means that collections should be assigned to the storage array in ways that make allocation of space and retrieval of specimens most efficient, rather than allocated to some predetermined systematic or other classificatory order.

Throughout the history of museums, the way that most collections have been organized has been a reflection of our understanding of systematic philosophy (Asma 2001; Simmons 2010), but is this the best way to house very large collections? What is the purpose of arranging a collection in a particular order? In natural history museums, collections are commonly allocated to the storage array in alphabetical order (e.g., by

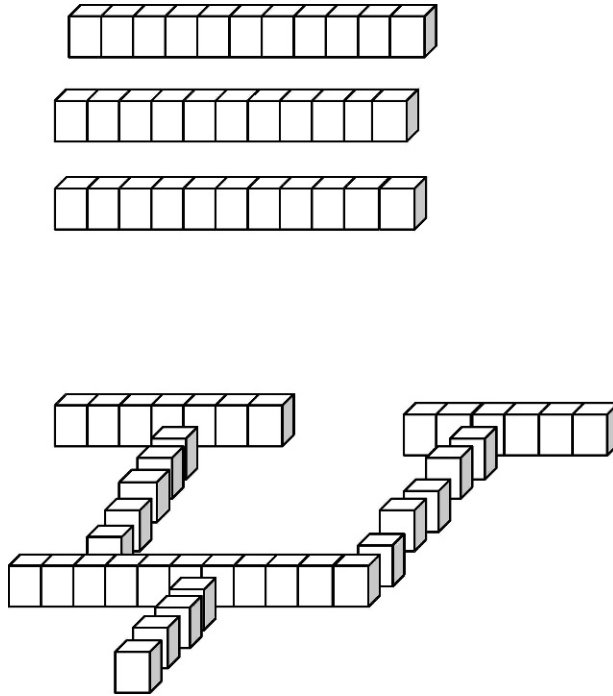


Figure 3. Schematic representation of traditional linear arrangement of collection storage furniture (above) and theoretical schematic representation of storage furniture in “phylogenetic” order (below).

family, genus, and species), some collections are organized based on the stratigraphic origin of specimens, a few are based on the size of the containers, and on rare occasion we find a collection that is housed in the order in which the specimens were received at the museum. In the vast majority of systematic collections, the organization of the collections has been a reflection of the curator’s systematic philosophy (Asma 2001), sometimes with disastrous results. Louis Agassiz (1807–1872), the founder of the Museum of Comparative Zoology at Harvard, was the last major scientist in the United States to reject Darwinism (Windsor 1991). Agassiz arranged his collections to be what he called an “exhibition of ... divine thought” in which “each [species] has its place” to reflect a divine Creation (Marcou 1895:89). However, this system did not work, because species are not a reflection of divine thought but the result of evolution, so Agassiz had to constantly rearrange his collections (Ford and Simmons 1997). One of his students complained that “almost every three months ... some new idea was put forward by Agassiz, which ... changed what he had already proclaimed as definite and immutable classification,” resulting in a corresponding rearrangement of the collection (Marcou 1895:89). Are we doing any better than Agassiz today? Most contemporary curators claim that their collections are arranged phylogenetically. This, of course, cannot be true, as none have a branching sequence of shelving or cabinets (Fig. 3). In fact, modern collections are arranged in a linear pattern (or several separate linear patterns), which means that we are using a slightly more modern version of the *scala natura* of Aristotle, so that in actuality the arrangement of the collection does not reflect the evolutionary history of the specimens and is really no more helpful than an alphabetical arrangement.

A further complication for systematic collection storage arrays is that the practice of molecular systematics is radically changing ideas about the evolutionary history and diversity of life on earth. For example, the changes proposed in classification and in scientific names of amphibians with the publication of *The Amphibian Tree of Life* (Frost et al. 2006) and subsequent studies are extensive, yet no large collection I am aware of has been rearranged to fit the new classification system. Even if the time and financial resources were available to make the changes in catalogs, labels, and allocation of specimens in the storage array, the bottom line is that a scientific name and its place in the hierarchy is a hypothesis, susceptible to being supported or nullified by the accumulation of new evidence, and not a very practical basis for the arrangement of a large collection.

