Realising standards – Proceedings of the 20th Anniversary Conference

(Edited by C. Giles Miller)

Contents continued from outside back cover

Instructions to Authors

Articles for Collection Forum are six to 30 pages double-spaced (approximately 7500 words including abstract and literature cited), plus figures and tables. They may include original contributions to the literature or significant review articles dealing with the development and preservation of natural history collections. Contributions may include, but are not restricted to, reports of research and methodologies for the collection, preparation, conservation, storage, and documentation of specimens, and discussion of some philosophical, theoretical, and historical aspects of natural history collection management. Case studies that serve to document or augment a philosophy, methodology, or research activity will be considered, but general descriptions of a specific collection or institution are not accepted.

Manuscripts should be submitted digitally in Microsoft Word or WordPerfect, IBM format. All parts of the manuscript must be double spaced to letter (8 ½ × 11 inch; 21.6 × 27.9 cm) or A4 paper size with at least one inch (2.5 cm) margins on all sides. Each page of the manuscript should be numbered. Do not hyphenate words at the right-hand margin. Each table and figure should be on a separate page. Each table and figure should be in a separate file unless they are .doc files. The ratio of tables plus figures to text pages should generally not exceed 1:2.

On the first page indicate only the name, email address, telephone, and mailing address for the author to whom correspondence and proofs should be addressed. The second page then includes only the title of the article, names of the authors, affiliations and addresses of authors, and the abstract. Begin the text on the third page.

The preferred language for manuscripts is English, but a summary in another language can precede the literature cited, if appropriate. Manuscripts written in other languages may be considered at the discretion of the Managing Editor if the language uses the Roman alphabet, an English summary is provided, and reviewers are available for the language in question.

Abstract. An abstract summarizing in concrete terms the methods, findings, and implications discussed in the paper must accompany each article. The abstract should be completely self-explanatory and should not exceed 200 words.

Style and Abbreviations. Symbols, units, and nomenclature should conform to international usage. Cite all references in the text by the author and date, in parentheses. For example, (Deer et al. 1992, Fraser and Freihofer 1971, Mahoney 1973, Taylor 1967) would be an acceptable citation. Footnotes are not accepted in the text.

Literature Cited. This section includes only references cited in the manuscript and should be double spaced. References are listed alphabetically by authors' names and take these forms:

Brokerhof, A.W., R. Morton, and H.J. Banks. 1993. Time-mortality relationships for different species and development stages of clothes moths (Lepidoptera: Tineidae), exposed to cold. Journal of Stored Products Research 29(3):277-282.

Jones, E.M. and R.D. Owen. 1987. Fluid preservation of specimens. Pp. 51-64 in *Mammal Collection Management* (H.H. Genoways, C. Jones, and O.L. Rossolimo, eds.). Texas Tech University Press, Lubbock, Texas. 219 pp.

Thomson, G. 1986. *The Museum Environment*, 2nd ed. Butterworth's, London, England. 293 pp.

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ICOM International Committee for the Training of Personnel. 2000. ICOM Curricula Guidelines for Museum Professional Training. http://museumstudies.si.edu/ICOM-ICTOP (15 July 2002).
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PREFACE: REALISING STANDARDS 2005

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The SPNHC 20th Annual Conference was held at the Natural History Museum in London on 12–18 June 2005 in conjunction with the Natural Sciences Collections Association (NatSCA), the Geological Curators' Group (GCG) and ICOM-CC Natural History Collections Working Group. Seventy-seven abstracts were published prior to the meeting (Miller and Davis 2005) and all talk and poster presenters were invited to contribute to this Collection Forum volume. Nineteen papers are presented here, at least one from each the sessions of the conference and at least one relevant to each of the workshops on IPM, Standards and Risk Assessment. The theme running throughout the conference and indeed this volume is 'Standards'. Many of the papers cover 'case histories' and these have been carefully edited to illustrate how standards have been set and applied in these situations, in some cases when funding and other criteria have determined that the initial situation is far from ideal. Some papers present baselines for assessing and setting standards, while others cover conservation techniques that help to maintain the standard of collections.

The volume starts with a paper outlining SYNTHESYS Network Activity-C, a project attempting to benchmark standards in European Natural History Institutions (Collins et al.). Assigning numerical values to levels in collection standards is a theme also covered by Adrain et al. for Geological collections; both papers inspired by the pioneering work of McGinley (1992). SYNTHESYS Network Activity-C also contains elements of conservation training, a theme picked up by the third paper (Buttler and Child), the first of three papers covering case histories from the National Museum of Wales. The second (Howlett and Horak) covers integrated collections management and shows how external reviews and integrated policies can be a useful lever for obtaining funding for collections management. The third (Kerbey and Horak) deals specifically with Petrology and Mineralogy Collections and shows how the policies and standards outlined by Howlett and Horak have been achieved and will be maintained in the future at the National Museum of Wales. Continuing with Mineralogy, Welzenbach et al. outline the Smithsonian and NASA's Johnson Space Center curatorial standards for collection, storage, handling, classification and data management of Antarctic Meteorites in the light of US Federal Regulations. The next few papers in the volume have a common theme of minimizing risks associated with collections facilities with many citing Waller (2003) as a key publication. Andrew outlines how the risks from the ten agents of deterioration were minimised for two new West Midlands museum resource centres in the UK. Viscardi et al. provide a similar collections building scenario but in this case provide recommendations for when the environment in a building is uncontrollable and funding is not available for the necessary renovations. Strang and Kigawa return to numerical quantification of standards, this time on the subject of integrated pest management (IPM), providing benchmark levels and IPM solutions for a number of scenarios ranging from completely uncontrolled to perfectly controlled pest situations. Bergh et al.

provide some experimental IPM data useful for facilities where pest control freezing is available but only from −18 to −20°C and simulated scenarios inside heavy woollen material, upholstered furniture and wood. Specimens damaged by pests can be repaired using Japanese paper tissues (Moore) which can also create tidy, effective, strong repairs and gap fills for broken taxidermy specimens. The next two papers deal specifically with taxidermy specimens, quantifying the physical properties of taxidermy skins relative to different fixing techniques (Pequignot et al.) and providing experimental data in support of standard spot tests for arsenic compounds in taxidermy mounts (Marte et al. this volume). Anderson and Newberry outline techniques and give recommendations for maintaining packaging and documentation standards while processing and shipping exhibition loans. Exhibition documentation in a database for gallery objects is covered by Waddington et al. and is the first in a series of papers that covers documentation standards. The second is a similar case history from the North Carolina State Museum of Natural Sciences but this time where the database was built from an existing structure to cover standards of documentation required (Hogue and Raine). The third documentation standards paper (Harpham) presents rules and procedures as an aid to data cleaning during a database upgrade and is a useful review of data standards available. Morris and Macklin provide some scripts that aid in the display of a wide variety of Natural History images on web pages and also help to maintain large databases of these images. The final paper (Rabeler and Macklin) describes the 2005 situation for a 'Toolkit' Committee formed to focus on standards required at all stages of the data capture process for herbarium specimen data.

A glance at the reference sections of the final few papers in this volume show that many references can now be found on the Web. There are also many other useful references to standards that appear throughout this volume. Although the Web references are not what we would deem 'permanent', it is hoped that this volume can act as a useful reference source for standards texts as well as a celebration for 20 years of SPNHC.

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McGinley, R.J. 1992. Where's the management in collection management? Pp. 309–333 in *Current Issues, Initiatives, and Future Directions for the Preservation and Conservation of Natural History Collections* (C.L. Rose, S.L. Williams, and J. Gisbert, eds.). Ministerio de Cultura, Madrid, Spain. 439 pp.

Miller, C.G. and P. Davis (eds.). 2005. SPNHC Realising Standards 2005. SPNHC 20th Annual Meeting and Workshops 12–18 June. Abstracts and outline programme. Natural History Museum, London. 103 pp.

Waller, R. 2003. *Cultural Property Risk Analysis Model—Development and Application to Preventative Conservation at the Canadian Museum of Nature.* Goteborg Studies in Conservation 13, Acta Universitatis Gothenburgensis. 107 pp.

FOREWORD

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Collections are at the heart of what we do in natural history museums. However, if they are to continue to be valuable we need to have a clear view of why we have them and how they fit into the broader scientific endeavour. This is especially important as we face somewhat contradictory challenges; collections are both at the threshold of enormous opportunity yet at the same time are under threat of extinction in a number of places.

As ever, perhaps the most significant threats are financial. Collections are perceived to be too expensive for the return in some quarters. If managing collections can be made more efficient (a number of papers in this volume show how this can be done), and their value to society made more explicit, then this threat can be addressed. For example, we need to continue to increase access to a broader community from the traditional scholastic users (nationally and internationally) to policy makers and citizen scientists. We also face increasing claims for the 're-patriation' of material, in short the dissolution of the very concept of a collection into what could be, unless it is intelligently managed, a distributed nationalistic chaos. There are many innovative ways of sharing information and material that benefit all partners. These ideas need to be made more widely known through such organisations as SPNHC. Finally, collection based research faces increasing competition for resources, most crucially people, from other rapidly growing areas of science. With some imagination this can be used as an opportunity rather than a threat. To address all these challenges will require quite radical thinking on behalf of museums and the starting point is articulating why we have collections and what they are supposed to do.

Since the days of the enlightenment we have tried to make rational sense of the world around us. To understand the diversity of the world's biota and geology we have made collections. They are essentially models of the world that we can manipulate not only to increase our understanding of what is here but also to have insight into the processes that generate diversity. Accepting that collections are models means we have to articulate models of what? A regional flora or fauna, a taxonomic group, genetic variation, a longitudinal study of change in abundance or distribution? Answering this question gets to the very core of developing, managing and conserving a collection. For example, it means that the quality of a collection is not simply its size but how well it reflects our contemporary knowledge of a topic. It may even need to be smaller to be fit for purpose. Reflecting our contemporary knowledge means that collections are dynamic; they must change over time not only what is collected but also what is kept or passed on. In this way collections are able to make a clearer case of their relevance to society in a concise and even measurable manner.

Tackling the difficult questions around what our collections are trying to achieve when our history is based on assumptions that there will always be collections and they will always get larger is challenging. Meeting this challenge head on will benefit collections not only now but for generations to come.

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SYNTHESYS NETWORK ACTIVITY C—ASSESSING STANDARDS OF COLLECTIONS IN EUROPEAN MUSEUMS

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Abstract.—SYNTHESYS is a European Project focused on improving access, use and development of taxonomic collections, with the aim of increasing the quantity and quality of taxonomic research in natural history institutions throughout Europe. The SYNTHESYS programme is split into five network activities, with Network Activity C (NA-C) focusing on identifying and improving standards of care and access to European natural history museums. In order to assess how SYNTHESYS partners meet these standards a sub-group of NA-C has developed a standardized survey methodology that benchmarks levels of attainment that European natural history institutions currently meet. The survey also identifies how institutions can move from level D, the lowest benchmark, to level A, the highest benchmark. NA-C, the initial development of the standards, survey, and associated methodology are described here and represent work completed at the time of the SPNHC meeting in June 2005. Since then, significant progress linking the results of surveys of all SYNTHESYS member institutions has been made. Results will be presented at future SPNHC meetings and documented in publications discussing in more detail the standards themselves and their attainment.

INTRODUCTION

Plant and animal collections in museums, herbaria and research institutes across Europe represent a significant global resource for taxonomic and biodiversity research. More than half the of the world's type animal, plant and fungi specimens as well as many historically important specimens are held in European collections. These collections represent a significant commercial, academic and educational resource and their loss would have a serious effect on collection-based research across Europe. The transfer of orphaned collections to core institutions has focused the responsibility for managing collections onto fewer institutions. Inadequate resourcing of these collections has often reduced their accessibility and exposed them to risk of deterioration or worse, loss, to the research community. Some countries, e.g., The Netherlands (Netherlands Ministry of Welfare, Health and Cultural Affairs 1992), have responded to this by putting in place plans for assessing and improving management of their cultural collections. In order to improve access to and use of the European collection resource it is essential that institutions are made aware of the value of their collections and that investment in higher standards of management and care will lead to improved levels of use of collections.

HISTORICAL OVERVIEW

The SYNTHESYS programme grew out of earlier collaborations. In 2000, the Natural History Museum, London, the Royal Botanic Gardens, Kew, and the Chelsea Physic Garden successfully applied jointly under European Framework Programme V (Improving Human Potential/Access to Research Infrastructures) for funding to enable researchers in Europe to access their respective collections for systematic, evolutionary and conservation purposes focused on research. In the UK the project was called SYS-Resource. Applications were made simultaneously by natural history collection-based institutions in a number of European countries including:

- Paris (COLPARSYST)
- Copenhagen (Copenhagen Biosystematics Centre, COBICE)
- Stockholm (Access to naturhistoriska riksmuseet—high latitude, HIGH-LAT)
- Madrid (BIOIBERIA)
- Brussels (ABC)

Funding was secured for 4 years and the use and productivity of the programme led to a further successful application in 2004 for an Integrated Infrastructure grant under Framework Programme VI called the Synthesis of Systematic Resources (SYNTHESYS). The application for a 5-year grant was supported by the Consortium of European Taxonomic Facilities (CETAF) and led by the Natural History Museum, London. This five-year grant comprises two parts which together aim to create an integrated European infrastructure for researchers in the natural sciences. The infrastructure will aim to develop taxonomic research across Europe and improve access to all natural history collections through improved levels of management and care.

Synthesys

SYNTHESYS consists of two parts. The first part enables researchers based in Europe to access the earth and life science collections, facilities and taxonomic expertise of 20 institutions based in 11 National Taxonomic Facility Consortia (TAFs) by providing funding for travel and research projects. The SYNTHESYS access programme is run in a similar format to a previous programme *Framework Programme Five,* 'Improving Human Potential FPV IHP-funded', (SYS-RESOURCE, London) but with modifications. The bulk of funding has been allocated to this part of the programme.

The second part of SYNTHESYS consists of five Networking Activities (NA, B through to F) whose aims are to improve access to collection infrastructure, through better levels of collection care and management, identifying collections of international significance and identifying new techniques for investigating these collections.

Network Activity B: Complementarity

Network Activity B aims to establish a network through SYNTHESYS that optimises co-ordination and improves user access to collections and expertise at a European level. The activity comprises four distinct objectives that describe the relative strengths of collections in institutions:

1. review the strengths of partner facilities and expertise
2. identify taxonomic knowledge and collection strength
3. assess current policies and planning
4. review development of taxonomy in partner institutions

Network Activity C: Collections Standards

This Activity is described more fully below and is the focus for this paper.

Network Activity D: Developing and Maintaining Databases

Network Activity D aims to engage and aid the active participation by all European countries in the delivery of information systems about their taxonomic collections. These systems will bring the information held by SYNTHESYS partners to all user sectors that depend on organism-related information for their research and/or decision making processes.

Network Activity E: Developing Storage and Retrieval Systems for New Types of Collections

Network Activity E is developing guidelines for building storage facilities and the development of retrieval systems for new types of collections, e.g., tissue banks and DNA samples. This activity will establish appropriate standards for collection, curation, preservation, and databasing of new types of taxonomic specimens and associated genetic products.

Network Activity F: Implementation of Novel Physical Analytical Methods in Collections

The overall objective of this Network Activity is to explore non-destructive and/or non-invasive physical analytical techniques such as Computerised Tomography (CT) scanning, MRI, and low vacuum SEM that can be applied to the study of specimens housed in natural history collections. The review will lead to the sharing of best practice techniques and the opportunity to plan jointly the installation of new analytical equipment throughout the 13 partners (see below).

Network Activity C: Collections Standards

The principal aim of Network Activity C (NA-C) is to establish a European collections standards network that will encourage the active participation of all European countries in the long-term preservation, targeted development and wide use of their collections and inherent information. This activity involves partner institutions in identifying the standards to which collections are maintained and managed and then identifying areas for development. A list of partners and their affiliations is given in Table 1.

The European Collections Standards Network aims to:

- Improve specimen conservation, management and ethical standards for the maintenance of natural science materials and their associated archives
- Ensure the extended preservation of European collections using preventive and remedial strategies and contribute to the long-term security of collections
- Increase and improve collection management systems
- Improve access and marketing of collections
- Use collections to support the active participation by all European countries in their varied contributions to geological, life and environmental science studies

NA-C partners are working towards three objectives in order to achieve these aims (as defined in SYNTHESYS work plans).

Objective C.1: Assess the Current Status of Institutional Collections

(a) The network will establish criteria to enable the partners to benchmark all collections and to assess how they can be brought up to a minimum acceptable standard of conservation that:

- improves accessibility
- maintains the future potential use of the collections
- enables the institution to write and implement a development strategy

(b) An expert panel derived from CETAF members will act as a peer review body. The results will be delivered to Network Activity B to be used in policy development and gap analysis.
(c) The project will benchmark standards around Europe, encourage pan-European support for their implementation through seminars and demonstration tours, and will publish them on CETAF, SYNTHESYS, and partner websites.

A representative range of natural history institutions will be assessed to identify the condition of collections across Europe and to identify attitudes to and levels of management applied to these collections. The development of the assessment strategy is covered later in this paper. Assessment reports are to be added to the database of priority collections being compiled by Network Activity B to give a profile of European Natural History collections.

Objective C.2: Training Curators and Raising Standards

The overall aim will be to ensure that long-term access to and use of collections are improved by initiating standards and establishing on-going mechanisms to improve levels of care and management in partner institutional collections.

There are two main training initiatives planned:

1. Improved training for collections managers and conservators on aspects of collections management including related subjects such as health and safety
2. Improved training for the users of collections e.g., researchers and others, on the use and management of collections

These initiatives will network and market the various projects underway in host partner institutions and establish a monitoring and development programme to ensure these training schemes are co-ordinated and work to common standards and goals.

A collections care and conservation syllabus for staff managing natural science collections in Europe will be generated both in printed form and online. The project will be based around key partner institutions in Europe that would provide strategic training and research support for students.

The development of a co-ordinated preventive conservation group is envisaged to look at better methods of collection storage and environmental control around natural science collections. This group would be key to the development of a curatorial and conservation training workshop for collection managers throughout Europe on preventive conservation strategies. Where gaps in staff expertise are noted, the network will put into place a training plan aimed at bringing all collections staff up to the agreed standard.

The training will ensure awareness and improve communication between all collection holders and their users and would specifically encourage the use of new facilities, new technologies, and technological developments as they appear. The most recent example of the beneficial crossover between collections preservation research and future uses of collections is in specimen storage. Modern approaches to collection care include the use of anoxic environments. These are now being used to cost-effectively store sensitive organic and inorganic materials in stable, non-invasive environments. These environments enable better preservation of specimens, reduce the need for invasive treatment and enhance the preservation of objects and the data that they contain.

Objective C.3: Disaster Planning

Currently there is no European support structure for dealing with a major disaster to a natural history collection or any procedure to ameliorate the economic effects of collection loss. The occurrence of a major event affecting the preservation, use and development of collections is increasingly high. In development of the risk assessments for collection preservation it is essential that a suitable disaster response be established. This objective will raise awareness of the need to establish a standard disaster plan in NA-C partner institutions and develop a pan-European disaster plan and emergency response mechanism.

In addition the objective will identify and mobilize key European conservation resources that can respond to major disasters. It is envisaged that such a pan-European group would link into initiatives such as the ICOM/UNESCO International Committee of the Blue Shield (ICBS 2006).

Survey Development (Objective C.1)

NA-C began with series of workshops that established a range of collections and management practices that would be assessed as part of the survey. The partners also reviewed the range of benchmarking and risk assessment survey methodologies available for collection survey (HM Treasury 2004, Keene 1992, McGinley 1992, Resource 2002, Waller 2003). Investigation of each of the methodologies identified weaknesses and strengths for their use in this project. The benchmarking document produced by Resource (2002) was identified as the most appropriate structure from which the survey could be developed as it:

- already covered many of the areas that required investigation
- identified progressive benchmark levels
- had been widely used as a standard benchmarking survey

However, the document did not cover all subject-areas that were agreed at the workshops, e.g. documentation procedures. In addition, the Resource (2002) methodology was expanded from three to four benchmark levels as it was felt that this gave a better statistical range of benchmarks. The methodology was quantified so that easier assessment of the results could be made. Statements in the survey included aspects of Michalski's framework (Michalski 1992) to ensure that it provided a balanced review of collections care issues and where necessary either adapted or added new criteria where required. Details of the standards required to meet the four benchmark levels are given in Appendix 1.

Partner institutions in Vienna and Budapest were chosen for an initial pilot assessment because of their broad spectrum of collections, e.g. botanical, palaeon-

Table 1. Participants from partner institutions in SYNTHESYS Network Activity C.

Name	Institution
Simon Owens	Royal Botanic Gardens, Kew, UK (Network Activity C Leader)
Robert Huxley	Natural History Museum, London, UK (Deputy & Core group member)
Monika Akerlund	Naturhistoriska riskmuseet, Stockholm, Sweden
Josefina Barreiro	Museo Nationales Ciencias Naturales, Madrid, Spain
Chris Collins	Natural History Museum, London, UK (Core group member)
Lorraine Cornish	Natural History Museum, London, UK (Core group member)
Mark Newman & David Harris	Royal Botanic Gardens, Edinburgh, UK
Hans Walter Lack	Botanischer Garten und Botanisches Museum Berlin-Dahlem, Freie Universität Berlin, Germany
Isabel Rey	Museo Nationales Ciencias Naturales, Madrid, Spain
Laszlo Peregovits	Magyar Természettudományi Múzeum, Budapest, Hungary
Jacek Szwedo	Museum i Instytut Zoologii Polskiej Akademii Nauk, Warsaw, Poland
Michel Giraud	Musée National d'Histoire Naturelle, Paris, France
Ernst Vitek	Naturhistorisches Museum Wien, Austria
Wioletta Tomaszewska	Muzeum i Instytut Zoologii Polskiej Akademii Nauk, Warsaw, Poland
Jan Wieringa	The National Herbarium Nederland, Netherlands

tological, mineralogical and zoological, dried material and liquid preserved material. Prior to a survey being undertaken at an institution a list of policy documents was requested from the institution (Appendix 2). This list is derived from an unpublished survey of worldwide standards undertaken by the Natural History Museum (Davis 2004). These provided documentary evidence on the development of policy and procedures within the institution. A core group of three reviewers was sent to both of the pilot institutions to test the assessment survey itself, to learn about the best way to conduct the assessment, and to identify any other potential issues that might accompany the assessment. The core group verified that their application of the assessment standards was consistent for standardisation purposes. For subsequent assessments, one assessor was always taken from the original core group that developed the survey to ensure consistency of investigation. The two other members of the survey were taken from partner members of SYNTHESYS NA-C (Table 1).

At the end of each survey visit (usually 4 days duration), the survey team gave a verbal overview on the major points highlighted by the survey to senior management of the institute. This review gave the institutes a chance to comment on how the survey was conducted and to raise any issues or misunderstandings that may have arisen during the survey process. A final overview will only be produced once all the selected partner institutions have been assessed and consulted on the findings of their individual surveys.

Assessing And Attaining Benchmark Scores

Written in Microsoft Excel©, the survey form is structured so that an overall benchmark assessment of the level to which a natural history institution manages their collections and resources and provides access to their facilities can be determined. A benchmark level of performance is then calculated for each subsection (Table 2) and amalgamated to give an overall benchmark level for the institution (Appendix 1). Each sub-section has 4 benchmark levels of attainment;

Table 2. Breakdown of core sections and sub-sections of surveys.

Core sections	Subsections of core section
Procedural and Management	Access Acquisition and Disposal Finance and Administration Survey Health and Safety Procedural Management and Risk Staff Structure
Buildings and Maintenance	Security Buildings and maintenance
Collection Care and Maintenance	Emergency Preparedness Preparation Handling and Transportation Conservation Grade Materials Storage and Furniture Conservation (Remedial) Environmental Monitoring and Control
Access and Education	Training and Education Access and Research Access for Public and Education

A, B, C, or D, with A being the highest expected level of attainment and D being the lowest. The areas surveyed are divided into 4 core areas and 18 sub-sections (Table 2). Where possible, for each sub-section of the survey a list of recognised national or international standards is provided in the survey as a guideline for assessors. The surveyed institution must meet or exceed these standards to attain a benchmark level C or above. The overall benchmark is not based on the management of a particular collection but on the overall performance of the institution. The benchmark levels are progressive and it is hoped that each institution will strive to progress from one benchmark to another. Level C is the standard to which most institutions are expected to attain and equates to a standard to meet the Museums Association Registration Scheme (MLA 2003). Results from the survey are not perceived as a marking or grading system but as a method of assessing the strengths and weaknesses of an institution.

Future Project Development

Network Activity C is currently reviewing the results of the initial phase of survey of the following institutions:

- Royal Botanic Gardens, Kew, UK
- Natural History Museum, London, UK
- Naturhistoriska riksmuseet, Stockholm, Sweden
- Museo Nationales Ciencias Naturales, Madrid, Spain
- Magyar Természettudományi Múzeum, Budapest, Hungary
- Muzeum i Instytut Zoologii Polskiej Akademii Nauk, Warsaw, Poland
- Musée National d'Histoire Naturelle, Paris, France
- Naturhistorisches Museum Wien, Austria

The survey development team are integrating a risk management calculation

(Waller 1994, 2003) into the assessment process and reviewing comments from the institutions that were surveyed as part of Objective C.1. Once the current survey form is finalised a web version will be made available on the SYNTHESYS website (SYNTHESYS 2006) for institutions to download and use as a self-assessing benchmarking tool. It is hoped that this methodology will be developed as a working European standard that can be used to establish progressive benchmarking of Natural History institutions that complements other recognised survey methodologies. As a tool it provides a simple management aid for comparing and analysing the performance of collection based institutions. It provides a tool to ''snap shot'' current benchmark status and to monitor progress in improving standards of care for Natural History Collections. It is envisaged that the survey will be used on a regular basis by all institutions to monitor progress and development in collections care and management. It is hoped that the findings of NA-C assessments can be used to support funding initiatives that will improve access to these collections and shared resources. SYNTHESYS will also be publishing a review of the standards project undertaken by the Natural History Museum, London (Davis 2004).

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Appendix 1. Benchmark Levels and the performance expectations for each level.

Level	Area	Review of expectation
D		Defines the baseline level that an institution should maintain to ensure basic protection for its collections. This includes acceptable standards for managing and caring for collections within institutions. These should require minimum extra resources to attain (resources must be committed) but expects that the institution has produced a written cost effective strategy for managing, caring and giving access to the collections. Attainment shows baseline commitment from institutions towards improving care and access.
	Procedural and Management	Should have a structure for a Collection Management Policy (CMP) in place at departmental or collection level, including an Acquisition Policy, Collecting Strategy, Disposal Policy, Sampling Policy, Loan Policy and Procedures. The institution is expected to have started production of a Business Plan for implementation of developments to Level C. Health and Safety Standards relevant to regional location of institution are clearly defined. All policies, procedures and protocols must be held at departmental level.
	Building and Maintenance	The institution must have a well maintained and secure building.
	Collection Care and Maintenance	Collections spaces should be clean and dust free, safe and secure and the institution must have access to conservation advice.
	Access and Education	Institute should understand the need to allow access and provide education services through its collection.
C		This level is expected to compare with an institution meeting a standard for the UK Registration Scheme (MLA 2003)
	Procedural and Management	Institution must have a Trustee (or equivalent) approved Collection Management Policy (CMP) to include clearly defined Acquisition Policy, Collecting strategy, Disposal Policy, Sampling Policy, Loan Policy and procedures, confirmation of core standards to which museum subscribes within CMP. A Business Plan for implementation of developments to level B with a 5 year strategy. Vision/Mission statement, Development of 3, 5 and 10 year planning cycle targets. Health and Safety Standards relevant to regional location of institution are established, clear management structure with responsibility or access to professional advice on, Conservation and Building Management.
	Building and Maintenance	Institution demonstrates commitment to the development of an improved service from baseline D and the development of acceptable standards and codes of practice for managing and caring for collections. The institution has produced a written cost effective strategy for managing, caring for, and giving access to the collections. The institution must have a well maintained and secure building and security protocols in place to ensure that buildings and collections are held in a secure environment. The protocols must include, building walls/roof maintenance, maintenance of an intact infrastructure with maintenance programme providing a secure internal environment, secure building with 24 hour monitoring and housekeeping.

Appendix 1. Continued.

Level	Area	Review of expectation
	Collection Care and Maintenance	○ Access to professional and experienced conservation advice relevant to collections ○ Policy that commits museum to taking and implementing collections care advice ○ Has produced a collection care strategy to move to Level B, involving: Rolling assessment of storage and packaging materials, Specimen handling, Storage furniture, Environmental control and monitoring. ○ Collections stored in clean environments (maintained in containers adequate to protect object from pollution and pests). ○ Objects of value, which require storage in specific environments outside the museum's ambient conditions, should be stored in suitable, stable environments. ○ Collection Care Review (Michalski 1994, Waller 1994) Framework. ○ Commitment to undertaking an review of collection care in the institution. ○ Basic environmental monitoring with access to (conservation) expertise assessment to advise on suitability of environments. ○ All processes undertaken on objects must be fully documented. ○ Conservation documentation must be centrally achieved.
	Access and Education	Should be integral to all operations in the museum: ○ Exhibition ○ Storage ○ Loans ○ Access strategy Museum should begin to define an access strategy that includes issues pertaining to security (broadest sense) of objects for exhibition and loan. The institution should have a written policy on the use of objects for handling/schools loan collections, the provision of non-accessioned objects and use of surrogates or replicas. Implemented protocol for monitoring the use of collections (used to inform preservation and conservation planning).
B		Level B shows consolidation and integration of all policies and procedures across the institution. Commitment to regular funding and review, Development of integrated cross-institutional policy and management structures. The institution should begin to show international leadership and maintenance of standards in areas of collection management and conservation.
	Procedural and Management	Risk management embedded across museum. Risk Management training undertaken and risk review implemented. Business Risk reviewed and business plan developed to incorporate changes and growth in critical business as institution moves towards level A. Collection Management strategy implemented across museum. Development of a project management strategy that guidelines the development of cross-museum projects (exhibition, conservation, environmental monitoring, and building maintenance). Written protocols on specimen loans procedures and procedural mechanisms to review institutions to be loaned to. A centralised cross-institution security policy and security department. Acquisitions, Disposals, Documentation, Loans strategy and policy clearly implicated across the institution

Appendix 1. Continued.

Level	Area	Review of expectation
	Building and Maintenance	The Buildings Maintenance System (BMS) must ensure basic environmental management systems with rolling maintenance contract that ensures the control of the environment to comfort levels and meets recognized standards in storage areas. ○ Building management expertise to ensure maintenance of environment around collections, work and display. ○ Established Building Staff Management Structure ○ Installation or review (if applicable) of building wide security strategy to ensure that security of collections, staff, users and exhibitions from Fire, Flood, Theft ○ Employment of building maintenance staff ○ Cross-museum advisory and communication network
	Collection Care and Maintenance	The institution must have written cross museum IPM and Environmental Monitoring Strategy. The strategy should include policy to improve storage furniture for collections to conservation grade storage cabinets. The institution must have developed a professional staff structure with a Collections Department subdivided into Collection management and Conservation and Collection Care. Implementation of Collection Care strategy must ensure that collections are stored in suitable archival or conservation grade materials, in suitable environmental conditions and that audit cross museum environmental is in place.
	Access and Education	Exhibition programme strategy produced on 5 year rolling programme. Loan procedures integrated across institution. A research structure that has a defined research strategy and management.
A		Defines an Institution that has met and maintains best practice in all areas of management of collections, collections care and building management. Its Collections must be fully accessible with access policies in place. The Institution provides outreach support in benchmarking regional collections with international significance, has Audit/Risk strategy for reviewing and assessing risks to institution and its business continuity fully evolved. The Institution also supports an integrated European Disaster/Business Continuity Plan.
	Procedural and Management	7 year commitment to improving and implementing Collection Management strategies identified at Level B. Review of Business Plan and implementation with 5 year rolling business plan in place. Stability and growth of museum through the development of an Identified stakeholder group, Policy group working with stakeholders to oversee financial and political security of institution, Centralised Collection Management Strategy, Integrated with Departmental collection management policies and Integrated and active project management protocols. The institution must have a stable staff structure with full representation of professional expertise appropriate to each of the Standards Headings. There should be an Audit and Assurance Department responsible for Risk Management, an annual audit of museum Finances and Procedure and Policy. This should include a 3–5 yearly audit of Collection Management and Care in Institution. **Finance** There should be a 5 year Forward Business Plan covering, Buildings and Maintenance, Procedural and Maintenance Conservation, Collection Care and Maintenance. **Health and Safety** The institution will comply with all local, national and relevant EU Health and Safety statutory regulations.

Appendix 1. Continued.

Level	Area	Review of expectation
	Building and Maintenance	○ Centralised maintenance department responsible for building maintenance ○ Permanent funding commitment to building maintenance and development ○ Maintained environmental control plant ○ Development of institutional 'green policy'/energy management strategy (E.g. ISO 14,000/1) ○ Annual Maintenance Audit ○ Maintenance reporting system ○ Professional Staff employed in museum to maintain building fabric ○ Maintained security and fire monitoring and control systems ○ Integrated environmental monitoring systems linked to Building Management Systems ○ Formal conservation–Building and Maintenance communication links and reporting system
	Collection Care and Maintenance	The institution must have a Cross Museum Disaster Plan Implemented as a rolling 3-year programme. A Cost Benefit performance review of collection care and maintenance undertaken on a bi-yearly basis. Remedial conservation programme in place, remedial conservation undertaken by professional accredited in-house conservators. The institution should have a maintained cross-museum environmental control systems that meet environmental standards and storage systems must fully meet support and protection requirements for objects in collections and exhibition; Rolling Collection Survey Plan using recognized benchmarking and risk models. Integrated environmental Monitoring and IPM strategy Centralised and Integrated Conservation Documentation System. Archival Storage meeting WS 5454 or equivalent European standard. Environmental Conditions maintaining collections controlled within recognized standards. Triage system for collection/specimen assessment and response in place.
	Access and Education	**Training** ● Defined Management Goals ○ Defined Job descriptions and objectives ○ Employee understanding of roles ○ Clearly defined Performance Targets ○ Commitment to continued professional development ● Staff training needs in the field of curation and conservation are assessed within institutions planning cycle ● Internal museum-wide training goals established to match performance standards and ensure staff awareness (management, security, IPM, environment, specimen handling, preventive, remedial conservation). ● Internal training scheme established to cover overviews of core activities in institution (delivered by SYNTHESYS recognized individuals/groups). ● Defined mechanisms for disseminating information on training and literature. ● Accreditation and continuous professional development in place. ● Orientation training scheme for all new staff. **Education** There must be a Rolling exhibition programme. Including a rolling travelling exhibition programme. There should also be an education and outreach programme that reflects institutional research policy and collection strengths.

Appendix 2. Request sent to both pilot institutions prior to the site visit.

Pre-survey document request

To ensure that the survey team undertakes a thorough and professional survey we would be grateful if the following documents were available to the survey team prior to the survey being undertaken. If possible these should be provided one week before or at the latest on the day of the survey.

- ○ Collection Management Standards
- ○ Collection Management Policy
- ○ Access Policy
- ○ Acquisition Policy
- ○ Archives Policy
- ○ Audit Policy
- ○ Cataloguing Policy (including databasing)
- ○ Conservation & Collections Care Policy (including IPM Policy)
- ○ Consultancy Policy
- ○ Intellectual Property Rights & Copyright Policy
- ○ Deaccession & Disposal Policy
- ○ Despatch Plicy
- ○ Destructive Sampling Policy
- ○ DNA & Frozen Tissue Policy
- ○ Exhibitions Policy
- ○ Field Collection Policy
- ○ Health And Safety Policy
- ○ Human Remains Policy
- ○ Indemnity Management Policy
- ○ Insurance Management Policy
- ○ Inventory Control Policy
- ○ Loan policy (including Loans In & Loans Out)
- ○ Location & Movement Control Policy
- ○ Loss Policy
- ○ Object Condition Checking & Technical Assessment Policy
- ○ Object Entry Policy
- ○ Reproduction Policy
- ○ Retrospective Documentation Policy
- ○ Risk Management Policy
- ○ Security Policy
- ○ Staff Development Policy
- ○ Training Policy
- ○ Use of Collections (including Research) Policy
- ○ Valuation Control Policy
- ○ Volunteer Policy

The Collection Management Policy must also cover the following areas:

- ● Authority of the Institution
- ● Acquisition, Disposal and Registration Procedures and Policies
- ● Scope of the Collections including:
  - ○ Range of Objects
  - ○ Geographical Limits
  - ○ Chronological Limits
  - ○ Preservation of Material
  - ○ Expertise
  - ○ Brief Review of the Collections in Each Department

IMPROVING CURATION STANDARDS IN PALEONTOLOGY COLLECTIONS THROUGH THE APPLICATION OF "MCGINLEY LEVELS"

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Abstract.—Two methods for quantifying collections standards, ''McGinley Levels'' and the ''Curation Continuum,'' reviewed herein, are useful tools that can be adapted to suit the needs and curation procedures of different collections. They were modified to design surveys for the University of Iowa Paleontology Repository collections and part of the fossil echinoderm collection at the Natural History Museum, London. Examples of survey preparations, curation standards and assessment, and survey results are given. The surveys enabled planning for curation standard improvement and prioritizing of curation projects, a basic collections inventory, determination of current research accessibility and the determination of realistic curation goals and projects. A collection survey can be useful in assessing curation standards, determining future curation requirements, and prioritizing curation projects. A survey can also be used to determine conservation issues. Survey results in spreadsheet format can be used to record the improvement of curation standards as projects are undertaken. A collection survey is an excellent starting point for forward planning or for making backlog curation projects less overwhelming.

INTRODUCTION

This paper discusses the adaptation of ''McGinley Levels'' as a tool for surveying different museum collections and determining curation goals and priorities. ''McGinley Levels'' refers to the Smithsonian Collections Standards and Profiling System (McGinley 1989), a system for identifying the curation status of collection units (a single specimen, drawer, cabinet, or other division of a museum collection) and prioritizing curation tasks to attain the desired curation standard. A slightly different scheme, the Curation Continuum (White 2000) is also discussed as an additional means of identifying curatorial grades. The paper provides survey examples from two collections, the University of Iowa (UI) Paleontology Repository and part of the fossil echinoderm collection at the Natural History Museum, London (NHM).

Using the example of these two collections, this paper aims to examine the goals of collections surveys, and discuss the adaptation of McGinley Levels and the Curation Continuum, survey preparation, collection survey and curation level assessment, recording and interpretation of results, prioritizing of curation tasks, and the benefits of surveying. The goal is to show that existing systems can be adapted to survey any collection and that the benefits are worth the effort of the survey. We focus on fossil collections, but any type of natural history collection can be surveyed (McGinley Levels were developed for entomology collections originally).

The curatorial state of a collection of fossils will alter as it is used. This is inevitable as material is examined and re-examined, identifications made and remade, specimens developed or damaged, and more items added to the collections. New additions need to be curated and incorporated properly into the collections so that they can be accessible for research. However, even in the best-curated

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collections, conditions alter. For example, humidity and temperature changes, or dust accumulation can lead to deterioration, not only in the appearance of the collection, but the specimens and their associated documents. Regular checks have to be kept on specimens, documentation and storage to measure damage and decay or to ensure that when problems occur, they can be remedied.

Museum codes of ethics are explicit that stewardship of collections entails the highest public trust and carries with it the presumption of rightful ownership, permanence, care, documentation, accessibility, and responsible disposal (American Association of Museums 2000). In many cases, specific parts of collections may be very well curated while others are almost neglected because they have low use or are awaiting preliminary curation. Collections containing type and figured material, specimens that are borrowed frequently, and field material that is part of an active research program are more likely to receive priority attention, than material that has not been unwrapped since it was collected in the 1930s. The backlog of material that needs curating can be overwhelming, but must be tackled for these collections to be accessible. Where does one start?