The system of order used in the storage array for large collections has always been and remains a compromise between the size of the collection, the storage space available, how the collection is used, and the resources available to maintain the collection. Therefore, instead of attempting to arrange collections based on systematic philosophies we should allocate specimens in the storage array in ways that help us provide the most efficient use of collections and best care for the specimens despite limited collections management resources. Collections should be arranged in consideration of the following issues:

- Long-term preservation in optimal storage environments based on type of specimen and method of preparation
- The most efficient use of collection storage space
- An arrangement that allows for efficient specimen allocation to and retrieval from the storage array.

The standard for a good arrangement of a collection in the storage array should include these factors (Simmons and Muñoz-Saba 2005):

- Can the specimens needed be located quickly and efficiently?
- Can the specimens be easily returned to their proper place in the storage array with a minimal error rate?
- Can the collection be used efficiently?
- Can the collection be maintained in good order with a minimal input of resources (time and energy)?
- Does the storage array arrangement allow collection growth with minimal rearrangement of specimens, containers, and storage furniture?
- Is the best possible storage environment provided to ensure the long-term stability of the collection and associated data?

A method of grouping specimens has been proposed (Simmons and Muñoz-Saba 2006) that allocates specimens to the storage array according to the environmental requirements for each type of specimen and preparation (Table 3), irrespective of traditional departmental divisions (e.g., entomology, botany, geology). The culture of modern systematic collections, with collections balkanized into departments based on traditional “-ology” specializations, necessitates too much duplication of effort and resources and results in poor use of space. Museums cannot afford to maintain this culture as collections grow ever larger, but instead must manage collections better while coping with fiscal and physical constraints. An objection may be raised that reordering specimens based on specimen and preparation type will lead to confusion and make specimens hard to find, but collection databases that are designed as modern collections management tools should include finding aids to avoid these problems.

Table 3. Categories of natural history specimens by type of material (after Simmons and Muñoz-Saba 2006).

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Group 1. Dry-preserved specimens

## Category:

1. Animals and plants, whole organisms or parts, nests
2. Bones and teeth
3. Invertebrate shells and exoskeletons
4. Rocks, fossils, and minerals

## Group 2. Fluid-preserved specimens

## Category:

5. Animals and plants, whole organisms or parts
6. Histological preparations, whole or parts
7. Rocks, fossils, and minerals

## Group 3. Documentation

## Category:

8. Paper archives
  9. Film and tape archives
  10. Digital archives
  11. Molds and casts
  12. Other media
- 

The proposed rearrangement of Simmons and Muñoz-Saba (2006) prioritizes the long-term use of the collections, as opposed to prior systems that were based on browsing for specimens according to some systematic philosophy. In the very large collections of the future, most browsing (searching for specimens needed for some use) should be done using collection databases or other finding aids. In most cases, when specimens are needed for study, it is better to retrieve them from the collection storage array and take them to a suitably equipped space for work—collections storage areas should not be where collections are studied (among other things, it is disruptive for the collections storage environment). This is not a new idea. In 1727 Caspar Neikelius (a pseudonym for Kaspar Friedrich Jenequel) published a book called *Museographica* that addressed problems of classification and presented techniques for caring for collections (Holdenraber 1987; Schulz 1994). Neickelius stated that museums should have separate storage areas and places to study specimens, and recommended putting a table in the middle of a room “where things brought from the repository could be studied.”

In addition to promoting the long-term stability of the specimens, storage arrays of the future should be designed to reduce the level of disorder (entropy) in the collection. There are three types of entropy in collections (Simmons and Muñoz-Saba 2003):

1. Lack of order because there is no system.
2. Lack of order that results from a system that is inadequate to keep up with the rate of growth or use of the collection.
3. An acceptable level of entropy.

Collections that lack order are unusable because specimens cannot be efficiently located; inadequate systems may be too simple or too complex to be useable. A collection with an acceptable level of entropy means that there is always some short-term disorder because specimens are displaced from the storage array by use—so what is an acceptable level of entropy? No entropy in a collection would signify that all specimens are in their place in the storage array at all times. Not only is zero entropy the most expensive form of

order to maintain (because lower rates of entropy require greater inputs of energy), it also means that the collection is not being used. Manageable entropy means that in the short term, specimens are displaced from their order in the collection storage array so that they can be used, but in the long term, overall order is maintained in the collection. The location of each specimen in a storage array is called its cell (see discussion in Simmons and Muñoz-Saba 2003). Entropy increases geometrically as collection size increases arithmetically because a larger collection has more cells, more specimens to be displaced from their cells, and more ways the specimens can be displaced, therefore the cost of controlling entropy increases geometrically with collection growth. Unfortunately collections management budgets (including the number of collections care personnel) rarely increase geometrically as the collection grows arithmetically.