The paleontology collections at the NHM number some 9 million registered curatorial units, approximately 10% of which are type, figured and referred specimens. Perhaps 10% of the collection has been catalogued electronically and the rest is in book-type registers. None of the information is yet available on-line and there is a considerable backlog of unregistered specimens, much in field state awaiting preparation and preliminary curation.

The UI Paleontology Repository contains over 1 million specimens, 25,000 of which are cited in scientific publications. Approximately 10% of the collection is catalogued in a card index, with only 3% electronically catalogued and available on-line.

From 2001 to 2005, the UI Paleontology Repository was reorganized and storage upgraded as part of a project funded by the National Science Foundation to improve the collections. The next phase of the improvement will be the computerization of the collection to provide as much data as possible on-line. Cataloguing the entire collection will take more than one 3-year project, so the computerization projects must be prioritized. A longer-term project is to improve the curation standard of the entire collection. To determine curation and computerization needs and priorities, the Repository holdings were surveyed. The fossil echinoderm collection in the Department of Palaeontology, NHM, was surveyed to determine conservation issues and to plan and prioritize curation projects. Both surveys determined where parts of the collections meet or fall short of acceptable curation standards.

The first aspect to consider before surveying the curation level of a collection is the desired curation standard. This information may be available already in a collection policy or procedure manual. Both the NHM echinoderm collection and the UI Repository have both, based on published standards and recommendations (e.g., Brunton et al. 1985, Paine 1993, White 2000).

Quantifying Levels Of Curation

A wide range of natural history collections has been surveyed at other institutions by adapting McGinley Levels. These collections include invertebrate paleontology at the University of Kansas (Lieberman and Kaesler 2000), The Pea-

Table 1. Summary of Curation Status Levels (McGinley 1989).

Level	Curation status
1	Conservation Problem
2	Unidentified material, unsorted, inaccessible for research
3	Unidentified material sorted and effectively accessible to research community
4	Identified material (to species level) not incorporated into general collection
5	Inadequately curated material, not meeting departmental standards
6	Physical curation complete, meeting departmental standards
7	Physical curation complete, species level inventory complete
8	Physical curation complete, individual specimen label data captured
9	Physical curation complete, specimen label data captured, research data captured.

body Museum of Natural History (White 1998), botanical collections at the Natural History Museum, London (Huxley 1994), and extant vertebrates at the Museum of Texas Tech University (Williams et al. 1996).

McGinley (1989) identifies nine levels of curation status for entomology collections (Table 1), which can be applied to most museum collections. Depending on the type of collection, Levels 3, 6 and above are the goals. The authors developed additional Conservation and Demand Levels, based on McGinley's system:

Conservation Levels:

- A: Stable material, in good condition.
- B: Stable material but in hazardous condition, not stored in suitable conditions (e.g., pyritic specimens in fluctuating environment).
- C: Unprepared or damaged material requiring preparation or repair.
- D: Conservation problem that MUST be resolved:
  - D1: Unstable material actually decomposing.
  - D2: Unstable material likely to decompose.

Demand Levels (levels indicating access demand) are defined as:

- A: High demand material:
  - a: type, figured, referred and research material, of highest quality.
  - b: display quality material.
  - c: material requiring special security (e.g., amber).
- B: High quality material of potential research interest.
- C: Material infrequently studied.

Conservation Levels and Demand Levels can be used to further prioritize curation tasks once the Curation Level has been established. Depending on local collection management goals, material that is decomposing is most likely to be a higher priority for action than material that is not, for example.

Comparable to this system is the continuum of curatorial activity for invertebrate paleontology collections described by White (2000), and Hughes et al. (2000) (Table 2). Depending on the collection, Grade 2 and 5 may be the ultimate aims (Hughes et al. 2000). Grade 2 may be the highest achievable grade for a collection that has not been researched. Grade 5 may be more applicable to type and figured material. Achieving Grade 5 also depends on the available resources.

Table 2. Summary of continuum of curatorial care (White 2000, Hughes et al. 2000).

Grade	Curation status
1	Acquired and accessioned
2	Sorted by age, locality, collecting event. Description of collection disseminated
3	Sorted taxonomically or geologically; locality data recorded electronically, linked to collection (labels)
4	Taxon/biofacies identified, taxon/assemblage sorted, fully prepared, boxed
5	Taxon/locality lots catalogued electronically and marked, fully labeled and organized. Collection description fully disseminated to scientific community

The UI Paleontology Repository collection was surveyed previously using the Curation Continuum Model (Table 2). Approximately 10% of the collection (including 100% of the type and ammonoid material) reaches Grade 5, the most desirable level. The Neogene corals (<10% of the collection) reach between Grades 4 and 5. The other major research segments (echinoderms, conodonts, nautiloids, fusulinids, and vertebrates; approximately 30% of the collection) reach between Grades 3 and 4. The remainder of the collection (approximately 50%) is mainly Grade 2 to 3, with several segments of the collection between Grades 1 and 2. Following reorganization, we adapted the McGinley survey method to allow a finer division of levels and determination of priorities.

Determining New Curation Level Standards

Curation of any collection requires forward planning: determining what needs to be done, what the priority curation projects are, which ones are achievable within a specified time frame, and what resources will be needed. Once the curation standards and goals have been identified, the current curation status of the collections can be determined.

Two surveys were carried out: a total collection survey (UI Paleontology Repository) and a drawer-by-drawer survey of specimens (NHM). Each survey had slightly different aims and methods but both had the common goal of prioritizing the improvement of curation standards. The aims of surveying the entire UI Paleontology Repository were to identify conservation projects, provide a forward plan prioritizing major curation projects, such as reorganization and documentation, determine and prioritize computerization projects, and become familiar with the collection. The collection was surveyed according to taxonomic or stratigraphic group, each surveyed unit including multiple cabinets. The aim of the NHM survey was to prioritize curation tasks for forward planning and assess future conservation requirements. Individual specimens were surveyed.

Curation Levels for each collection were based on McGinley Levels and, for the UI Paleontology Repository Survey, the Curation Continuum also. To determine how curation activities corresponded with McGinley Levels and/or Curation Continuum Grades, the process of curating a new acquisition to the desired standard was divided into logical steps. Ideal step-by-step curation procedures for the Repository are outlined in Table 3, those for the NHM Echinoderm Collection in Table 4. Each curation step is the equivalent of a curation level and reflects a logical break in the curation process. Each of the levels developed for our partic-

Table 3. UI Paleontology Repository step-by-step curation procedure, with reference to Curation level, McGinley level and Curation Continuum grade.

Curation level	McGinley level	Curation Continuum grade	Curation activities completed
1	2	1	Acquired, awaiting curation, acquisition documents secured
2	3	2	Unwrap specimens, preserve original labels, field notebooks, etc., print temporary labels, cross referenced with field notes, clean specimens, put in temporary boxes, organize in temporary storage. Assess conservation requirements, act if necessary
3	4/5	2/3/4	Prepare for electronic cataloguing: assess specimens for different collections, e.g., duplicates, taxonomic, stratigraphic, biocommunities. Identify (if possible), prepare (if possible), collate relevant data. Determine permanent storage location
4	6/7/8	5	Electronic cataloguing: assign unique number and mark on to specimen/lot, identify specimens (if possible), enter all relevant data into database. Place specimens in correct boxes. Print out labels and register pages; organize specimens in permanent storage location
5	8		Update specimen data: location indices and drawer labels, bibliographic data, identification etc. updated as necessary
6	9		Maximum curation: all data up to date and electronically available. Expansion space available

ular collections described either the action required to complete the level or the action required to get to the next level.

These curation levels can be matched to the applicable McGinley Level or Curation Continuum grade (Table 3). The match need not be perfect. There are differences between McGinley Levels and the Curation Continuum, and the curatorial practices and historical organization of the collections at both institutions. For example, Grade 3 of the Curation Continuum states that locality data are recorded electronically; at the UI Paleontology Repository, locality data are only recorded electronically when individual specimens and lots are catalogued (equivalent to Grade 5), and there is no in-house locality numbering system.

Although Level 6 (specimens and data fully accessible for research) is the desired curation level in the UI Paleontology Repository scheme, it may be possible only to curate some collections to Level 2. Large unprocessed collections and faculty research collections in the UI Paleontology Repository usually remain at Level 2 for long periods of time. Further curation of unprocessed collections that require preparation and identification often depends on the needs of researchers to study the collection. Where there is no in-house specialist, visiting scientists should be encouraged to assess the collection so that an announcement can be made to the scientific community, otherwise a situation arises where the collection remains unused because no preliminary study has been made to promote its use. University of Iowa faculty field or research collections usually are not incorporated into the Repository collections until research is nearing completion and specimen numbers are required for publication. This is because some material may be destined for other institutions. However, one of the purposes of the Repository is to support faculty research, and therefore these collections are accorded the same storage, preventive conservation and care as the permanent collections.

Table 4. NHM fossil echinoderm collection curation levels, based on McGinley Levels (Table 1).

Curation level	Description
1	**Unidentified, unsorted material (backlog and field state material):** Status: Material is not sorted into major taxonomic (or any other) groups (e.g., echinoderms, arthropods) Availability: not registered (computer catalogued), unavailable for loan, inaccessible for research Action: sort, identify, register, incorporate, adjust indexes and labels Tasks: Prepare specimens, prepare data for registration of specimens, register specimens
2	**Unidentified material, partly sorted:** Status: Material is sorted into major taxonomic groups only (e.g., echinoderms, arthropods) Availability: not registered, unavailable for loan, inaccessible for research Action: identify, register, incorporate, adjust indexes and labels Tasks: Prepare specimens, prepare data for registration of specimens, register specimens
3	**Identified material, not incorporated into main collections:** Status: material studied by researcher, identified but not in permanent storage Availability: not registered, unavailable for loan, may be inaccessible for further research Action: register, incorporate, and adjust indexes and labels Tasks: register specimens, incorporate into permanent collection
4	**Incompletely curated material, below departmental standards:** Status: material is all or partly identified, integrated and mostly in documentary good order, but substandard in storage (e.g., temporary labels, non-archival storage materials, e.g., on old exhibit boards, low quality boxes, disorganized) Availability: available for loan, accessible for research, but requires storage improvement Action: replace boxes etc., attend to presentation and organization Tasks: Prepare specimens, monitor and conserve
5	**Curation complete, meeting departmental standards:** Status: material is identified, properly integrated, in correct trays, with documentation and expansion space, and conservation notes included with specimens Availability: available for loan, accessible for research Tasks: Enhance collection (updated additional data, prepare catalogues)
6	**Collection is properly curated and also incorporates a list of:** associated material, geographic area of representation, miscellaneous remarks (e.g., name of curator)
7	**Labels are present for individual specimens.** This may be practical only for parts of larger collections e.g., type, figured, cited material, research collections, special collections
8	**Research data are present,** including specimen measurements, data sets, digital images, reprints of articles citing specimens

In the NHM scheme, the normal state of a collection should be Level 5 at least, which means a collection is in good order, with suitable containers, with primary data included, in need of no further essential curation, and which is available for research and borrowing. Levels 6–8 are desirable but their necessity depends on the type of collection and the availability of resources. Lewis assessed the fossil echinoderm collection on a drawer-by-drawer basis (Table 6 for example of results). The NHM scheme included determination of Availability Levels for research access (Table 4), and the Demand Level for each survey unit.

An adaptation of McGinley Levels common to both collections was removing curation Level 1 Conservation Problem (Table 1). This was made Priority 1 instead, because a conservation issue can arise at any time in any part of a collection at any state of curatorial completeness. A collection unit may be at curation level 6 but if there are signs of active pyrite decay, immediate attention is required and the collection is Priority 1. Assigning a collection to Level 1 because of a conservation concern would mask the curation level, the identification of which was a purpose of the survey. Instead, presence of a conservation problem was used to flag the collection as a high priority for action. Prioritizing collections is dealt with in more detail in a later section of this paper.

Surveying The Collections

The UI Paleontology Repository collections were divided into collection units for survey. We intended to survey the entire collection, so the collection was divided according to organization (taxonomic, stratigraphic, microfossil, oversize specimens, type collection). The taxonomic collections were broken down into nautiloids, ammonoids, echinoderms, bryozoans etc.; the stratigraphic into Cambrian, Ordovician, Devonian, etc. A floor plan was made of the entire collection, showing the location of collection units. This ensured that all relevant storage cabinets were surveyed together. Active faculty research collections were not included in the survey, as these are not necessarily destined for accessioning. Each unit was surveyed using a separate survey questionnaire. Every drawer of a collection unit was examined and the survey question answered for the collection unit as a whole.

To aid the assessment of the UI Paleontology Repository curation levels and avoid indecision and inconsistency, a checklist or key was developed which asked very simple questions and required yes/no answers (Appendix). The McGinley Level 1 Conservation Problem is addressed separately, in the first question, so that any conservation problem could be prioritized, regardless of the curation level. In the absence of in-house conservators, typical conservation problems such as those described by Collins (1995), Collinson (1995), and the Canadian Conservation Institute (1994), were determined for different materials (including documentation) in the collection. These were divided into active and stable problems in order to prioritize action. Active conservation problems include active pyrite decay, pests, fungal or mold attack, active reaction with storage medium (e.g., corroding paperclips, Byne's disease), fluid preserved specimens drying out, and specimens that are deteriorating due to drying, cracking and shrinking. Where the activity status of deterioration was not determined, the collection was flagged for monitoring. Stable conservation issues include dirty specimens, incorrect boxes, presence of non-archival materials, overcrowding, and lack of cross-reference between specimen and documentation (e.g., label potentially easy to disassociate). Where any conservation issue was seen, the relevant box on the survey sheet was checked. A Conservation Score was determined based on the number of issues that needed attention (number of boxes checked), and the presence of active conservation problems.

The remaining five questions are concerned with the curation process and help determine the curation grade or level. Questions are answered by checking "yes" or "no." If there are any checks in the "no" column, the key follows the instruc-

Table 5. Example results from collection units within the UI Paleontology Repository collection survey. Curation Levels (Table 3), Conservation Score (based on the number of boxes checked in Q.1 on the survey sheet, Appendix), Priority (described in text under prioritizing curation tasks).

Collection unit	Location	Curation level	Conservation score	Upgrade to next level—requirements	Priority
Nautiloids	A1-12	3	10 (Stable)	1 (database)	4
Ammonoids	A13-30, B2,4,6	3	6 (S)	1 (database)	4
Johnson Shell Colln	B8	1	4 (S)	1 (temporary labels)	2
Silurian Strat Colln	P1, 3-5	3	9 (S)	3 (catalogue, print permanent labels, rebox)	2
Pope Colln	M1-3, N11-12	1	4 (S)	2 (rebox, temporary labels)	2
Fish Colln	I28-29	3	1 (Active) 13 (S)	2 (database and rebox)	1

tion beneath that column even if there are more checks in the ''yes'' column. In parts of the collection where there is a mixture of curation levels, e.g., some specimens have catalogue numbers while others do not, the ''yes'' box was checked if more than 50% of the collection unit applied. This was done because most collection units held some less well curated specimens, and the goal was to get an overview of the collection. An exception to this was at the lowest level (Q.6) where 75% of the unit had to have received preliminary curation for ''yes'' to be checked. This weighting was designed to prevent underestimating the number of preliminary curation projects.

The purpose of a collection survey is to show areas where the curation standard needs to be improved and what improvements are required. In the long-term, a survey can be used to show how a collection has improved or deteriorated over time (McGinley 1992). Information from the survey can be recorded in a simple table (e.g., Tables 5, 6) that can then be used to evaluate a collection or parts of a collection, and identify quickly and easily the curatorial state and areas requiring improvement. Actual quantities, in terms either of specimens or numbers of drawers of material, can be recorded alongside each category so that graphic profiles of the collections may be generated if required and a collection health index can be calculated. A graphic format can show the developing state of the collection, how the collection has improved or deteriorated over time, areas where improvement is necessary and what improvements are required. Allocation of resources may also be implied. A description of methods is given by McGinley (1992) and Williams et al. (1996).

Assessing Curation Levels—Examples

Some examples from the UI Paleontology Repository collections can be used to illustrate how various collection units were assessed (results are shown in Table 5). A collection unit given the lowest curation level (1) is the Johnson Shell Collection of modern mollusks. The collection, donated by the family of an amateur collector, is beautiful but has no documentation whatsoever. Question 1 of the survey asks ''Is there a conservation problem?'' Some of the specimens are in old acidic boxes with cotton wool and other non-archival materials. There are no labels. This means there are 4 stable conservation issues. Question 2 asks ''Is

Table 6. Example survey results from a few drawers within the NHM fossil echinoderm collection. Conservation and Demand Levels (in text under quantifying levels of curation section), Curation Level (Table 4), and Priority (in text under prioritizing curation tasks).

Collection: Eocene, London Clay starfish and others; numbers of specimens in 5 drawers

Taxon (quantity) Asterozoa	Conservation level	Curation level	Availability level	Demand level	Priority	Location
Coulonia (20)	1/D1: 14/B-D2; 5/A	L5	15/L4; 5/L5	C	15/P1; 5/P6	J14
Coulonia (20)	19/B-D2; 1/A	L5	19/L4; 1/L5	C	P1	J15
Hippasteria (9)	9/B-D2	L5	9/L4	C	P1	J16
Teichaster (37)	35/B-D2; 2A	L5	35/L4; 3/L5	C	P1	J16
Ophiura (110)	110/A	L5	110/L5	C	P6	J11, J12

the material catalogued and entered into the main collection?'' There are no catalogue numbers assigned, even in the collections card index, and the collection is not entered in the Repository database. It is in temporary storage, and is not entered in a location index—four ''no'' checks for Q.2, which directs the survey to Q.4, ''Is the material ready to be integrated into the main collection?'' The collection is not catalogued, has no labels, specimens are not identified or organized, nor has a permanent location been identified. Some specimens are in correct storage boxes, but five ''no'' boxes are checked against this one ''yes,'' so on to Q.5: ''Is the material ready for data entry?'' Specimens are not identified, there are no accompanying data, there is no known accompanying publication and no permanent location identified—three ''no'' checks and one ''not applicable.'' On to Q.6 ''Has the material had any preliminary curation?'' Specimens are unpacked from field state into acceptable storage, and in specimen boxes, but there are no labels. This collection is therefore at Level 1: Acquired and awaiting curation.

Also at Level 1 is the Pope Collection, a Pennsylvanian stratigraphic collection donated recently by a PhD student, consisting of material from localities that are no longer accessible. The collection has basic locality and stratigraphic documentation, and some specimens are identified, but most of the material is bulk collections of taxonomic groups still housed in shoe boxes and ice cream tubs with the locality and identification (if any) written on the outside. The material is not catalogued and no specimen numbers are assigned. There are no temporary labels and the index has not been updated. The collection is organized by locality in the permanent storage location.

At the other end of the curatorial scale is the Type Collection, which consists of all material that has been cited in a publication (not just primary types). This collection is catalogued and available on-line, and contains only material that is curated to the maximum accepted standard, Level 6. Material awaiting publication or updating is stored separately in a ''Future Types'' cabinet.

Table 6 shows example results from the NHM echinoderm survey, a more detailed survey of a smaller collection unit (five drawers), including levels for conservation problems, availability (as per Table 4) and demand. Where there is a mixture of curation states in one drawer, the predominant level (majority of specimens) is recorded first, followed by the secondary level and so on. This is done on a specimen basis, but for larger collections could be applied to drawers or even cabinets.

Using drawer J14 of 20 specimens of *Coulonia* as an example (Table 6), Conservation Level shows that one of the fossils is actually decomposing (1/D1). There is a conservation problem for 14 specimens (14/D2) which, although stable at present, could become unstable because of the unsuitable storage conditions (14/B) and so are recorded with both B and D categories (14/B-D2). Five specimens are stable because of their different preservation (5/A). Curation Level indicates that all are well documented and their arrangement satisfactory (L5). Availability is reduced for 15 specimens (1/D1, 14/D2); one is decomposed by pyrite decay, 14 others are unavailable for use until they have undergone treatment for actual or potential pyrite decay (15/L4), and five are available for immediate use (5/L5). Fortunately, demand for any of the specimens is currently low (C). The demand status is subjective, but can be based on how often, or the last time, the material was examined.

Prioritizing Curation Tasks

After determining the curation levels, the next step is to prioritize curation projects to improve the curation standard. Priorities are established to determine which task should be done first. Rationale for prioritizing curation projects depends on research potential, use, scientific importance, resources, and the goals of the parent institution. Our scheme closely follows McGinley 1989, but also reflects individual institutional curation procedures.

Priority 1.—Any collection with an active conservation problem takes precedence over all other activities regardless of its curation level. In the examples herein, Priority 1 action would involve stabilizing the environment of specimens experiencing the greatest risk from pyrite decay until they can be conserved in the case of the NHM echinoderms, and scanning and preserving fragile original labels in the UI Paleontology Repository fish collection.

Priority 2.—Secure specimens and associated data, place in correct storage as outlined in Table 3, Curation Stage 2. Any field collection or bulk acquisition that is still in field state with minimum collection data physically associated or cross-referenced to the specimens needs to be unpacked and documented with temporary labels. Where several specimens are stored in a single tray, include duplicate labels in case specimens have to be separated later. Field notes should be secured or copied and cross-referenced with the collection. It is not unusual for institutions to have material still wrapped up from field collecting, with the history of the collection and associated data passed verbally or by memo between curators over the years. The collection and its data could be disassociated very easily and the research potential of the collection diminished, making these types of collection a high priority for curating to the next level.

Priority 3.—Prepare material for cataloguing as outlined in Table 3, Curation Stage 3. At this point, specimens that were placed in one tray together might be separated, and specimen catalogue numbers assigned and marked on specimens and temporary labels in preparation for data entry.

Priority 4.—Enter specimen data into database as outlined in Table 3, Curation Stage 3 and move to permanent storage if necessary. This will bring specimens to a point where they are accessible for research and loan, and their data available on-line (if using a web-accessible database).

Priority 5.—Update identifications, publication data, collection indexes or inventories, drawer and cabinet labels.

Priority 6.—Make all associated data (digital images, measurements, analyses etc.) available electronically. Organize expansion space.

If several collection units have the same priority level then further prioritizing may be needed at the curator's discretion. For example, the UI Paleontology Repository's Pope Collection and Johnson Shell Collection are both Level 1 Priority 2 (Table 5). The Johnson Shell Collection is smaller in size and requires only temporary labels to reach the next curation level so under normal circumstances this might be completed before the Pope Collection curation. However, the Pope Collection has far greater research potential and the data are available to record so curating this collection would be a more efficient use of resources. The Johnson Shell Collection is more likely a candidate for transfer to the teaching collections because there is no specimen data.

The UI Paleontology Repository nautiloid and ammonoid collections are both Level 3, Priority 4 (Table 5), but the nautiloid collection has more stable conservation problems to address that may justify curating this collection first. Where published specimens are involved, newly acquired specimens that are not already electronically catalogued may take precedence over published specimens that are, because the former are not available for further study, while the latter are available although their records are not updated. Curating newly acquired published specimens may also take precedence over curation projects at Priority 2 or lower because of their research importance. Recording the collection size could help identify curation projects that can be completed in a few hours or a day, and longer-term projects that will need advance planning. Recording the main tasks that need to be done may help identify projects for volunteers and interns, e.g. re-boxing and organizing specimens, replacing non-archival storage materials with archival ones, and encapsulating original, handwritten labels.

Conclusions

Collection surveys can be very helpful in assessing the curation standard of collections ranging from a single drawer of specimens to an entire repository collection. They are especially useful for becoming familiar with a new collection (whether it is the collection or the curator that has just been acquired). A survey can be adapted to suits the needs and curation procedures of different collections and can be used to uncover conservation issues as well as determine curation standard. A collection survey provides an overview of a collection (or part of a collection) that will determine future curation requirements and help prioritize them. A collection can be assessed during one survey or over a series of several, depending on time and resources. Survey results recorded on a spreadsheet can be updated as collections are curated to the next level, providing a record of the overall curation standard of the collection over time. The amount of time taken to curate a collection to the next level can be recorded for use when planning future curation objectives. For those backlog collection projects that always seem to pile up and become overwhelming, a collection survey will provide a very useful starting point.

Acknowledgments

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Appendix. UI Paleontology Repository curation survey questionnaire.

University of Iowa Paleontology Repository Survey sheet

Unit description

LEVEL
PRIORITY
UPGRADE SCORE
CONSERVATION SCORE
MONITOR

No of metal cabinets
No of wooden / dental cabinets
Total No of drawers
No of specimens

Time spent:

No of wooden drawers
No of metal drawers

Q1. Conservation
Is there a conservation problem?

a) No conservation problem -> Q2
b) Yes, active conservation problem -> **PRIORITY 1**
c) Yes, but collection stable -> Q2
d) Can't tell, specimens still wrapped up -> **PRIORITY 1**

b) Active conservation problem
Specimen

drying, shrinking, cracking
organic material flaking off
active pyrite decay
deterioration of adhesives
fungal/mold attack
"wet" colln drying out
particularly fragile specimens at risk
deterioration of resins (amber etc)
Active reaction with storage medium

Storage

deterioration of storage unit
(slide broken, mounting medium failure)
fungal/mold attack of storage material
deterioration of SEM stubs
specimen with loose flakes in electrostatic box
active reaction with storage medium
specimen in wrong size drawer
or incorrect storage cabinet

Documentation

ink fading
paper deteriorating
pest attack

c) Stable conservation issue
Specimen

old pyrite decay
dirty/dusty

Storage

incorrect box size
cotton wool
old acidic boxes
glass
cork
overcrowded
other non-archival materials
(elastic bands, aluminum foil, paper clips, twisty ties, cloth bags)

Documentation

no label
dusty/dirty
unprotected
easily disassociated from specimen

Q2. Is all the material catalogued and integrated into the main collection?

	YES	NO
Catalogue numbers assigned...		
Catalogued in database (available on-line)..........................		
Correct storage location...		
Location indices up to date...		
	Go to Q3	Go to Q4

Q3. Does the curation meet accepted documentation standards?

	YES	NO
Specimen citations up to date...		
Identifications up to date...		
Specimen labels up to date..		
drawer labels and indices up to date....................................		
Expansion space available..		
	Level 6	**Level 5 Priority 6**

Q4. Is the material ready to be integrated into the main collection?

	YES	NO
Material is electronically catalogued......................................		
Specimens are identified...		
Specimens placed in correct storage boxes........................		
Specimens organized..		
Permanent location identified..		
Specimen labels present and up to date...............................		
	Level 4 Priority 5	Go to Q5

Q5. Is the material ready for data entry?

	YES	NO
Specimens identified...		
Locality and stratigraphic details available...........................		
Publication data available..		
Permanent location identified..		
	Level 3 Priority 4	Go to Q6

Q6. Has the material had any preliminary curation?

	YES	NO
Correct storage...		
Unpacked into specimen boxes..		
Temporary labels..		
	Level 2 Priority 3	**Level 1 Priority 2**

Notes

STANDARDS FOR THE U.S. ANTARCTIC METEORITE PROGRAM COLLECTION: PRESERVING OUTER SPACE IN MUSEUM SPACE

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Abstract.—In 1981 the U.S. National Science Foundation (NSF), NASA and the Smithsonian Institution formed the U.S. Antarctic Meteorite program for the collection, curation, classification, and distribution of Antarctic meteorites. In 2003 a U.S. federal regulation (45 CFR 674) was implemented that set required standards for non-governmental collecting and to protect this unique resource, which may hold keys to life in the solar system. The significance and origin of three curatorial and classification standards from 45 CFR 674 are discussed with reference to practices at the Smithsonian and NASA's Johnson Space Center. These evolved from, but are largely unchanged from those used for the lunar samples from the Apollo missions. These curatorial standards in areas of collection, storage, handling, classification and data management are outlined and the significance and origin behind each standard discussed. The classification of Antarctic meteorites in part governs the level of long-term storage, as do levels of funding available. These standards are a guide to others responsible for curation of Antarctic meteorites and provide input to governmental organizations empowered with implementing the recommendations of the Antarctic Treaty Organization.

INTRODUCTION

Since 1976, Antarctic meteorites collected by the United States have provided a continuous, inexpensive supply of extraterrestrial materials to the international scientific community. Among the 15,000 specimens collected to date, are the first meteorites identified as coming from the Moon and Mars, a wide range of asteroidal material previously known only from a single strange rock, and a rock that may hold keys to the origin of life elsewhere in the Solar System, and sampled processes that occurred even before our Solar System formed. As we enter the 21st century, space missions are planned that will return samples of asteroids, comets and Mars. The Antarctic meteorites will still be important, as they will provide the framework used to interpret these rare returned samples.

History of Meteorites from Antarctica

Serendipitous finds of meteorites from Antarctica were documented as early as 1912 from Adelie Land and several similar finds occurred in the early 1960s as scientific investigations in Antarctica increased (expeditions to Lazarev 1961, Thiel Mountains 1962 and Neptune Mountains 1964). In 1969, the recovery of nine in the Yamato Mountains by Japanese glaciologists, catapulted meteorites from mere curiosities to the focus of exploration. Such accumulations of multiple meteorites typically represent a single fall that broke up in the atmosphere and showered an area with stones. This discovery suggested a unique ''concentration

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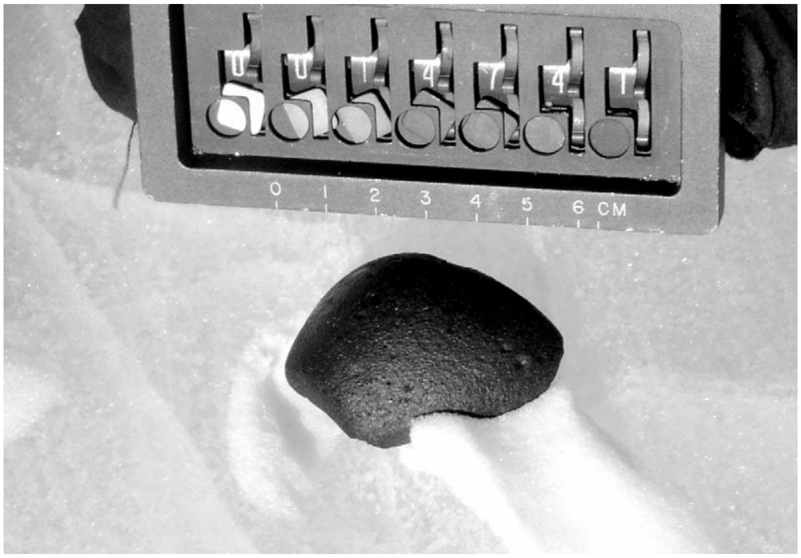

Figure 1. The MAC 02874 (L5 chondrite) meteorite as it was found *in situ* on a blue ice field at MacAlpine Hills, Antarctica, during the 2002–2003 field season. The counter records a provisional field number, provides a scale for the image and the square tabs allow calibration of true colors.

mechanism,'' as these nine meteorites represented 6 different types, including two rare chondrites (primitive meteorites formed in the Solar nebula) and a diogenite (a rock formed by melting on the surface of an asteroid) (Shima and Shima 1973).

The 12 million square kilometers of Antarctic Ice sheet acts as an ideal catchment area for fallen meteorites (Harvey 2003). As the East Antarctic ice sheet flows toward the margins of the continent, mountains or obstructions below the ice occasionally block its progress. In these areas, old, deep, blue ice is pushed to the surface carrying the meteorites along with it. Strong katabatic winds remove large volumes of ice, concentrating the meteorites and prevent the accumulation of snow on the stranded deposits (Fig. 1). As a result representative sampling of meteorite falls can be undertaken.

Of additional significance is the terrestrial residence time of the meteorites. Antarctic meteorites record terrestrial ages ranging from tens of thousands to two million years (Welten et al. 1997), and are less weathered than meteorites found in temperate climates. The newly fallen meteorites are quickly frozen and preserved into the thickening ice sheet, reducing the amount of weathering and contamination. The relatively pristine state of the samples allows studies that were previously difficult or impossible. The lack of weathering also means that much smaller meteorites survive and, thus, provide a broader sample of the material in our Solar System.

The U.S. Antarctic Meteorite Program

The Japanese began regular collecting expeditions to the Antarctic in 1973, collecting a modest 12 meteorites. In 1974 they returned hundreds of meteorites. At around the same time, University of Pittsburgh meteorite scientist Bill Cassidy submitted three proposals to the National Science Foundation (NSF) to fund a

Figure 2. Principal author (lower left), team leader Dr. Nancy Chabot of Case Western Reserve University (standing) and Dr. Daniel Glavin of NASA Goddard Space Flight Center (right), collecting a meteorite from blue ice at MacAlpine Hills in 2002. The meteorite is picked up with pre-sterilized stainless steel tongs and placed into a Teflon™ bag. A GPS reading is taken at the find site.

U.S. expedition to find other suitable areas of meteorite accumulation. When word of the Japanese success reached the NSF, support was granted for a 1976–1977 expedition. Cassidy was joined by Ed Olsen (Field Museum, Chicago) and Keizo Yanai (National Institute for Polar Research, Tokyo) to search in areas accessible by helicopter between McMurdo Station, and Allan Hills. Nine specimens were found that season (Cassidy 2003).

The collection effort evolved and 27 full seasons have now been completed with the recovery of more than 15,000 meteorites, more than were collected from the entire surface of the Earth in the previous 500 years. The field party grew from three members initially, with six to eight members during much of its history. Additional funding from NASA, who hoped to recover more Martian meteorites, has now expanded the group to 12 members, with two separate field parties exploring different regions. The NSF Division of Polar Programs, with decades of experience in exploring the harsh Antarctic environment, provides the field collection support for the ANSMET program run by Ralph Harvey, an associate professor at Case Western Reserve University. Each year, the field teams comprised of planetary scientists, work together collecting meteorites in remote field locations for about six weeks during the Austral summer (November–January). Their primary goal is to recover complete and uncontaminated samples of meteorites. Systematic searches are conducted in a series of 30 meter wide parallel transects by snowmobile on areas of snow-free blue ice. If the concentration is high, transects are searched on foot instead, ensuring the recovery of meteorites as small as one centimeter in diameter. Many stranding surfaces are large enough to require several seasons in the same area. The first and third authors of this paper have both participated in these field efforts (Fig. 2). Collection efforts in

Antarctica have been so successful that collecting parties from Europe (EUROMET), Italy and China have joined the U.S. and Japan in mounting regular expeditions to collect meteorites in Antarctica.

As the field efforts evolved, so did the curatorial efforts. The first nine meteorites recovered by the U.S. were curated and samples distributed to scientists by the Field Museum in Chicago, Illinois. As it was recognized that hundreds or thousands of meteorites could be recovered under the auspices of the federal government, attention quickly turned to designing a robust, long-term plan for curation, classification and distribution. An ad hoc committee was convened on November 11th 1977 in Washington DC. The meeting included representatives of NSF, ANSMET, the Smithsonian, NASA and the scientific community (Antarctic Meteorite Working Group 1978). This meeting produced ''A plan for the collection, processing, and distribution of the U.S. portion of the Antarctic meteorites collected during 1977–78.'' It was agreed that NASA, Johnson Space Center would provide initial, short-term curation modeled on, but less rigorous than, standards for lunar rock curation. The Smithsonian would assume responsibility for classification and long-term curation and storage. Both agencies would provide samples for distribution to interested scientists. Although the program has evolved during the last 30 years, a strong heritage can be traced to this formative period.

Curatorial Standards

Several events over the last decade have highlighted the need to collect Antarctic meteorites; the raging debate over life on Mars spurred by the Antarctic Martian meteorite Allan Hills 84001 (McKay et al. 1996) and the dramatic increase in the value of meteorites on the commercial market. The increase in recovery of meteorites from the hot deserts of northern Africa spurred non-governmental organizations to consider collecting meteorites in Antarctica. Indeed, a few privately funded expeditions actually recovered meteorites. These events caused the Antarctic Treaty Organization to encourage participating countries to take measures to protect this valuable scientific resource. The U.S. Federal Government, through the NSF, responded by implementing a federal regulation that defined for the first time, collection and curatorial standards to be used by the U.S. Antarctic Meteorite Program (45 CFR 674) (NSF 2003). It is important to note that other national governments and government consortia (e.g., EUROMET) follow similar standards, although each is adapted to their unique situation. Below are details of the three curatorial and classification standards. These sub-elements are most pertinent to museum-based collections care. For each, we discuss its significance and origin.

Curation. (Sec. 674.4, part b, number 3.) 'Make prior arrangements to ensure that any specimens collected in Antarctica will be maintained in a curatorial facility that will: . . . '

The Federal regulation does not discourage or preclude collection of Antarctic meteorites by non-governmental organizations. Its sole purpose is to provide a standard of care that must be met in order to obtain permits for collecting through the NSF. As such, applicants for such permits can satisfy the requirements of collection care by either establishing a curatorial facility of their own or surren-

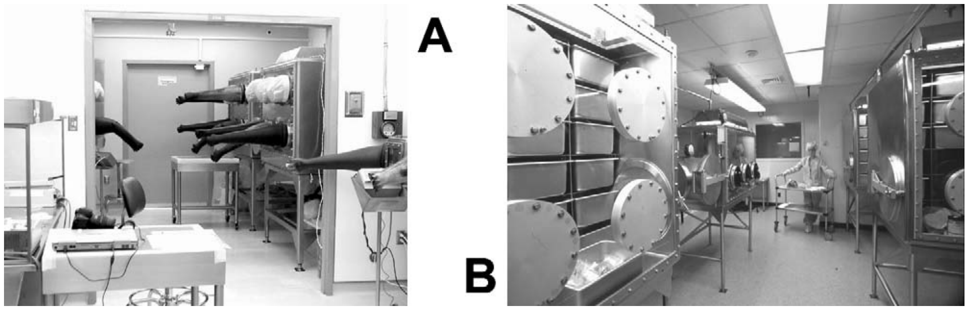

Figure 3. The meteorite processing and storage laboratories at A) NASA, Johnson Space Center, Houston, Texas (B) and the Smithsonian meteorite storage facility in Suitland, Maryland.

dering collected meteorites to the U.S. Antarctic Meteorite Program either in the field (e.g., at McMurdo Station) or by arrangement directly with the curatorial facility at Johnson Space Center, Houston, Texas.

(i) 'Preserve the specimens in a manner that precludes chemical or physical' degradation'

The regulation was deliberately written to be vague to allow interpretation appropriate to available resources. Proprietary equipment is not mandatory as long as the primary requirement is met. A framework for this element is provided in section 674.4 (b) (I), which calls for sample handling that minimizes contamination, including (i) Handling the samples with clean Teflon™ or polyethylene coated implements or stainless steel implements (or equivalent); (ii) Double bagging of samples in Teflon™ or polyethylene (or equivalent) bags; (iii) A unique sample identifier attached to the sample container; (iv) Keeping the samples frozen at or below −15°C until opened and thawed in a clean laboratory setting at the curation facility; and (v) Thawing in a clean, dry, non-reactive gas environment, such as nitrogen or argon.

These standards stem directly from procedures used in the lunar processing laboratory where only stainless steel, Teflon™ and dry nitrogen are allowed contact with lunar samples. For Antarctic meteorites, a few additional materials were allowed, including aluminum sample pans for processing and polyethylene gloves. In practice, NASA's Johnson Space Center and the Smithsonian have adopted a common procedure for the curation of Antarctic meteorites. Both have adopted stainless steel, gloved cabinets flushed with nitrogen for sample handling and storage (Fig. 3). Meteorites are stored in the gloved, nitrogen storage cabinets shown at right rear (A). Positive pressure forces the gloves out of the cabinets and prevents contamination. Initial processing of the samples is done either in a gloved, nitrogen processing cabinet (not shown) or on a laminar flow bench (foreground left, A). Storage cabinets (B) typically contain 60 stainless steel pans in which meteorites are arranged by field area and/or meteorite type. The Johnson Space Center maintains their entire facility within a class 10,000 clean room (10,000 particles per cubic meter of air). Although rated for 10,000, weekly surveys over the last few years show counts that routinely fall below 1,000 particles (K. Righter pers. comm.).