### CONCLUSIONS

Managing very large collections to make the best use of space, provide for efficient specimen access, rapid specimen allocation, and retrieval in the storage array, and provide the best storage environment for long-term preservation will require many changes in traditional practices, but ultimately will make the best use of limited resources for safeguarding the global systematic resource that enables us to understand the biodiversity of the world. The changes in traditional practices will need to include the following:

- Emphasis on improvements to the buildings housing the collections to neutralize external environmental conditions
- Maintenance of stable collections storage environments
- Design and configuration of storage furniture to enable efficient inspection of specimen condition
- Use of archival-quality materials for specimen tags, labels, containers, and supports
- Developing collections databases that can be easily used to improve the care and management of systematic collections
- Developing means to economically and efficiently preserve collection data in electronic formats in perpetuity
- Configuring collection storage arrays based on the type of specimens and preparations rather than dividing collections into systematic-based groupings that result in duplication of efforts in collections care.

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## PRESENTATION OF THE CAROLYN L. ROSE AWARD TO CATHARINE HAWKS

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The Carolyn L. Rose Award for significant contributions to the objectives of the Society for the Preservation of Natural History Collections (SPNHC) was conferred to Catharine Hawks at the 2012 annual meeting in New Haven, Connecticut. Although this can only be considered a midcareer award, her contributions during the span of her career as a conservator, educator, author, and consultant have changed how all of us approach preservation issues for natural history collections, and she is indeed commended.

Cathy's efforts on behalf of SPNHC and all museum professionals exemplify the Society's goals as well as those of her mentor, Carolyn Rose. As one of those rare individuals who work in many academic and professional fields with aplomb, grace, and acuity, Cathy is unfailingly generous with her time, expertise, and advice. Everyone who wrote to support her nomination has mentioned her generosity in working with colleagues and her unfailing ability to encourage and inspire professionalism among those concerned with preservation issues. Although 10 people wrote to support the nomination, the list of those who could have written is much more numerous and straddles many professional organizations.

Cathy's support and contributions to the museum field are copious and deep. She currently belongs to more than 10 professional organizations and has served various organizations in at least 32 different capacities, often resulting in ground-breaking work that has forever changed our perspectives on topics like health and safety, collections care, emergency and disaster response, and museum education. Like Carolyn Rose, her career spans across disciplines and has already influenced generations of museum professionals.

She has contributed to almost every field of natural science, and her foci have included the history of specimen preparation, pesticide and preservative contamination, health and safety for museum professionals, and emergency preparedness and recovery. Much of her work has had significant ramifications for collections containing natural history specimens, such as her work on heavy metal pesticides and formaldehyde exposure.

Early on, she played a significant role in facilitating collaboration between various professionals as project coordinator for a National Science Foundation (NSF) and National Institute for Conservation (NIC) project that led to the publication *Preserving Natural History Collections: Chronicle of Our Environmental Heritage* (1993). During the same period and soon after, she worked closely with Carolyn Rose and others on the two-volume publication *Storage of Natural History Collections: A Preventive Conservation Approach* (1995) and *Storage of Natural History Collections: Ideas and Practical Solutions* (1992). Seminal in the field and still used as a reference resource, this book continues to shape how conservators and collections managers approach issues of storage, support, and environmental stability. Cathy has continued to shepherd important publications, such as two issues of *Collections Forum* (2011) that focused on issues of pesticide residues and removal, *Museum Studies: Perspectives and Innovations* (2006), and recently, *Health and Safety for Museum Professionals* (2011). Her role in editing and coordinating the 2011 volume involved organization of a core editorial team of seven, an author pool of more than 40, and a countless number of peer reviewers. Her list of publications that contribute to the advancement of preservation, conservation, and collections care is long and spans a wide range of topics.