New meteorites arrive at the Johnson Space Center Meteorite Processing Laboratory still under refrigeration from the time they left Antarctica. Each is unpacked from insulated containers called isopods, into −10° to −15° F freezers until they are selected for processing. Processing involves numerous steps. The first step is retagging and repackaging of all the frozen meteorites. Each rock is removed from its field packaging and placed into a new bag, which is preferably Teflon™, but nylon is a satisfactory and less expensive equivalent. A new name tag then replaces the field number and records a unique identifier: a three letter abbreviation for the field locale followed by a five digit number indicating year of find and the individual lot number. For example, one of 390 meteorites collected from MacAlpine Hills in 1987 might bear the name tag MAC 87302, where 87 is the collection season, and 302 is the assigned curation number that identifies this meteorite from all other meteorites collected from MacAlpine Hills. The repacking process is conducted on the flow bench in less than 5 minutes to prevent thawing. Thawing and drying is conducted in flowing nitrogen to prevent degradation from hydration. When completely dried, the samples are described macroscopically, photographed, measured and weighed, and recorded into a computer database. Only about 10 meteorites can be thawed and dried per day, per person.

The final step is removal by stainless steel hammer and chisel, of a small sample for classification. From field descriptions, meteorites can be broadly grouped by type (e.g., iron, achondrite, carbonaceous chondrite), ensuring that each object is processed in the appropriate cabinet to prevent cross-type contamination. In cases where the rock is thought to be of a new or unique type of Martian or lunar meteorite, the cabinets may be specially cleaned with ultra pure water, when mechanical sweeping doesn't remove previous sample particulates.

Obviously, this level of care is both expensive and time-consuming. As the size of the collection increased, standards of care evolved. The most significant change has been the acceptance that equilibrated ordinary chondrites (which comprise about 95% of Antarctic meteorites) cannot be accommodated within the space and budget constraints available. While still maintained in clean-room conditions, both NASA and the Smithsonian have moved away from dry nitrogen storage for these specimens. Since most scientific investigations focus on the rarer types of meteorites, these will continue to receive the highest level of curatorial care. It is also interesting to note that the curatorial standard does not require the prevention of biological contamination of the specimens. Initial curation included both low-temperature storage for specific samples (carbonaceous chondrites) and special organic cleaning of the cabinets (D. Bogard pers. comm.). However, it was soon recognized that even Antarctic meteorites were exposed to biological activity, either atmospheric or in the ice during their thousands to millions of years of residence on Earth. Further, biological experiments, originally targeted at moon rocks to detect pathogenic organisms, failed to detect any indigenous organisms in meteorites. In the wake of the debate on life on Mars stimulated by Allan Hills 84001, a renewed interest in the field of astrobiology has caused several investigators to re-examine the biological effects of curation of Antarctic meteorites (Steele et al. 1999). While such care might be warranted for select specimens (e.g., Martian meteorites, some organic-rich carbonaceous chondrites), it would require both ready identification of such specimens in the field and a significant increase in funding, primarily for construction of biohazard facilities that both prevent contamination at the specimen level (e.g., flow benches, cabinets) and isolate those collections (e.g., negative pressure rooms and buildings), both of which are problematic.

(ii) Produce an authoritative classification for meteorites that can be shown to belong to a well-established chemical and petrological group, and provide appropriate descriptions for those meteorites that cannot be shown to belong to an established chemical and petrological group

After macroscopic descriptions are completed at NASA's Johnson Space Center, a small sample is removed and sent to the Smithsonian for classification. Antarctic iron meteorites, which make up less than 10% of the entire Antarctic meteorite population, are permanently transferred to The Smithsonian. The Smithsonian has unique equipment for the physical and chemical preparation of iron meteorites and handles all processing, curatorial and classification of irons. Each sample is assessed visually to distinguish equilibrated ordinary chondrites (the most common type observed among meteorites) from the rarer types. Equilibrated ordinary chondrites are classified visually, either through identification as part of a large, well-characterized pairing group (these are stones that break up in the atmosphere and can number in the thousands) or through use of oil immersion techniques (a classical optical mineralogy technique which compares the optical properties of a small subsample of mineral grains to those of calibrated oils to determine mineral composition). Using these simple techniques, about 70% of all meteorites are classified. Unequilibrated ordinary, carbonaceous, and enstatite chondrites and achondrites are sent for thin section preparation, along with some meteorites that cannot be confidently classified due to brecciation, shock or severe weathering. The Smithsonian's Antarctic thin section library now contains almost 5,000 thin sections and about 200 new sections are prepared each year. Mineral compositions (olivine and orthopyroxene for most chondrites; olivine, pyroxene and plagioclase for achondrites) are determined using the JEOL JXA-8900R electron microprobe. The Smithsonian prepares brief descriptions, tables of data, and digital petrographic images that are published in the *Antarctic Meteorite Newsletter,* which is also posted on the website (Satterwhite and Righter 2006). This classification effort requires about 1 week per month on average. While all meteorites are classified, a procedure that is not possible for private collectors, the Smithsonian's major task is identifying those specimens of particular interest to scientists that are worthy of further study. Figure 4 illustrates the results of these efforts, where the plots show number of samples recovered, the number of meteorites (slightly lower reflecting the collection of a small number of terrestrial rocks) and the number of meteorites that are not equilibrated ordinary chondrites (e.g., unequilibrated ordinary chondrites, carbonaceous and enstatite chondrites, achondrites, irons). Each year, virtually independent of the total number of meteorites recovered, about 50 fall into this latter category. This apparent lack of connection between the number collected and those of greatest scientific interest owes to the occurrence of numerous paired meteorites that result from breakup in the atmosphere, showering local areas with thousands of individual fragments. While most scientific studies focus on the small subset of the most interesting specimens, the collection as a whole offers clues to the concentration mechanism and influx of material to Earth over time (Harvey 2003). Only through the systematic collection and classification can these studies be undertaken.

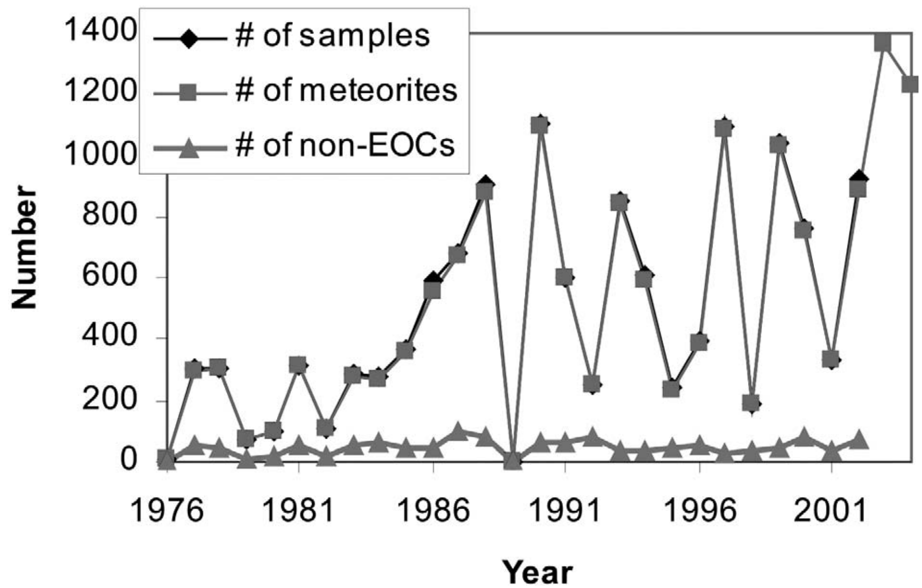

Figure 4. Plot of number of meteorites collected by year. The sharp dip in 1989 was due to a cancelled field season.

(iii) Develop and maintain curatorial records associated with the meteorites including collection information, authoritative classification, total known mass, information about handling and sample preparation activities that have been performed on the meteorite, and sub-sample information

The value of a meteorite is dependant on the time, effort and cost of recovery and curation, but is underscored by documentation of provenance, physical details, handling, and any analytical data generated through scientific studies. NASA applies the same format of documentation used for samples from the lunar program, creating a file called a data pack. The data pack contains images of the meteorite in all stages using a quadrant system of views, from initial processing to sub sampling for scientific studies; vital statistics about the specimen, including size, weight, color, weathering class and any distinguishing features; curatorial orders which record the distribution history, from the initial chip for classification, consumption of dust during cutting and sectioning, to the final transfer for long-term storage; all correspondence related to requests and sample preparations for scientific investigations. These data packs provide not only a curatorial record, they have often proven invaluable when an unusual feature is identified within a meteorite and the location of that feature relative to other studied samples can be ascertained by reference to the processing images in the data pack. Such documentation also prevents over sampling or potential misuse, providing opportunities for scientific investigations long into the future.

Conclusions

Standards and techniques for curation of Antarctic meteorites developed by the NSF, NASA and the Smithsonian Institution have changed very little over the last

30 years. These were based on similar standards employed for the curation of the lunar rocks of the Apollo program. In most cases, processing has been simplified to balance the increased number of meteorites with the mandate of preventing inorganic contamination of the most scientifically valuable specimens. The federal regulation 45 CFR 674 for collection and curatorial practice has already proven beneficial, spurring the U.S. Antarctic Meteorite Program to reevaluate and tighten our own procedures. At least one private expedition has deferred plans to collect Antarctic meteorites based on the rigor required for collection and delivery of meteorites. To date, no non-governmental party has submitted a plan for curation of Antarctic meteorites outside NASA's Johnson Space Center/Smithsonian Institution system, so the full impact of this regulation is largely unknown. The greatest challenges facing the collection center are the ever expanding collection effort, and renewed interest in reducing biocontamination of samples that may originate on planetary bodies possibly harboring extant or extinct biotas of their own, e.g., Mars. Fortunately, these challenges are being addressed as we look forward to Mars sample return, where planning for bioquarantine is a necessary element of curatorial planning, although taking these steps for Antarctic meteorites would likely require an order-of-magnitude increase in funding.

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MAINTAINING STANDARDS IN THE CARE OF PETROLOGY AND MINERALOGY COLLECTIONS AT THE NATIONAL MUSEUM WALES

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Abstract.—The Department of Geology at the National Museum of Wales (NMW) holds about 66,000 rock and mineral specimens. The NMW Collection Policies (2000) and previous in house condition surveys (Lambert 1994, Buttler 1995) have been used to develop specific standards to maintain a high level of collections care and provide a baseline for future improvements. A pre-acquisition, collection impact assessment determines specific conditions or levels of care needed. Specimens are identified using a variety of visual and analytical techniques and according to international standards of nomenclature for minerals (Hey Classification) and igneous rocks (IUGS). These standards form the basis for the organisation of the collection, which is housed in oak cabinets, roller racking and on low-level pallets. Inert packaging such as Corex® and Tyvek® is utilised when required. Storage conditions are set at 18–23°C and 45–55% RH with exceptional cases stored in customised microclimates. Seven hundred and fifty radioactive specimens are now stored in a special isolation store. Two hundred and eighty-eight mineral species are being monitored due to UK COSHH health and safety regulations. Pest monitoring is due to become routine in 2006 and the planned new storage areas will improve physical access whilst maintaining these standards of collection care.

Introduction

The National Museum of Wales (NMW) was founded by Royal charter in 1907 and is a multidiscipline institute spread over eight sites across Wales. The Museum receives its core funding through grant-in-aid from the Welsh Assembly Government and has custodianship of more than four million items, which include objects and specimens as diverse as a Welsh chapel, impressionist paintings, and the world's largest leatherback turtle. These are organised into nine main collection areas that are managed by five curatorial departments and the NMW Library. The geological collections are housed in the capital city of Wales, in the National Museum, Cardiff, and comprise approximately 400,000 accessioned specimens, divided into three main areas, palaeontology, petrology and mineralogy. All specimens are documented on an electronic database, part of an electronic collection management system Sn-Base, a natural science version of the Mobydoc, Micromusée system. The *approximately* 66,000 mineralogy and petrology specimens range from hand samples and microscope thin sections to borehole core, display quality minerals, gemstones and meteorites, and are supported by three curators, a collection manager, and a geological conservator. The overarching management, care, and use of NMW collections is guided by the National Museum of Wales Collection Policies (NMW 2000) which support the Museum in its aim to be 'the best possible repository for the collections of national renown and importance held in care for Wales'. These policies are then implemented by a set of seventeen generic Collection Management Procedures, which are customised for each collection-area to include collection specific details. Further details of these policies and procedures are provided by Howlett & Horák (this volume) and the policies themselves are available on the internet (NMW 2000). Information produced in the course of routine collection-based work at NMW is used to provide museum-wide performance indicators (such as number of items electronically catalogued) that serve as a useful guide to improvements in standards of curation.

This paper outlines these standards and how they have been implemented within the petrology and mineralogy collections to achieve and maintain the aims of the museum.

Evaluating Accession Standards

Collection Impact Assessment

The first stage in the effective management of the collections starts prior to formal acquisition of specimens with a Collection Impact Assessment (CIA). This evaluates the resources required to store, conserve, and curate the specimens under consideration and these data are documented on the CIA form. Where the impact is evaluated and considered acceptable, the form becomes part of the acquisition proposal documentation. The current version of the CIA form was introduced across all NMW collection areas in 2004, to ensure that the implications of and the reason for accepting any acquisition, no matter how small, is considered fully. It also allows detailed costings associated with post-acquisition work (e.g., curation, documentation, conservation, and storage) to be itemised. This is particularly important where significant costs are associated with larger collections, or an individual specimen requires intensive treatment or highly specialised storage. The form is completed by the relevant Collection Manager, along with a recommendation to acquire or not acquire, and then is authorised by the Head of Section. Where the CIA Form recommends acquisition of items valued at more than £500 a higher level of authorisation is required (typically by the Keeper). The current version of the form will be reviewed in 2006, with a proposal that the current Department of Geology procedure of hazard checking be formally added. An example based on a recent mineral donation to NMW is shown in the appendix.

Risk Assessment

Of particular pertinence to mineralogy and petrology specimens, is a risk assessment to identify potential hazards presented by the specimens. Although the impact of pests is mentioned within the Museum-wide Risk Assessment Procedures, no comprehensive pest surveying at acquisition stage is undertaken at present. This is currently under review within the Department of Geology. Materials originating from foreign fieldwork programmes and collections that may have been subject to infestation prior to acquisition, are considered the highest risk. To remedy this, a new collection surveying area, allowing collections to be quarantined during pest testing, is planned, and will be in operation in 2006.

In addition, testing for radioactivity is undertaken on all incoming material, and the likely presence of carcinogenic and toxic minerals evaluated. Such specimens are not necessarily excluded from the collections. However, rigorous evaluation of the benefits of acquisition is required. If accepted, such specimens are given specialised packaging, labelling and secure storage (see below). All unidentified specimens are treated with caution until their composition is known.

Condition Report and Surveys

As a result of a major conservation review of the geological collections that was started in 1989 (Buttler 1995), it is a requirement that a Condition Report (Fig. 1) is prepared by the Geological Conservation Officer for all possible acquisitions to geology. The condition report states the environmental conditions most suitable for the specimens and any special packaging requirements. It is presented in a written form though the terms used such as 'slightly dirty' or 'moderate damage' are taken from a quantitative scale used for surveys (Buttler, 1995) and described in more detail in the conservation section below. Using descriptive terms for the report enables it to be understood by a wider audience once it becomes part of the documentation for the specimen.

Whilst identified specimens can be evaluated easily, unidentified specimens can be assessed only on visible signs of instability, such as friability or the smell associated with pyrite decay. Scientific knowledge can also be used, for example a rock composed of silicates is more likely to be stable than a rock containing crusts of secondary mineralization, or particular localities may be flagged up as yielding unstable specimens. Where specimens are unidentified, but of possible high scientific value, for example a potential new mineral occurrence, identification may be undertaken as part of the Risk Assessment and prior to the Condition Report. This process is facilitated greatly by access to modern X-ray diffraction and Fourier Transform Infrared Spectroscopy (FTIR) facilities at the NMW. As a precaution against any deterioration, unidentified collections are stored in a controlled environment from the time they arrive in the Museum and a rolling condition-checking program is in place that should detect specimens that show signs of change in condition.

Where particularly large collections require condition reporting, this can be done by representative sampling. For the Buttler conservation survey undertaken to establish a baseline for the NMW mineral collection (Buttler 1995), sampling was achieved by evaluation of the specimen at the front left of every drawer. Whilst this works well for the collections stored at the NMW by chemical classification it will be less representative for collections that are not sorted on a chemical basis; for example, if the collection is being assessed at the donor's address in its original storage arrangement. In these cases, assessment may have to involve checking a greater proportion of the collection and will rely heavily on visual assessments. Detailed information on effective sampling for condition surveys is given in Keene (1991).

Documentation Standards

Identification and Terminology

The NMW mineral collection is organised according to the Hey's Mineral Index, 3rd Edition (Clark 1993) and using the International Mineral Association, Commission on New Mineral and Mineral Names (CNMMN 2006) approved terminology. All specimens are identified by naked eye and using optical microscopy. However, improvement in the range of non-destructive analytical equipment available to curatorial staff means that a higher level of non-destructive techniques are increasingly applied, particularly to the core Welsh mineral collection. For instance, FTIR is used at NMW, particularly in the rapid identification

Entry Form: 9999 Minerals and rocks from South Wales

NATIONAL MUSEUMS & GALLERIES OF WALES
DEPARTMENT OF GEOLOGY
CONDITION REPORT

DATE	**CONSERVATOR**	**ACCESSION NUMBER**
20.10.2005	CJB	NMW 1999.999G

SPECIMEN NO.	CONDITION
M1	**Sphalerite:** condition stable. No remedial conservation required. Old label stained, requires cleaning by paper conservators
M2	**Sphalerite:** condition stable. Slight abrasion damage to surface of specimen.
M3,4,5	**Calcite, galena, pyrite/marcasite:** 3 specimens – acidic smell indicating that pyrite decay may be active, recommend storage in a low humidity microclimate
M8-18	**Clinozoisite:** 10 specimens – stable, no conservation required
M19	**Pyrrhotite:** 1 specimen – stable, however could oxidise in high humidities so recommend storage in a low humidity microclimate.
M20-30	**Polished blocks:** Majority of the specimens are currently stable, although the resin has yellowed with age, but 2 have active pyrite decay. It is recommended that all the blocks should be stored in low humidity microenvironments to prevent deterioration of any sulphides. Storage could be in Stewart boxes with silica gel or in a low humidity cabinet.
M31	**Celestine:** Deep blue colour, monitor for light fading.
M32-37	**Bysolite:** Five specimens contain the fibrous mineral byssolite, recommend these are packaged in zip-lock bags.
M38	**Realgar:** Must be stored in light proof containers to prevent light induced change to pararealgar.
R1	**Pyritic coal:** Packaging in a low humidity microclimate recommended.
R2-4	**Slag:** Condition stable. No conservation required. Some larger specimens will require correx boxes to protect them from physical damage.

Figure 1. A composite example of a condition report constructed from several recent acquisitions.

of organic substances, sulphate, and carbonate group minerals, as this requires only a small powder sample. New X-ray microdiffraction facilities enable rapid and non-destructive identification of small minerals and some rock samples. Identification of specimens from Welsh localities is also made by comparison to a known 'encyclopaedia' of mineral data, as presented in *A Mineralogy of Wales* (Bevins 1994) and shortly to be available online in a greatly expanded and updated version, via the NMW website (NMW 2005). New mineral species and specimens identified only to a mineral group or family level are not found in the Hey 3rd Edition, and so are stored alphabetically in a Non-Hey section of the collection, until a revised version of the Index is produced. In reality, the number of specimens held in this section is small so this does not present an inconvenience.