Her influence in the field of preventive conservation and collections care can be garnered by looking at the long list of collecting institutions where she has performed general surveys, consultations, and workshops. Cathy has influenced countless museum professionals through her innumerable discussions with other professionals and her intelligent, innovative, and direct approach to problem solving. She has gone on to teach and design innovative curricula in at least 10 institutions, including the Collections Care Pilot Training Program (CCPTP) at the Los Angeles County Natural History Museum and the museum studies program at George Washington University and continues to play an important role in encouraging collections care through various venues. Her courses provide underpinnings in conservation theory while emphasizing how to apply acquired knowledge in a real museum environment. The range of her expertise in teaching is tremendous, reaching from big picture issues such as the building envelope to individual specimen issues such as specific preparation techniques.

In addition, Cathy's role as within SPNHC is also significant and inspiring. She has chaired the Resources Committee and the Conservation Committee and has served as a Member-At-Large. Most significantly, she is always available to SPNHC members as a mentor and advisor. Her ability and willingness to give in this venue have played important roles in raising consciousness about preservation issues. Throughout it all, her ability to give generously to her peer professionals in time, expertise, and advice cannot be overstated.

Now, in her role as the first ever Museum Conservator at the National Museum of Natural History, Smithsonian Institution, all of her experience, expertise, and enthusiasm is at work

as she advises and makes decisions about preservation issues for the entire institution. Cathy is able to effectively walk the fine line between preserving an object for future needs while allowing sufficient and immediate access, and this quality is one of the reasons she can resourcefully reach a wide range of museum professionals within her institution.

Cathy Hawks has continued to explore and inspire others in the conservation and natural science community with many of the same qualities that Carolyn Rose shared with all of us. She has set the standard for collections care professionals to emulate, particularly by sharing what we know with others. She has contributed generously and significantly to the objectives of SPNHC and is a most deserving recipient of the Carolyn L. Rose Award from the Society for the Preservation of Natural History Collections. Thank you, Cathy, for who you are and all that you do!

## ACCEPTANCE OF THE CAROLYN L. ROSE AWARD

CATHARINE HAWKS

*National Museum of Natural History, Smithsonian Institution, Washington, DC 20013, USA*

Many eons ago, I fell into natural science conservation largely by accident. Carnegie Museum of Natural History had been hosting a sponsored conservation internship. The young conservator holding the position had successfully completed the Anthropology part of the program but, on looking at the bioscience collections that were the target of the second half, elected to run off with her boyfriend, leaving Joan Gardner and Steve Williams desperate for a replacement. So, having little other choice, they decided to give me a try. The interview for the position consisted of being sent to a prep lab, handed some lightly defrosted rodents, and being told to make them into study skins. Having grown up on a farm, skinning was no problem, although I'm quite sure the quality of the resulting study skins left a lot to be desired.

Anyway, Joan and Steve decided that if nothing else, I was a reasonably good sport, and we went on to explore a host of questions about care of a range of natural science collections. I was hooked, but also extremely distressed to learn that there was no place in the United States where I could pursue this as a conservation specialty. Realizing that I wasn't going to give up easily, and probably anxious to off-load me, Joan and Steve suggested that I talk with Carolyn Rose, who was at the time running the George Washington University program in ethnographic and archaeological conservation.

So I went to Washington and confronted Carolyn with my aspirations. She was skeptical, so I cited work by Rob Waller and Frank Howie as proof that this was legitimate conservation. Convinced by this, although not yet by me, Carolyn told me to work on a number of natural science specimens slated for a new exhibit, and if I demonstrated any talent at treatment, she'd take a chance and structure a program for me. I'm still unendingly grateful to her and a host of professors at George Washington University who helped make that happen. I'm also still very grateful to my mentors at Carnegie who found jobs I could do for them in Washington so I could afford to do the GW program. Trust me: the funding normally available to conservators-in-training was *not* available for doing anything this far out of the arts and humanities mainstream.

My first few American Institute for Conservation meetings were a bit trying, but eventually I discovered that conservators really are human, despite rumors to the



contrary, and at least some of them were actually pretty darn friendly. Of course, Carolyn's support helped tremendously in actually having natural science conservation recognized as a legitimate subspecialty in objects conservation.

So, happily, and after six years on the AIC Board, much has changed, and I've had a wonderful opportunity to work with like-minded colleagues around the world on a host of projects and programs. Like most conservators, I'd like to spend my time doing intricate treatments but have learned to embrace preventive conservation as the only efficient way to address large collections such as those in our field. I'm currently at an institution with an estimated 126 million specimens. Treatment is not the priority.

That said, perhaps how we prepare our specimens for use today and in the future should be a priority. Let's face it—much of what we do is what has been done with some modification for nearly three centuries. Sometimes this has resulted in good preservation for a growing number of uses, and sometimes not. Bringing to preparation the same level of scientific rigor that is used in systematics research is actually long overdue. I was delighted to hear from Chris Collins yesterday that The Natural History Museum, among others, is beginning to address this. Applying the materials science, chemistry, and physics of conservation to preparation has great potential to improve both the utility of collections for present and future research and the potential for long-term preservation.

So, now I'll quit proselytizing and go back to what my colleagues all said I should do on this occasion, which is just say, "thank you." My husband once told me that I was extraordinarily fortunate in my choice of profession because it allowed me to get to know some of the most decent, intelligent, and delightful people on the planet. As is so often the case, he was right. I have deeply enjoyed the opportunity to work with hundreds of wonderful students and to work with many of you here today. And I'll always be grateful to Carolyn for having taken a chance that allowed me to have an uncommonly rewarding career. So, my many, many thanks to her, and to all of you.

Editor's Note: A video tribute to C. Hawks can be found on YouTube: [http://www.youtube.com/watch?v=t\\_8KnyrcOMg&feature=youtu.be](http://www.youtube.com/watch?v=t_8KnyrcOMg&feature=youtu.be)

## **PRESENTATION OF THE PRESIDENT'S AWARD TO RUSSELL D. (TIM) WHITE**

**JEAN-MARC GAGNON<sup>1</sup> AND GREG WATKINS-COLWELL<sup>2</sup>**

<sup>1</sup>*Canadian Museum of Nature, 240 McLeod Street, Ottawa, Ontario, Canada, K1P 6P4*

<sup>2</sup>*Division of Vertebrate Zoology, Yale Peabody Museum, 170 Whitney Avenue, New Haven, Connecticut 06520, USA*

The 2012 SPNHC President's Award was presented to Russell D. White at the 2012 SPNHC meeting appropriately held at Yale University, New Haven, Connecticut, where "Tim" was the chair of the organizing committee. To those who know Tim, it comes as no surprise that the meeting was one of the most successful in SPNHC history, setting a new attendance record! The nominators felt that it was highly appropriate to present Tim with this award in front of a majority of his colleagues at Yale, where Tim works as the Assistant Director for Collections and Operations at the Yale Peabody Museum of Natural History.



Tim has been involved in the natural history community since graduating from the University of Kansas with a Master's degree in invertebrate paleontology following a Bachelor's degree in geology from Eastern Connecticut University. Tim began his career as the collection manager for invertebrate paleontology at the Yale Peabody Museum of Natural History and immediately made an impact. Tim helped push forward the idea of relational authority files from analog file cabinets and ledgers into the museum's early databases. He also helped to define the role of "Collection Manager" at the museum. Recognition of Tim's broader abilities came when he was made project manager for the new Environmental Science Center in 1999. This involved not only liaising with administration, faculty, project planners, and engineers toward the construction of a premiere collection facility and research space but also managing the move of millions of specimens from their disparate homes to their new state-of-the-art facility. For all those who have been involved in collection moves, you know how onerous this task can be! Following the successful completion of the Center, Tim became the Assistant Director for Collections and Operations and continues to serve in that role today. Most recently, Tim supervised a move of over 2 million objects to Yale's West Campus within one year and orchestrated the return of artifacts to Peru, which involved significant planning and dedicated skills of dozens of personnel.

The President's Award is presented to a member, or former member, whose activities have furthered the objectives of the Society through (a) outstanding committee work, (b) prolonged officer roles, or (c) promotion of activities of the Society. Here there is no need for a single choice for Tim, as he is clearly a "do all of the above!" Yes, Tim was a "no-brainer" as a recipient of this award as he has raised and continues to raise the bar of the Society and the community through the "professionalization" of natural history collection management. During his tenure as President of SPNHC his vision led the Society to cultivate and greatly improve outreach to affiliated organizations such as the National Science Collection Alliance, Society of Vertebrate Paleontology, Geological Society of America, and many others. Tim's forward-thinking approach, exemplified by the actions of a Committee on Publications and Outreach, led SPNHC to develop a new logo, increase Internet presence, evaluate membership services, and further professionalize its publications. All are now benefiting from the implementation of these recommendations.