Within the petrology collection, igneous rocks are named following the IUGS Subcommission on the Systematics of Igneous Rocks (SSIR) nomenclature (Le Maitre 2002). This is not ideal for volcanic rocks where a whole-rock geochemical analysis is not available, but works well with plutonic and hypabyssal rocks, as thin sections can be prepared to confirm the mineral composition and abundance within a specimen. Specimens sometimes have obsolete names that no longer fall within this classification, often with a regional connotation and significance. For example, Skomerite is found on Skomer Island, off the coast of southwest Wales. These are renamed and the original name retained and recorded under a designated 'original data' database field. Although the IUGS Subcommission on the Systematics of Metamorphic Rocks (SCMR) has produced recommendations for the naming of metamorphic rocks (SCMR 2004) this has yet to be adopted by the NMW. A simple, but consistent, nomenclature has been used, based on texture and mineral composition. However, the new classification will be introduced when documentation resources permit. A similar situation exists with sedimentary rocks within the NMW collection, as a sedimentary rock classification scheme is yet to be produced by the IUGS, Commission on Petrology. NMW terminology is based on grainsize and composition and loosely follows the nomenclature used by the British Geological Survey (BGS 1999). Where a colloquial or trade name for a rock is known such as *Campan vert* (mottled limestone marble), *Stonesfield Slate* (calcareous sandstone) *Doulting stone* (Jurassic limestone) or *Gwenith faen goch* (red sandstone), it is recorded in a dedicated database field, alongside the scientific term, and can be particularly useful when dealing with public enquires or accessing older scientific literature.

Document Curation

The Geological collections at NMW include many documents such as maps, field slips publications, and correspondence. There is a specialist Archive store and map room for historical items and every acquisition has a 'history folder' where Collection Impact Assessments, Condition Reports and related information are stored in paper form. As well as an electronic catalogue, all specimen details are recorded on hard copy registers and these along with items such as original transfer of ownership forms are kept in a fireproof safe. As an additional measure all pre-1995 register details are held in the central museum archive on microfiche.

Standards Of Storage And Care

Minerals

The mineral collection is arranged according to the Hey System 3rd Edition (Clarke 1993) in a Bruynzeel Monta Mobile System of roller racking (Howe 1987) necessitating only a few extremely large specimens to be stored on static shelving elsewhere in the room. Environmental conditions, whilst not an issue to most of the petrology specimens, are typically set at 18–23°C and 45–55% RH to suit the majority of specimens, based on guidelines given by Thomson (1978), and Howie (1992). The most important factor is the stability of the climate hence these conditions are controlled by an air conditioning unit. At the NMW some problems have been experienced in maintaining optimum storage conditions in this storage area as a result of plant failure and this has for time to time resulted in temperature fluctuations. These fluctuations have in part also been attributed to possible external input of heat to the store from heating pipes and may be resolved by producing a thermal imaging map of the room to identify the location of 'hot spots' and allow vulnerable specimens to be relocated to more stable lower risk positions within the storage units.

The introduction of roller racking increased capacity within the storage area by over 110%. However, the condition survey (Buttler 1995) identified abrasion as a major or potential cause of damage amongst the mineral specimens, directly resulting from specimen movement when the roller racking was operated. As a result, all minerals have been repacked using chemically inert polyethylene foam (e.g., Plastazote®), and all new additions are now carefully packed in high-sided trays with acetate lids. To prevent the trays from sliding any spaces within a drawer are filled with empty card trays.

Access to collections held by the Department of Geology is governed by the NMW Access Policy and implemented by a department-specific Access Procedure. This supports the balance between the maximising the use of the collections with their long-term preservation. On a practical level the procedures dictate that; only staff working on the mineralogy and petrology collection have access to these storage areas, that all external visitors and users are supervised at all times, and that the details of visits to the stores are logged. Access to both the geological stores and the roller racking within them, is controlled by keys, which are held by a restricted number of geological staff. The stores have signs on the door reinforcing these access rules and providing emergency contact information.

Petrology

Rocks are stored by geographical subdivisions (e.g., Wales, England) and within each of these sections by acquisition order. Although this may appear a highly unsophisticated system, all specimens are held on electronic inventory so this has proved the most efficient method of access. Hand specimens are stored in acid-free trays in closed, static oak cabinets. No environmental problems have been identified from the use of oak cabinets, although in exceptional circumstances microclimates are used for rocks containing evaporate minerals or pyrite. Though the oak cabinets appear to provide a satisfactory method of storage, access and health and safety considerations have lead to the collection being included within NMW's plans to relocate the petrology collections to new roller racking at an off-

Figure 2. A hand-made Corex® box for protecting a large petrology specimen from abrasion and dust.

site store. Where possible, larger specimens are incorporated with the specimens within the cupboards and roller racking. However, those that are too large are stored in hand-made Corex® boxes (Fig. 2) or fitted with custom made Tyvek® covers (Fig. 3) to protect against abrasion and dust. These materials were chosen because they are sufficiently strong to accommodate all but the largest petrology specimens; they are relatively cheap; and they can be manipulated easily and quickly into customised boxes or dust covers by curatorial staff.

Thin Sections

Thin sections are stored horizontally in wooden cabinets, with polished thin sections placed in small plastic bags so that their surfaces can be protected. Polished ore blocks frequently contain sulphides and are prone to extremely rapid tarnishing after polishing. To slow down this process they are stored in desiccator-style, stainless steel cabinets with environmental control provided by conditioned silica gel at 30%RH. All specimens are organised by accession number into Welsh and non-Welsh collections. As with the rock collections, all specimens are held on an electronic inventory and full acquisition details can be rapidly obtained.

Borehole Cores

The Museum holds approximately 200 borehole cores, mainly from less than 100m boreholes, or significant stratigraphic sections relating to Welsh geology. The cores are acquired typically in large wooden crates like a recent addition from Llandegfedd, near Usk, which forms part of a Ph.D. thesis collection (Fig.

Figure 3. A Tyvek® cover protecting a large calcite crystal from dust and abrasion.

4). As core may have been stored in a less than ideal environment prior to acquisition (e.g., evidence of rat infestation has been noted in some older core boxes), all core is cleaned and repacked into standard one metre long card boxes of an appropriate cross-section. This reduces the potential pest hazard presented by the boxes, and the health and safety hazards associated with handling the core. The standard core boxes are stacked uniformly on pallets which allow individual boxes to be moved by hand and a pallet of cores to be manoeuvred with a pallet truck by a single member of staff. The height of each pallet is set to no more than 0.5 m to prevent the bottom boxes being crushed and ensure that the pallet truck or handling weight limits are not exceeded. A space saving system of vertical pallet stacking on dedicated racks is planned for the new off-site store, the construction of which is due to commence at the end of 2006.

Preventative Conservation

The Buttler conservation survey (Buttler 1995) determined that the geological collections at NMW were most at risk from six factors: abrasion, dirt, pyrite decay, efflorescence, delamination and light damage. These factors as well as packaging, stability, conservation and general condition were all assessed quantitatively for each specimen sampled. For example, the quantitative scale used for the 'Dirt' category was 1: clean, 2: slightly dirty, 3: moderately dirty, and 4: extremely dirty. A quantitative survey provides a valuable baseline for measuring changes and this survey has been useful for monitoring the status of the pyrite

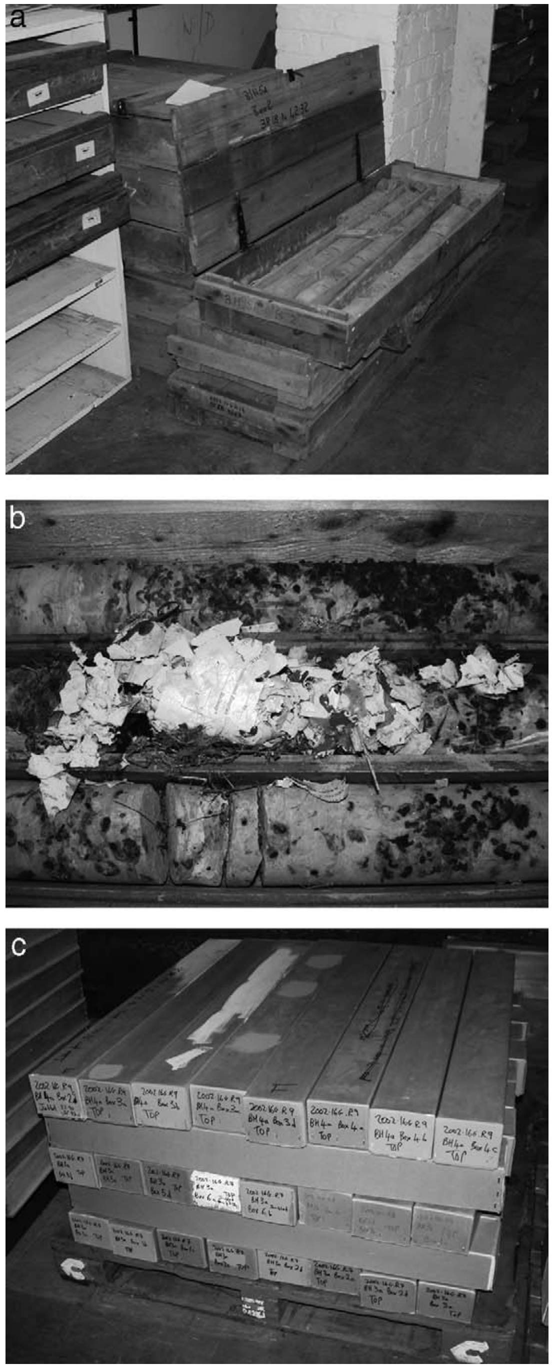

Figure 4. Llandegfedd Reservoir core. a) The borehole core when acquired in large wooden crates with b) signs of previous infestations, and c) after repacking into standard 1m boxes and being stacked uniformly onto pallets.

collection, particularly in light of problems with the air conditioning unit described above.

A comprehensive list of specimens requiring environmental conditions outside the normal range, such as pyritiferous rocks, is given by Howie (1992). These specimens are packed in customised microclimates and then placed back in the stores. A mineral containing some pyrite is typically stored at 30%RH in Escal™ barrier film with an RP System™ oxygen absorber and is routinely monitored for signs of change. Marcasite and pyrite specimens most at risk are placed in microclimates and then given an extra layer of protection by being placed in a special 'low humidity cupboard'. This is a sealed unit in the store to which access is minimised, and where the environment is conditioned with silica gel to 30%RH. All specimens in conditioned climates are routinely checked and the silica gel reconditioned as necessary.

Approximately 120 mineral species can show a change in colour when exposed to light (Horák 1994). The time over which this occurs can be as short as days and for many specimens irreversible chemical changes such as oxidation occur. To protect against light damage any light sensitive minerals, for example realgar, are stored in standard card trays, but with solid card, instead of acetate lids and labelled to indicate the specimens should be protected from unnecessary exposure to light.

Standards For Specimens Hazardous To Health

Hazardous Substances

COSHH, the Control of Substances Hazardous to Health Regulations in the UK (1988), require all substances to be assessed for hazards and appropriate controls to be put in place. General and the latest details of COSHH can be found on the web site (COSHH 2005). At the NMW, various sources of information on hazardous minerals (Brunton et al. 1985, Puffer 1980, Howie 1987) were used to build up a list of 288 mineral species potentially hazardous to the health for curators and laboratory workers, because of their toxic, radioactive or carcinogenic properties. A COSHH form detailing the hazards along with an assessment of the risk and the appropriate control measures required in handling and storage (Fig. 5) has been filled out for each of these 288 mineral species. It should be noted that toxic and carcinogenic specimens might only become apparent once a specimen is identified therefore all minerals and rocks are treated as 'guilty until proven innocent.'

The original NMW COSHH list of minerals is currently being refined to include more precise information on hazards associated with different modes of usage. For instance, some mineral may present only a low risk while sealed in boxes within the collection, but present a high risk to a laboratory worker when sent for cutting or grinding for analysis. A range of man-made chemical compounds and refined specimens (such as arsenic powder) that form part of the collections and were transferred from the NMW Department of Industry, are now also included within the COSHH listing.

Radioactivity

The 1985 Ionising Radiation Regulations for the United Kingdom (updated 1999) require steps to be taken for dose restriction when levels rise above 7.5

MINERAL DATA SAFETY SHEET

MINERAL NAME ***TOBERNITE.***

SYNONYMS Chalcolite, Chalkolith, Copper autunite, Copper uranite, Cuprouranite, Green mica, Kupferautunit, Kupferuranit, Kupfer-uranglimmer, Orthotorbernite, Torbernite, Uranphyllite

CHEMICAL FORMULA $Cu^{+2}(UO_2)_2(PO_4)_2.8\text{-}12H_2O$

HEY NO. 19.11.1

....

HEALTH HAZARD DATA (toxicity, effects of ingestion, etc)

Ingestion

Potentially carcinogenic via this route.

Inhalation

Potentially carcinogenic via this route.

Skin contact

At close range exposes skin and tissue to penetrative ionising radiation.

RISK OF EXPOSURE

Accidental ingestion or inhalation in handling poses a carcinogenic risk.

HANDLING PROCEDURES FOR CURATORIAL STAFF

Irradiates skin at close range, handling should be kept to a minimum. Gloves must be worn.

....

PROTECTION INFORMATION FOR CONSERVATION AND LABORATORY PROCEDURES

Respiratory protection

Respiratory protection is essential if airborne dust is likely to be generated.

Protective clothing

Gloves must be worn.

Ventilation

Releases variable quantities of radon gas, local exhaust ventilation should be used

....

ADDITIONAL COMMENTS

Radioactive uranium bearing material.

REFERENCES

Lambert (1994)

Figure 5. An example of a COSHH form for the hazardous radioactive mineral Torbernite. The form is displayed on bright yellow paper.

μSv hr^{-1} (Health & Safety Executive 2000). Unfortunately the process of storing minerals by chemical classification means that radioactive minerals are likely to be stored near to each other or even together. Of the 288 mineral species covered by COSHH regulations 219 are radioactive. Tests undertaken in the mineral store (Lambert 1994) showed that more than 750 NMW specimens were a radiation risk and that large doses of ionising radiation were possible along with exposure to considerable amounts of radon gas. The 1999 UK action level for radon in homes is 200 Bqm^{-3}, and 400 Bqm^{-3} for work places. The mineral store when measured in 1990 was measuring 400 Bqm^{-3} and was therefore at an actionable level. In 1992 an isolation store equipped with purging ventilation was established in a separate part of the museum and any newly acquired radioactive specimens from both mineralogy and petrology are now located there. The Radioactive Store is in a little used corridor with restricted access. It has concrete walls, floor and ceiling and forced extraction of the air several times an hour prevents radon build up.

Summary

The mineralogy and petrology collections at the National Museum of Wales are managed following collection-specific procedures drafted to implement the NMW Collections Management Policies (NMW 2000). Previous surveys of the collections (Lambert 1994, Buttler 1995) have highlighted problems in the collections, particularly those of conservation and radiation, and established baseline standards, which are used for future improvements and condition checking. The implementation of a pre-acquisition Collection Impact Assessment ensures that the resources required to care for new acquisitions are identified as clearly as possible and acquisitions only accepted where the resource requirement can be met, thus reducing liabilities for both current and future custodians of the collections. This along with the future improved pest quarantine procedure for the geological collections, and an on-going revision of the Collection Management Procedures supports high levels of collection care.

Acknowledgments

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Appendix. An example of a Collection Impact Assessment form based on a recent acquisition to Mineralogy and Petrology.

AMGUEDDFEYDD AC ORIELAU CENEDLAETHOL CYMRU
NATIONAL MUSEUMS & GALLERIES OF WALES
Ffurflen Gwerthuso Effaith ar y Casgliadau
Collection Impact Assessment Form
I'w gwblhau ar gyfer bob derbynodiad
To be completed for all accessions

ADRAN / DEPARTMENT	Geology

Nodwch at ba bwrpas y defnyddir y ffurflen hon:
Please indicate which of the following this form is being used for:

▪ *Casgliad ôl-groniad* Backlog Collection		▪ *Pwrcasiad arfaethedig* Proposed purchase	
▪ *Derbynodiad newydd* New Accession	X	▪ *Gwaith maes* Fieldwork	

▪ *Rhowch ddisgrifiad cryno o'r casgliad sydd i'w werthuso, gan ychwanegu unrhyw wybodaelh bellach, os oes angen*
Provide a brief description of the collection being assessed, attach additional information if required

The Smith collection - A collection of 249 polished blocks and 559 mineralised rocks from the Dolgellau Gold Belt. Originally collected for Smith's PhD and since acquired by Dr Jones and then worked on by J Black. The collection was rated as 'one of the most important research collections of Dolgellau Gold Belt remaining in private hands' and will make a valuable contribution to the mineral collections at NMW. See attached information.

		MANYLION PWRCASIAD **PURCHASE DETAILS**	
▪ *Amcan o faint y casgliad* Estimated size of collection	c. 800		
▪ *Rhif cofnodol y gwrthrych* Object Entry No	E002146	▪ *Rhif Archeb. AOCC (os yn berthnasol)* NMGW purchase order No. (if applicable)	n/a
▪ *Dyddiad* Date	19/10/2005	▪ *Rhif Rhagarcheb (os yn berthnasol)* Requisition No. (if applicable)	n/a
▪ Adroddiad Cyflwr Condition report done ?	Y	▪ *Pris a dalwyd (os yn berthnasol)* Price paid (if applicable)	n/a
▪ Asesu Risg Risk assessment done ?	Y	▪ *Rhif derbynodi* Accession No	

A fydd y casgliad sy'n cael ei dderbynodi yn arwain at unrhyw anawsterau adnoddau i'ch adran (neu unrhyw adran arall yn AOCC)? Os yw, parhewch i lenwi gweddill y ffurflen, ond os na, llofnodwch isod.
Will the collection being assessed lead to any resource problems for your department (or any other department in NMGW)? If yes, continue completing the rest of the form; if no, complete the sign off below.

***CYTUNWYD* / AUTHORITY TO PROCEED:** ____________________ ***DYDDIAD* / DATE:** ______________

Maint y casgliad / Size of Collection	c. 530 specimens
Os yw'n wahanol iawn i'r amcangyfrif eglurwch: If substantially different from estimate explain:	Not all of the specimens will be accessioned. Of the 559 rock specimens an estimated 281 are of a grade worthy of accession.

▪ A dderbyniwyd yr holl ddogfennau perthnasol? Have all associated documents been received?

▪ *Math o ddogfen* Type of document	*Derbyniwyd* Received	*Dyddiad* Date
Transfer of ownership	Yes	12/10/2005
Condition report	Yes	20/10/2005

LEFELAU CURADURAETH / CURATION LEVELS

Ar ba lefel mae'r casgliad nawr? What level is the collection at now?

Papur		Cyfrifiadur		Catalog	
Paper		Computer	Y	Catalogue	

I ba lefel y bwriedir cyrraedd? What level is it intended to achieve?

Papur		Cyfrifiadur		Catalog	
Paper		Computer		Catalogue	Y

Manylion pellach o lefel curaduraeth y casgliad (os yn berthnasol)
Further details of the curation level to which this collection will be moved (if appropriate)

This collection has already been published.