Tim has also directed the professionalization of the practice of natural history collection management through a modern focus on best practices in all aspects of the discipline. His influence has helped foster a new generation of museum professionals who consider themselves not as mere assistants dusting old bones or broken pottery, but as professionals in every sense of the word, proudly caring for the objects, data, and archives representing the known universe and contributing to an expanded understanding of it. Thus, Tim's actions and devotion to the Society and the field will no doubt be recognized for many years to come.

Nothing speaks louder to the influence that Tim has had on the Society and the natural history community as a whole than the words of his colleagues who supported his nomination:

Cathy Hawks (National Museum of Natural History): "Tim's tireless efforts on behalf of SPNHC and the development of best practices for the natural history field further support the appropriateness of this award."

John Simmons (Museologica): "Perhaps Tim's most long-lasting contributions in his role as a leader in SPNHC will prove to be the promotion of the professionalization of



collections management, and the establishment of national standards and best practices for natural sciences collections management.”

“Tim has long advocated for the development of standards and best practices in his publications, presentations, and personal lobbying activities, making the link between professionalization of the field and the achievement of best practices.”

Chris Norris (Yale Peabody Museum of Natural History): “I can think of few people who have done as much to advance the standing of our Society and our profession and none who deserve this award as much as Tim.”

“He is relentless in his promotion of SPNHC and its goals to the previously unenlightened.”

Clare Valentine (Natural History Museum): “I have no hesitation in saying that Tim is one of the pillars of the SPNHC community and epitomizes what the society stands for and strives to promote collections care and the profession in its widest sense.”

Janet Waddington (Royal Ontario Museum): “Even if they are not aware of it, few people in SPNHC have not felt the influence of Tim’s actions.”

Robert Waller (Protect Heritage): “Tim has worked continually and effectively to raise the standards within the field of natural history collection care and preservation.”

“Tim is also one of the most lovable and loved characters in SPNHC.”

Kelly Goulette (Denver Museum of Nature and Science): “Tim demonstrates a consistent commitment to the improvement of natural history collection management on many fronts.”

Judith Price (Canadian Museum of Nature): “His personality, an amazing combination of gravitas and good humour, always sets folks so at ease they never realize how much they have committed to help with whatever cause he espouses.”

Linda Ford (Museum of Comparative Zoology): “Even today, the unwavering commitment and devotion that Tim continues to show in his efforts and interactions on behalf of the Society are awe-inspiring.”

“From 2006 to 2008, Tim was the President of SPNHC. Through his strong leadership and unshakable dedication, he helped to guide the Society on the path towards broad influence and acknowledged professionalism beyond natural history. Nowadays, when one interacts with various other professional societies and/or U.S. governmental agencies, it is not uncommon to hear SPNHC referenced as a source of information which I think can be partly attributed to Tim’s effort.”

Bruce Danielson (Delta Designs): “His input in details such as tray handles, tray label holders, tray placement, cabinet door operation, and gasket selection were invaluable for ease in function for users of museum storage equipment.”

Andy Bentley (University of Kansas Biodiversity Institute): “His vision for the Society has led to numerous collaborative engagements with other societies and affiliated organizations while his dedicated pursuit of professionalism has led to numerous advances in best practices and collection management in general.”

Carol Butler (Smithsonian National Museum of Natural History): “In every action Tim took as President of SPNHC, he pushed for increased professionalism.”

“Among the many things I appreciate about Tim are his vision and passion for excellence, and the way he goes about working with others.”

“Tim exemplifies excellence in collections management, and in collections leadership. He raised the bar for collections management during his Presidency, and continues to do so as an active, visionary leader in the Society.”

Sally Shelton (South Dakota School of Mines and Technology, Museum of Geology): “Tim is one of the best leaders that SPNHC has ever had, and his contributions have advanced the organization and the field enormously.”

Congrats, Tim, and keep up the good work!

## ACCEPTANCE OF THE PRESIDENT’S AWARD

**RUSSELL D. (TIM) WHITE**

*Yale Peabody Museum, 170 Whitney Avenue, New Haven, Connecticut 06520-8118, USA*

This is truly an honor and a very pleasant surprise. I am not sure I deserve this award, but nevertheless it is very much appreciated. I want to thank Greg Watkins-Colwell and James Macklin for nominating me.