GWAITH ANGENRHEIDIOL / WORK REQUIRED

	Y/N	*Dyddiad Cyflwyno* Submission Date	*Dyddiad Adolygu* Review Date	*Dyddiad Cwblhau* Completed Date	*Adroddiadau yn Amgaeëdig* Reports attached
▪ *Adroddiad Cyflwr* Condition Report	Y			20/10/2005	E2146
▪ *Cadwraeth* Conservation	Y				See note below
▪ *Asesu Risg*	Y				See note below
▪ *Gwasanaethau Labordy* Laboratory Services	N				Already taken place - see note below
▪ *Gwaith Curadurol* Curation	Y				Information gathered - see note below
▪ *Storio* Storage	Y				See note below

GOBLYGIADAU ADNODDAU / RESOURCE IMPLICATIONS

	Amcan o'r Pris Estimate Cost	*Cyfleusterau ar Gael* Facilities available	*Ffynonellau Ariannu* Funding sources	*Adroddiadau yn Amgaeëdig* Reports attached
▪ *Cadwraeth /* Conservation	£10	Materials readily available		
▪ *Gwasanaethau Labordy* Laboratory Services				
▪ *Gwaith Curadurol /* Curation				
▪ *Arddangos /* Display				
▪ ***Storio /*** Storage	£30 - £800			See note on storage below
▪ *Staffio /* Staffing	Conservation: 0.5 days			
▪ *Pris Prynu /* Purchase Cost				
***Cyfanswm /* Total**	est £40			

***PENNAETH ADRAN / HEAD of SECTION*: ____________________ *DYDDIAD* / DATE: ___________**

***CYTUNWYD* / AUTHORITY TO PROCEED: ____________________ *DYDDIAD* / DATE:___________**

▪ *Os yw'r costau dros £500 rhaid cael caniatâd y Dirprwy Gyfarwyddwr Cyffredinol.*
If the cost exceeds £500, approval from Deputy Director General is required.

Collection Impact Assessment—E002146 The Smith Collection

The Smith collection:

A collection of rocks and associated polished blocks from the Dolgellau Gold Belt. Originally collected by J. Smith for a Ph.D. and since acquired by Dr Jones and then worked on by John Black. The collection has been thoroughly assessed and scientifically investigated by John Black and a number of reports written on the collection (see history file).

There are 249 polished blocks and 559 rock specimens.

Scientific information:

All of the specimens have been examined by John Black and the level of scientific information is high. The collection was used for at least one scientific publication.

All of the polished blocks have been thoroughly cleaned and reground for the microscope work and detailed mineralogical descriptions prepared. The rock specimens all have basic descriptions and have been graded according to their scientific worth. It is likely that this assessment will be used to select the best specimens for acquisition.

Conservation:

Pyrite decay is of major concern with some of the specimens. Some of the material originally part of the Smith collection has already decayed and has been disposed of. The condition report notes that some of the specimens will need microclimates. Specimens that show serious decay will be not be accessioned. It is estimated that around 5–10 specimens will need microclimates.

The condition reports recommends all the 249 polished blocks are stored in controlled conditions.

Storage:

The polished ore blocks are traditionally stored in environmentally conditioned 'Ore cabinets'. Either one of these cabinets will need to be purchased for the collection or alternatively a number of Stewart boxes. Stewart boxes will provide more flexible storage and are considerably cheaper and easier to get hold of, though they do not have the same visual appeal as ore cabinets.

Summary:

- The Smith collection is of significant scientific value.
- Much of the curatorial work has already been undertaken on these specimens and little extra work is required.
- Not all of the hand specimens will be registered.
- The polished blocks will require storage in a controlled environment. This could be achieved using Stewart boxes or an ore cabinet.
- A minority of the rock specimens will need conservation treatment for pyrite decay.

INTEGRATED COLLECTION MANAGEMENT AT THE NATIONAL MUSEUM WALES

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Abstract.—Over the last ten years a programme of integrated collection management has developed at the National Museum Wales (NMW) which supports and enhances best practices in this area. This paper documents how this was undertaken and identifies five factors involved in the raising of standards in Cryptogamic Plant, Vascular Plant, Entomology, Marine Invertebrate, Mollusca, Vertebrate, Fossil, Rock and Mineral collections. Critical reports from external reviewers such as the National Audit Office led to dedicated funding to establish a documentation unit and an enhanced conservation unit which embedded staff within the curatorial departments. Subsequent progress has been spearheaded by a multidisciplinary Collections Management Group (CMG). The blend of skills and expertise available to the group enables it to tackle a wide range of issues and oversee the development of collections management policies to enable NMW to achieve Registered Museum Status. Policies are reviewed every five years to take into account emerging practices and changing research priorities. The CMG runs an in-house training programme for collections management staff and supports external academic training for staff towards degrees and accreditation. The policies have also supported a successful bid towards £5 million for a new off-site store, a project currently being implemented.

History of the Collections at NMW

As a UK national museum, NMW is a relative new-comer, only receiving its Royal Charter in 1907. It is custodian of around four million items, which are managed by six curatorial departments: Archaeology, Art, Biodiversity & Systematic Biology, Geology, Social History and Industry, and the NMW Library. Over half of the four million items are natural history specimens. The collections within the two natural science curatorial departments are divided into nine collection areas (Table 1). Each of these areas has at least one specialist curator/collection manager, and each has specific collections care issues and requirements.

The building housing the Natural History collections was built between 1912 and 1927, the First World War delaying its completion. Two further extensions were added as funds became available, to the east wing in 1932 and a corresponding addition to the west wing in 1962. Prior to the museum opening in 1927, the collections, amassed by the Cardiff City Corporation were displayed in the adjacent Cardiff City Hall building. The ownership of these specimens was transferred to the NMW upon receiving its charter. Since that time, the different natural history collection areas have grown and developed by varying routes. For instance, the core of the mollusca collection is the Melvill-Tomlin collection bequeathed in 1955. It contains approximately one million shells and was one of the largest private collections in the world at that time. However, the collection is far from static as many smaller collections have been acquired since 1955 and the total holding now comprises approximately 410,000 lots. The collection is no longer accounted for in terms of individual specimens but documented as lots which group together specimens of the same species collected at the same time and place by the same collector. The entomology, cryptogamic and vascular plant

Table 1. Natural Science collections at the NMW.

Collection area	Size
Cryptogamic Plants	310,000 specimens
Entomology	950 specimens
Marine Invertebrates	62,000 lots
Mollusca	410,000 lots
Vascular Plants	277,000 specimens
Vertebrates	26,000 specimens
Fossils	339,000 specimens
Rocks	33,000 specimens
Minerals	33,000 specimens

collections are more focussed towards Wales and the rest of the UK and have been built up through the donation and bequest of numerous medium-sized collections. The palaeontology and mineral collections have their roots in the old Cardiff Museum collection but have been significantly enhanced and expanded by focused research and partnership programmes in the last 35 and 20 years respectively. In contrast to these more slowly amassed collections, the marine invertebrate collections have been developed within the last 15 years, almost solely through targeted research programmes. The routes by which NMW has acquired collections, impacts our ability to care for specimens contained within each collection. In many instances, resources are required to decode and evaluate the effects of previous treatments and storage conditions.

Collections Management at NMW

Within NMW, the term collection management encompasses all aspects of collections care, including documentation and conservation work. Collection care has always been a high priority for the Museum. From the opening of the new building in 1927, short-comings in storage conditions were recognised by curators and every effort was made to upgrade cabinets or cupboards whenever possible. Somehow the Museum managed this despite having to compete for scarce resources during the completion of building works which continued for many years after the opening of the original building. By the early 1950s, most of the natural history collections were housed in wooden cabinets with larger specimens on open shelves in line with the standards of the day. However, a point was reached in the late 1960s or 1970s when the size of the collections outgrew the available space; standards were compromised in some areas as it became increasingly necessary to cram more specimens into the limited space.

The 1980s saw a considerable upgrading of many of the natural history collection storage areas with the old cabinets and shelving being replaced by high quality compact roller racking units. However, other aspects of collection care remained piecemeal varying not only between departments but also within different collection areas within a single department.

The first stimulus for change came from outside the museum during the 1980s with the publication of two reports which prompted the Welsh Office to evaluate the standards at the NMW. One, a report by a working party to the Standing Commission on Museums and Galleries (1980), which identified a lack of conservation skills in many museums; the other by the National Audit Office which was highly critical of the standards of collection care and documentation at the London National Museums (NAO 1988). The initial benefit of these reports was that they elicited funding as well as providing useful directions in which to improve standards. Additional funding, from the Museum's pension holiday, was made available for three years to establish conservation and documentation units within the museum. After much discussion, the new staff were embedded within the curatorial departments rather than forming two new centralised units. In particular, the experience of conservation staff in departments outside natural science, in art, archaeology and social history, had shown that integrating conservators promoted best practice. This was without doubt the correct decision and has been highlighted as a strength in subsequent reviews. A major boost for collection care at the NMW was the transfer of these two project groups into permanent units at the end of the three year project funding.

In 1994, NMW took the decision to apply for museum registration under phase 2 of the Museum & Galleries Commission's registration scheme (MGC 1995). Following reorganisation by the UK Government the Commission has now become the Museums, Libraries & Archives Council and the scheme renamed the Accreditation Scheme for Museums in the United Kingdom—Accreditation Standard (MLA 2004). This step towards registration turned out to be the second external stimulus to improve collection care at NMW. Standards are fundamental to the registration scheme, and museums are required to show that they have policies in place on: acquisition and disposal, documentation (including a registration system in place), care of the collections, loans and risk assessment. There is also a strong emphasis on using the guidelines laid down in SPECTRUM (Ashby et al. 2005) to produce a documentation manual for staff to use.

Development of Collections Management Policies

At the time, the NMW did not have any formal policies in place, and senior management created the Collections Management Group (CMG) to redress this. This group consisted of collections managers, or curatorial representatives from all collection areas, in addition to those from the Conservation and Documentation Units, the Librarian and the Director of Collections & Research. The policies were completed and formally adopted by the NMW in 1995 and are reviewed on a five-year cycle by the CMG. NMW now has six over-arching collection management policies (NMW 2000) which cover the major areas suggested by SPECTRUM:

- Acquisition & Disposal
- Access & Use—including 'Use of the Collections in DNA-based Studies' (added 2000) and 'Access and Use of Human Tissue from Human Remains' (to be added in 2005)
- Care & Conservation of the collections
- Documentation
- Loans
- Physical Verification (added 2000)

The policies added in 2000 and 2005 demonstrate the importance of reviewing policies on a regular basis to take account of emerging practices and changing

Table 2. 2005 Collection Management Procedures at NMGW.

Procedures for Acquisition
Procedures for Deaccession & Disposal
Procedures for Object Entry
Procedures for the collections of Performance Indicator for the Documentation of the Collections
Procedures for Location and Movement of Objects Control
Procedures for Audit/Physical Verification
Procedures for Inward Loan
Procedures for Outward Loan
Procedures for Access and Use of Collections
Procedures for Inventory
Procedures for Cataloguing
Procedures for Reproduction
Procedures for Risk Management
Procedures following Loss
Procedures for Exit and Despatch of Objects
Procedures for Objects on Temporary Exhibition
Procedures for the Care and Conservation of the Collections

priorities. In this instance it was necessary to draw up the policy on Physical Verification in response to further reports from the National Audit Office and the National Assembly for Wales's Audit Committee which required regular random spot-checks. The need for a policy on the use of the collections for DNA-based studies reflects the changing nature of taxonomic research. The extraction of DNA from a specimen is now a major component of this research and, by its nature, is a destructive process. Such studies on museum collections need to be tightly controlled to retain 'copyright' over the genetic information associated with biological specimens. The last review cycle has just been completed and the new policy versions have been formally ratified by the Museum's Trustees, thus enabling them to be incorporated into the over-arching policies.

These policies are supported by seventeen, detailed, internal collection management procedures (listed in Table 2), which ensure standardised implementation of the policies across all our sites and subject areas. Clearly in a multidisciplinary institution that encompasses social and industrial history, art and archaeology, in addition to the natural sciences, significant variations exist between collections and the methods by which they are cared for. From the central museum procedures, specific collection or departmental procedures have been produced which still retain the core generic protocol but ensure that additional detailed procedures, not relevant to other collections, are formally documented. What is collected (rather than how it is collected, which is included in the *Policy on Acquisition and Disposal*) is subject to a separate strategy agreed by the Trustees, which may vary over time. NMW's institutional aims include being the best possible repository for the collections of national renown and importance held in care for Wales and staff are very conscious of that responsibility. To further ensure understanding of the procedures amongst all staff with access to collections in NMW, the CMG has run five half-day interactive training courses covering issues of ethics, acquisition and disposal, loans, risk management, documentation and conservation. To date, over a period of two years, fifty-five staff from all curatorial departments and collection-related staff have attended.

The effectiveness of the CMG in completing its initial task resulted in this group becoming part of the formal operational structure within the museum. In addition to providing an open forum to which any collection care related or topical collection issue can be discussed the group has responsibilities for:

- drawing up guidelines for collections management
- bench-marking best practice
- running training courses on these for curatorial staff
- continuation of the original task of reviewing policies and procedures.

The composition of CMG has been critical to its effectiveness; the blend of skills and expertise available to the group enables it to tackle a wide range of issues. The presence of non-natural history Collection Managers introduces topics and issues to the forum that might not be broached in a natural history context alone. For instance, curatorial staff in the Department of Art have wide and regular experience of international couriering for exhibition purposes, whereas natural history curators/collection managers rarely undertake such exercises. Being able to consult with such staff and being present during discussion of couriering issues, greatly expands the knowledge of the geology and biology collection managers. Similarly the ability to identify, measure and deal with radioactivity in man-made objects has transferred knowledge from the Department of Geology to the Departments of Art, Social History and Industry. Some of the milestones that the group has achieved are:

- 1995: Collections Management Policies introduced (reviewed in 2000 & 2005).
- 2000: SPECTRUM-based collections management procedures rolled out.
- 2001: Involved in simplification of curatorial performance indicators.
- 2002—to-date: Running collections management training courses.

The success of the group has been helped considerably by the fact that the policies and procedures were linked to Museum Registration. This issue was of great importance to NMW and consequently had high level support within senior management. Members of the CMG feel that the delivery of the policies and procedures and their role in securing registration has strengthened the status of collections managers and conservators within NMW, and the group is seen as a source of expertise and authority both within NMW by senior managers, and externally by other museums.

Another milestone was the involvement with setting curatorial and conservation performance indicators. Implemented without consideration, these indicators can be demoralising and waste much time. In 2001, CMG had the opportunity to help set the criteria used and ensure they were of use to NMW and a benefit to collection care. Initial indicators adopted by NMW had fixed curation (including documentation) and conservation indicators together in a sliding scale; this proved unworkable and of limited use in practice. CMG took the opportunity to suggest decoupling conservation and curation and have two separate indicators. One showing the percentage of the collections held under favourable conditions for long-term conservation; the other showing the documentation status of the collections, utilising a much simplified three level system. The adoption of these indicators has been partly responsible for two major changes. Firstly, the documentation indicators have enabled NMW to provide a strong case for abandoning the concept of item documentation of entire collections, where this is inappropriate, and adopt more workable and meaningful documentation strategies. Secondly, the ability to show the percentage of each collection housed in sub-standard conditions has proved very beneficial in supporting a successful bid for a new £5 million off-site store, a project currently being implemented, and towards which the Welsh Assembly Government has granted £3 million.

Conclusions

Over the last 10 years the National Museum Wales has significantly raised its standards of collections care. There are five main factors that contribute to this progress:

1. A multi-disciplinary operational group (CMG) to highlight problems and identify suitable solutions to collections management related issues. The success of the group has led to the increased status of collection managers and conservators within the organisation and has led to improved training opportunities through central support for academic training such as Masters Degrees, distance learning courses and professional accreditation.
2. The placing of conservators and documentation staff within curatorial departments, rather than within separate units. This ensures that both remedial and preventative conservation becomes an every-day part of departmental work, raising awareness of conservation in curatorial staff and increasing understanding of the collection management process in conservators.
3. The existence of external drivers, such as National Audit Office reports, to identify the need to change and suggest bench marks for achievement. It is good to see that such external influences can be beneficial.
4. The support of senior management to use the above drivers to obtain or allocate funding and other resources to enhance collection management capabilities.
5. The post of Director of Collections & Research was created in 1996, in recognition of the importance of these areas. Its holder is today the institution's Deputy Director General, reinforcing the institution's commitment to raising standards in this area.

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A STANDARD SYLLABUS FOR NATURAL HISTORY CONSERVATION TRAINING IN THE UNITED KINGDOM

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Abstract.—Until recently Natural History Conservation as a specialisation was rare in the UK and the preservation of Natural History material was traditionally carried out by collectors, researchers and curators. We suggest that there is a need for a standard formal training syllabus to cover the conservation requirements of Natural History collections in the UK. A standard training syllabus, based on courses given at the National Museum of Wales, is proposed to cover the conservation requirements of a Natural History collection with Botanical, Geological and Zoological materials. Certain essential core topics included are applicable to specialists in any Natural Science discipline. We suggest that the syllabus is best suited to applicants with a background in Natural Science to degree level, including those already employed in museums, such as curators or technicians who can then begin to conserve collections. The training is best carried out in museums with large mixed natural history collections and trained conservation staff; it could form part of a recognised accreditation scheme. It is hoped that the syllabus presented here, in conjunction with other European initiatives such as SYNTHESYS, can be used as a future template for any Natural History Conservation training course.

Introduction

Until the 1990s, Natural History Conservation as a specialisation in the UK was rare. The preservation and conservation of Natural History material has traditionally been carried out by the collectors, researchers and curators themselves. In larger institutions, trained technicians were used for specific aspects of care such as taxidermy, skeletal preparation and model making. The Standing Commission on Museums and Galleries, in its report on Conservation (Standing Commission on Museums and Galleries 1980), noted the absence of trained scientists and technicians outside the main UK national museums with large Natural History collections. A report on the 'State and Status of Geology in UK Museums' (Doughty 1981) revealed a wide scale neglect of geological collections. Organisations such as the Geological Curators' Group tried to highlight the problem in their newsletters and conferences (Crowther and Collins 1987). It was realised that valuable natural science collections in museums would be lost unless some action was taken.

In the 1980s and 1990s conservators began to be appointed in the natural science disciplines. Their appointment was still generally restricted to the larger national museums, although some Area Museums Councils did employ peripatetic natural science conservators, often as taxidermists. However, a repeat of the Doughty (1981) report (Fothergill 2005) revealed that half the museums surveyed felt that they had no access to a professional conservator. In the West Midlands of the UK there has been a reduction in the number of natural science specialists, with many museums reducing their staffing in the last five years (Arthur 2004) and recently St Albans, North Hertfordshire and Portsmouth have all lost their natural science posts (Stringer 2005).

This problem is not unique to the UK. In North America, the National Institute for the Conservation of Cultural Property published a report entitled 'Preserving

Natural Science Collections: Chronicle of our Environmental Heritage' (Duckworth et al. 1993). It recommended that an intensive graduate programme in the Conservation of Natural Science Collections must be established immediately to train a core group of conservators and that an ongoing programme should then be established to train conservators for the future. A survey was also conducted on the 'State and Status of Geological Collections in the Republic of Ireland' (Parkes and Wyse Jackson 1998) that revealed that no geological collection had a conservator on the staff and that there was no access to conservation staff.

Natural science conservation literature has burgeoned in the last ten years but as Crowther and Collins (1987) stated, "The conservation of the UK's geological collections will not be helped by providing . . . curators with a recipe book of techniques with which to dabble." Although it could be argued that some conservation is better than none at all, a training course would ensure that conservation standards are maintained and safe, legal, up to date methods are used.

Today there is a world-wide need for a training programme to promote Natural History Conservation amongst both Natural Science curators and general conservators with Natural History collections in their care. The only university conservation course to include Natural Science, in the United Kingdom, is the MA provided by the Royal College of Art and the Victoria and Albert Museum, in association with Imperial College of Science, Technology and Medicine. This course involves the Natural History Museum where, during a placement, much of the natural science conservation expertise is gained. It has been running since 2004 and so far one student has completed the course. In Europe, a bachelor's degree in Natural History Conservation can be undertaken at the Royal Danish Academy of Fine Arts, School of Conservation.

Conservation Requirements for the Natural Sciences

What qualifications are needed by candidates who want to train in natural science conservation? Experience at the National Museum of Wales has shown that ideally they should have a background in natural science to degree level, prior to acquiring post-graduate experience in conservation. This enables the candidate to have a detailed understanding of the materials on which they will work. It has proved more difficult to train those with another conservation subject qualification in the complexities of Botany, Zoology and Geology.