I have been very fortunate to work at an institution that values community service and in fact encourages participation in societies and community efforts. But still, I have always struggled to know where my Yale job begins and ends ... and where my SPNHC job overlaps. If an opportunity came up for us at the Peabody I am always thinking how can we make this a SPNHC initiative or get the SPNHC value Advancing Collections Care on the table for discussion? Recently Yale established the Institute for the Preservation of Cultural Heritage, and my first thoughts were how this institute could partner with SPNHC to promote natural history conservation and collections care on a global scale.

My instinct has been to look for partnerships for SPNHC, and we looked at this year’s meeting as an opportunity for SPNHC by pulling in AIC and CLIR as co-sponsors of

three topical sessions; and in my honest opinion we should be looking co-sponsorship events at their annual meetings as well.

There are a few people I would like to thank. Barbara Moore was our Conservator at the Peabody in the late 1980s and 1990s and a very early participant in SPNHC. Barbara showed me what it meant to be a professional and how important it is to give back to your community, in this case SPNHC. At our 1997 annual meeting in Madison, Wisconsin, Barbara, Rob Huxley, the SPNHC President at the time Grant Hughes, a few others, and I went on a sailboat ride around Lake Menota when Barbara mentioned there was a vacancy as Newsletter Editor and urged me to take the position ... and honestly I don't think she was going to let me off that boat till I agreed, so, yes, I happily accepted ... so blame Barbara for my participation in SPNHC.

There are a couple people at the Peabody I would like to thank. Patty Pedersen was our Development officer at the Peabody in the late 1990s and always had ... has this "can do" attitude and is someone I always look to for motivation when I felt a task or assignment was daunting. Leo Buss, one of our Curators at the Peabody, gave me this sense of the possibilities if you set your mind toward working toward a goal, and Mike Donoghue, one of our past directors at the Peabody, demonstrated how important it is to be yourself. The enthusiasm that we bring to our jobs is infectious, and the message I have got from Patty, Leo, and Mike was don't be afraid to think big and challenge yourself and challenge your institutions and communities. For me this has been the Peabody, the Paleontological Society, and SPNHC, but I urge you all to think big and find ways to challenge yourself.

Another person I would like to thank is Sue McLaren from the Carnegie Museum. I have always admired Sue and find her to be an incredibly inspirational person who always has thoughts on my various activities, no matter how crazy they may sound, and has been a great mentor in many ways ...and for the past year Sue has poked me just about every day on Facebook, and it was great to know you were thinking about me!

Prior to taking over as President I was very lucky to work with Lisa Elkin, Chris Norris, Linda Ford, and Barb Brown from the AMNH and Rachel Arenstein on the SPNHC 2004 meeting, which was a great experience and really was the beginning of SPNHC's Publicity and Outreach sessional committee, which included these colleagues, and James Macklin from Harvard. For me this became a great catalyst for the Society to move forward in so many new directions, so I want to thank you all for letting me come along for the ride. And a special congrats to Lisa on her award and thanks for spearheading that committee as well.

I also want to thank my good friend Rob Huxley. For many years Rob and I shared a room at SPNHC meetings, which was always worth a few laughs from our friends who thought this was odd that two 40-something guys would share a room ... but more importantly it was during this time we plotted how we wanted to see SPNHC evolve. We asked ourselves what role SPNHC could have in the international community and how we could raise the level of expectations of council and our membership. Many of the things that I have tried to promote over the past 10 years came from those discussions with Rob, and I cannot accept this award without sharing it with Rob, so thanks a lot for your friendship.

But where are we going as a Society? What are the challenges our institutions and community face? One of my favorite phrases is that "none of us work in a vacuum," and if we are going to continue to have impact on the natural history community, we need to continue to work together and look for the opportunities to partner with other groups or

organizations to move our agenda and the SPNHC value “Advancing Collections Care” to another level.

We cannot do this alone, and this is one of the reasons I have pushed SPNHC in recent years to step out of its comfort zone and look for opportunities to work with our colleagues in our discipline societies, the informatics community, and the art museums and library world as well. We have a lot to share, but we also have a lot to learn from others too.

Finally, the real reward for me has been working you all, and I look forward to continuing to promote the SPNHC values for years to come. Thank you.

Correction: The citation for the Carolyn L. Rose Award in *Collection Forum* 26(1–2) was incorrectly attributed. The author is Sally Y. Shelton, Museum of Geology, South Dakota School of Mines & Technology, 501 East Saint Joseph Street, Rapid City, SD 57701.