We suggest that there is a need for a standard formal training syllabus to cover the conservation requirements of a natural history collection. The syllabus would be divided into two: a core of essential conservation topics plus specialisations in Zoology, Botany and Geology. Knowledge of other media, such as paper and photographic materials used in natural history collections, would also be an advantage.

The desired standard of attainment should be to a post-graduate diploma level. However, separate standards may be appropriate for technicians, collection managers and those for whom natural science conservation is not a speciality.

Natural Sciences Conservation Syllabus

A proposed syllabus is given in Table 1. This syllabus is based on the accepted general criteria for conservation training, such as the curriculum suggested by the National Institute for the Conservation of Cultural Property for training and col-

Table 1. Proposed syllabus for the training of natural science conservation.

	Botany	Zoology	Geology	Other media & techniques
The agents of deterioration	Material types	Material types	Material types	Paper Labels Sketches
	Environmental effects	Environmental effects	Environmental effects	Field notes
Museum environment Monitoring Storage room Control	Deterioration mechanisms	Deterioration mechanisms	Deterioration mechanisms	Plastics
Requirements for natural history collections	Preparation & preparation methods both current & historical	Preparation & preparation methods both current & historical	Preparation & preservation methods both current & historical	Electronic media e.g. CD's Wax models
Pest control Identification of pests Monitoring Prevention methods	Herbarium collections Remounting Humidifying collections Cleaning Replacing bound herbarium volumes book block	Taxidermy, skeletal material and skin collections Cleaning Storage Repair & consolidation	Oxidation of sulphides (pyrite decay) Identification & prevention Treatment Storage in anoxic & low humidity microclimates Labels damaged by sulphide oxidation	Plaster models Photographic materials
Storage and packaging Conservation materials				Analytical techniques FTIR SEM XRD
Conservation documentation Condition reports Treatment records Databases	Lower plant conservation Repackaging 'Floating out' of algae Freeze drying of fungi	Fluid collections Different methods Identification Maintenance Labelling DNA preservation	Sub fossil bone & shale Deterioration Storage Repair and consolidation	Casting & moulding Digital photography

Table 1. Continued.

	Botany	Zoology	Geology	Other media & techniques
Condition surveys				
Reasons for use	Wood	Entomology collections		Laser cleaning
Survey methods	Determination	Cleaning		
	Storage conditions	Storage		
		Repair & consolidation		
Cleaning	Pest management	Pest management	Radioactive, toxic and asbestiform minerals	CT (computerized tomography) scanning
Reasons for cleaning				
What is dirt?		Hazardous material	Identification	
Cleaning methods	Pesticides		Monitoring	
	Use in collections		Control measures	
	Hazards & risks			
Adhesives & consolidants				
Identification				
Use		Other collections e.g.,	Other collections e.g.,	
Repair methods		Mollusca	Microfossils	
Reasons for repair			Amber	
			Human remains	
Ethics				
Risk assessment and risk management of collections				
Health & safety, COSHH (Care of Substances Hazardous to Health)				
Disaster planning				

lection care maintenance in Natural Sciences (National Institute for the Conservation of Cultural Property 1991) and on current literature (for example Carter and Walker 1999). The syllabus requires the student to have an understanding of the materials and how they deteriorate, with appropriate analytical techniques, methods of ameliorating damage by short term action and long term methodologies and all the legal, ethical and health and safety issues.

Methods of Conservation Training

The lack of natural science conservation jobs means that after taking a post graduate course in this subject, the prospects of being employed within the field are slim. However, collections are still at risk and action needs to be taken. Perhaps the solution lies in training people already employed in museums, such as curators or technicians who can then begin to conserve collections. If there is no in-house expertise, short-term training courses can be undertaken at institutions where it is avaliable. After training, the instructors can act as mentors and assistance can be provided by phone and email and by site visits.

The training is best carried out in museums with large mixed natural history collections and trained conservation staff. For example, the student who completed the MA in Natural History Conservation from the Royal College of Art and the Victoria and Albert Museum carried out the majority of the practical training at the Natural History Musem, with some additional experience at the National Museum of Wales. It is also advantageous if other conservation specialities, for example paper conservation, are represented at a training institution. Training could be aimed at natural science curators and researchers with responsibility for collections, and general conservation staff that may be required to advise or work on the conservation of natural science collections.

Whether training courses need to result in a recognised qualification or be ratified by a university is a matter for debate. In recent years the National Museum of Wales has provided training for several natural science conservators, including staff from the British Geological Survey, National Museums Northern Ireland, The Lapworth Museum (University of Birmingham), Royal Cornwall Museum, and the Museum of Evolution (University of Uppsala, Sweden). These institutions have recognised that the collections are at risk, usually following a condition survey undertaken by an external conservator, and grants have been obtained to fund the cost of individual conservation training. The personnel who undertook training were either already employed in another capacity by the organisation or were taken on to undertake the conservation work. The training took place at the National Museum of Wales in Cardiff and advice was given afterwards when it was needed. As a result valuable conservation work has been undertaken and in one case a new post of conservator was created. In these situations there was no need to have a paper qualification at the end of the course. Despite this, the training could be used as experience if the conservator continued in this field, or in another aspect of collections care, or if they wanted eventually to apply for accreditation with the Institute of Conservation.

The recommendations made in this paper are for discussion by the natural history museum community. If they receive broad acceptance then it is our hope that bodies such as the Institute of Conservation (ICON), the Natural Sciences Collections Association (NatSCA), and the Society for the Preservation of Natural

History Collections (SPNHC) will use them as their approved template for any future Natural History Conservation training. Conservation training is currently being developed under the networking element of the European SYNTHESYS project, focusing on improving access, use and development of research into taxonomy in European natural history museums (Collins et al. this volume).

It is envisaged that by setting out these standards in the form of a syllabus, flexible training courses can be tailor-made to the requirements of the individual and the sponsoring institution. If, at some later date, the market for natural science conservators expands, it would then be easy to develop the syllabus presented here into additional formal courses.

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MINIMIZING THE RISKS FROM THE TEN AGENTS OF DETERIORATION IN TWO NEW WEST MIDLANDS MUSEUM RESOURCE CENTRES, UK

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Abstract.—The West Midlands region of the UK is home to two new collection centres, the Herefordshire Museum Resource and Learning Centre and the Ludlow Library and Museum Resource and Learning Centre, housing around 200,000 items including substantial natural history collections. Both centres were created from briefs written by the author that set out the need to minimise the risks from the ten agents of deterioration—physical forces, theft and vandalism, fire, flood, pests, pollutants, light and radiation, incorrect temperature, incorrect relative humidity, and disassociation. The differing approaches to achieving minimal risks from each agent at a building, fittings or procedure level are discussed and the effectiveness of these measures compared and contrasted. Risks from the ten agents continue to be minimized, with monitoring showing acceptable temperature, relative humidity and minimal or no pest activity. Both collections can now be used far more effectively in exhibitions, for research and to answer enquiries.

Introduction

The Herefordshire Museum Resource and Learning Centre opened in 2005 and is a refurbishment of an existing building with a new build extension planned for 2006/2007. The Ludlow Library and Museum Resource and Learning Centre was officially opened by HM the Queen in May 2003 and is a new build. The theory of risk mitigation of the ten agents of deterioration was used in practice to plan, design and build both collection centres. The ten agents are: physical forces, theft and vandalism, fire, flood, pests, pollutants, light and radiation, incorrect temperature, incorrect relative humidity and disassociation. Risks from the agents were avoided or blocked at a building level, then at portable fittings level and finally by procedure.

The agents of deterioration were first set out in the Canadian Conservation Institute (CCI) wall chart (Costain 1994) and developed further by Robert Waller of the Canadian Museum of Nature (CMN). The framework had been used to plan the CMN collections facility and in the development of the Cultural Property Risk Analysis Model (Waller 2003).

This framework had been used successfully by the author as the basis of an M.Sc. thesis (Andrew 1991) and numerous unpublished collection assessments and reports between 1991 and the present for geological collections in the UK. Several of these reports have been used as supporting evidence for successful UK Heritage Lottery Fund bids for example the project at Whitby Museum, Yorkshire UK (Andrew 1999).

The Ludlow and Hereford Collections

In the nineteenth century, both Ludlow and Hereford were at the forefront of the development of the public interest in natural history, with the Ludlow Natural History Society founded in 1833 (Lloyd 1983) and its museum shortly afterwards.

The Herefordshire Natural History, Literary and Philosophical Society started in 1836 with the successor (and still extant) Woolhope Field Naturalist Club founded in 1851, (Churcher et al. 1999) with its Hereford Museum and Library opened in 1874. As a consequence, both institutions have or had historic natural history collections, though those of the Ludlow Museum were largely dispersed in the 1950s when the society was wound up.

At Ludlow, the curator John Norton MBE strove to re-acquire dispersed material, rebuild and enlarge the collections. By the time of his retirement, in the late 1980s the geology collection had reached some 30,000 specimens; the biology collections around 58,000 items and the total size of the collection was around 110,000 items. A re-organization of the service in the 1980s saw curatorial posts aligned around discipline rather than by site, so the post in Ludlow became that of County Curator of Natural History. The geological and biological collections housed at Ludlow are only part of the Shropshire County Museum collections with archaeology and agricultural collections held at other sites.

In Hereford, the former curators, particularly F.C. Morgan (1925–1945) concentrated their collection efforts on social history, agriculture, art, costumes and textiles. An entomologist curated the natural history collections from the mid 1970s onwards. From this time onwards, collections remained fairly static with the exception of a major entomology bequest in the late 1990s. The collections at Hereford, which are in fact the county collections, total some 150,000 items, of which around 10% is natural history. Currently three and a half full time equivalent curatorial staff are employed by the service.

The collections at Ludlow and Ludlow Museum are currently cared for by a staff of two and a half full time equivalents, one of whom is the Curator of Natural History. During the early 1980s a large number of recent graduates worked on the collections under the auspices of the Manpower Services Commission scheme. In the 1990s volunteer teams were developed to assist with collection care projects such as re-packing.

Since project completion, both sites have attracted considerable public usage via researcher visits, behind-the-scenes tours, open days and educational activities. The process of moving collections, leading to better staff knowledge of material, and the greatly improved physical arrangement has meant that collections can be used far more effectively in exhibitions, for research, and to answer enquiries.

The Projects

A brief comparison between the two projects can be seen in Table 1. At Ludlow, the long lead-in time and frequent setbacks in securing funding allowed a significant amount of work to be undertaken on expert surveys of collections and upgrading packaging and sorting of collections. One key decision taken early on was to standardise to a limited number of box sizes; this made it far easier to calculate the amount of space needed in the new facility and to use this space effectively.

At Hereford, with the exception of some old turkey boxes used for part of the archaeology collection, good quality storage materials had consistently been purchased for collection storage since the late 1970s. Regional grant funding schemes had enabled expert assessments to be carried out on the taxidermy, geology and herbarium collections and cataloguing projects on the trilobites and fossil fish.

Table 1. Comparison of the Ludlow and Hereford Projects.

	Ludlow	Hereford
Type of project	New build	Retrofit and new-build extension
Time scale	1995–2003	2000–2007
Total project cost	Approx £4 million	£900,000 for first stages; estimated £1.8 million for new build stage
Heritage Lottery Fund support	£2 million plus project development	£585,000 for Phase 2 £30,000 project planning for Phase 3 Stage 1 pass of £1.2 million for Phase 3
Number of items housed	110,000	150,000
Additional facilities	Public library Learning centre Exhibition space	Learning centre Exhibition space
Preparaton for move	7 years of collections upgrades	Collection care generally good. Only 6 weeks notice given for closure of one main collection site.
Collection removals	Undertaken in-house	Commercial firm
De-infestation	Complete freeze of all organic items	Quarantine and spot freezing of suspect items during re-location
New building replaces	One outgrown facility	Up to 15 storage locations in at least 7 different buildings

The decision to proceed with both projects came as a result of extreme pressure on space and service reviews. This led to a series of collections assessments and the realization that existing facilities were inadequate for the long term care of collections or to meet the requirements of UK museum standards. The emerging opportunities to seek funding for improvements from the Heritage Lottery Fund meant that it was at last possible to address issues in a strategic rather than fire-fighting problems as they arose.

The main differences between the projects were the restrictions imposed by a retrofit versus a new build (Table 1). The footprint of a previous scheme that had received outline-planning consent restricted both designs. In Ludlow the built scheme was the second design for the site. In Hereford the footprint of the sketch scheme for planning consent and a very tight site dictated the final design; the budget for first two phases of the Hereford project was also already set prior to writing the brief. However, the project in Hereford benefited from lessons learned with the Ludlow project and the phased nature made the project easier and cheaper to manage. For a more detailed description of the Hereford project see Andrew (2005).

Both projects had significant capital investment from the relevant local authority, Shropshire County Council for Ludlow and Herefordshire Council for Hereford but neither project could have been undertaken without the grant aid support form the Heritage Lottery Fund (Table 1). The National Lottery began in the United Kingdom in 1994. Prior to this, funding for capital developments was difficult, especially for collection care projects.

Minimizing the Ten Agents of Deterioration

The Canadian Conservation Institute wall chart (Costain 1994) identifies five stages to minimise and recover from the effects of the ten agents—avoid, block, detect, respond and recover. Three levels at which these stages can be applied are also identified—building, portable fittings and procedures. The Cultural Property Risk Analysis model (Waller 2003) takes this framework to a more detailed level, identifying three types of risk:

Type 1—catastrophic and rare
Type 2—severe and sporadic
Type 3—mild/gradual and constant

Certain combinations of risk types and agents are not feasible (for example, light damage could not be Type 1), thus 24 combinations of agent and type are possible. In developing these briefs, the intention was to avoid or block the effects of as many agents as possible at a building level, then at portable fittings level and finally by procedure. In the future at Hereford it is intended to further refine the approach by adopting the Cultural Property Risk Analysis Model (Waller 2003) to plan collection care projects and budgetary priorities. In Ludlow, the author was appointed just as the initial design phase of the project started in 1995 and the ten agents of deterioration framework was adopted immediately. In Hereford, the ten agents framework was not adopted until the author took on the project (Andrew 2005).

Zones for Security and Environmental Control

On the Ludlow project, although the brief was welcomed as comprehensive, and minimizing risks from the ten agents was very quickly grasped, the framework proved to be rather difficult for the design team to take on from a standing start and apply. Following discussions at the second design stage, Nigel Nixon, the senior museum officer on the Ludlow project added the additional concept of nested security zones, with the most secure and environmentally sensitive material stored in the centre of the building. This concept was also adopted for the Hereford project.

This concept made grouping of rooms and functions easier and therefore the task of the design team in planning the building layout more straightforward. Zones varied from 4 (the most secure) to 1 (the least secure), with the high security areas also needing greatest climate control and protection from insect ingress. Keller and Willson (1995) describe a similar concept for security control alone represented graphically with a security bull's-eye. This approach should also generate efficiencies in operational costs.

Physical Forces

Building Features

The main type 1 physical force considered in many countries is that of an earthquake. Although major fault lines run through Shropshire and the Welsh borders, the very occasional earthquakes are minor with only one quake (scale 3) in the autumn of 2002 noticeable since 1993. Shelving is therefore not protected with earthquake bars, nor are the buildings equipped with cross bracing. The brief for both projects requested an easy flow through the building, common levels on each floor with no steps and a lift between floors. Doors and corridors needed to be wide and high enough to allow the largest objects in the collection to pass through them. Smooth floors and boxed in compactor rails allow easy use of trolleys and ladders. Both projects failed to achieve all these requirements; for example, minor technical difficulties meant that the rails for the compactor units in Phase 1 of the Hereford project were fixed to the existing floor and boxed in with a sloped edge, which is not ideal for trolleys. The corridors of the Ludlow project were fitted with vinyl flooring with raised bumps, despite passing on the warning against this from staff at Norwich Museum and the effects on solid wheeled trolleys (Irwin 2000).

Fittings

In order to make most efficient use of collections storage space, both projects implemented mobile compactor storage systems to a greater or lesser degree. Since movement on a compactor equates to a type 3 risk for physical forces, certain fragile collections including pinned entomological collections and fluid collections were viewed as unsuitable for mobile storage and are housed on static shelving or cabinets. The Ludlow fluid collection has been stored on re-used wooden shelving as this was seen to offer slightly more resistance to accidental slipping of containers via friction. Since the collection is quite small and not densely packed, jars are grouped into 10 cm deep polypropylene storage trays to prevent accidental toppling and to contain any spillage (type 2 physical force risks). A major type 3 risk from physical forces is associated with poor storage methods. In Ludlow, very little money had been available to spend on collection storage in the past with most items stored in poor quality open card trays resting on cotton wool and then in shirt boxes obtained from the local gentlemen's outfitter. Larger specimens were stored in an assortment of containers from old wooden drawers to corrugated cardboard boxes. Following a collection assessment in 1993 a decision was taken to upgrade collection storage to minimize type 3 risks. With seven years lead in time to the collection move, upgrading of packaging also meant that specimens could be re-packed with care into containers that minimize risks during the move and could be used for long term storage.

Specimen boxes with clear lids in a four standard sizes that were units of each other were selected and these were padded either with Plastazote® (closed cell polyethylene) foam or acid free tissue pads (see Watkinson 1987, Waller 1992) and then stored in one of four standard depths of lidded storage boxes. Re-packing work was undertaken by volunteer teams, supervised by a volunteer supervisor. The size of the smallest box formed the basis for calculating the size of specimen drawers and the choice of supplier. Drawer and bay size was also a major factor in determining the size of the new store and the building itself.

Volunteers also made Ethafoam or Plastazote® (closed cell polyethylene foam) storage bases for larger geology specimens, osteology specimens and mounted birds that would not fit in boxes, adapting the concept of a form fitted palette and taxidermy mounts (Fitzgerald et al. 1992, Fuller 1992). For heavier specimens that required two people to lift them, an appropriate size of 20 mm marine ply base board was fitted with two battens or skids screwed to the underside, to provide access for lifting. The Ethafoam bases were fixed to the wooden base board using hot melt adhesive. Larger osteology and geology specimens were also provided with dust covers, sewn from Tyvek®, a spun bonded polyethylene sheet. Mounted birds were provided with polythene bag covers, occasionally with wire hoops to hold the bag away from less evenly shaped specimens, adapting the hoop and bag cover system of Fuller (1992). The larger geological and osteological specimens were not uniform enough to use bags. The bird bases were cut to extend beyond any protruding parts of the specimen,significantly reducing the risk of damage to specimens by crushing against another specimen or container. In Hereford there had been a significant investment since the mid 1970s in good quality storage boxes but without standardization of container size. Hereford and Ludlow now use the same style and sizes of individual specimen box and regularly procure such materials jointly. This will enable Hereford to adopt the same style of metal drawer storage unit as Ludlow during the planned new-build extension.

Procedures

At Ludlow, the improved packaging meant that collections could be safely moved and then stored in their containers without the need to insert and then remove and dispose of temporary packaging materials during the move. Using a limited number of box depths in one standard format meant that the boxes could easily be stacked for moving onto palettes into neat piles that were then secured with tensioned bands. L-shaped profile cardboard edging strips were used (and re-used several times) to stop the tensioned band from cutting into the boxes. This was the only temporary packaging used on boxed specimens and was chosen in preference to film wrapping the palettes as it generated very little waste. Collection moves in Hereford have mainly been carried out by removal contractors with only large social history items moved since the author came into post.

Theft & Vandalism

Building Features

Both projects followed the concept of nested security zones (Table 2). Preventing illicit access to collections was the principle concern with the securest zones located deep within the building and housed in rooms with no windows and limited doors. This concept was supported at the fittings level with good quality locks, closed circuit television (CCTV) coverage, high quality alarms and further with good procedures. Both projects benefited from security advice given at the design stage from the security advisor at the former Museums & Galleries Commission, now MLA (Museums Libraries and Archives Council). The advisor also made two site visits to the Hereford site. The layout of the Ludlow site meant that there are no windows on the ground floor of the building, since the ground floor also accommodates a mezzanine; windows into offices, labs and the research room are at second floor level and above.

Fittings

In Hereford the few remaining ground floor windows are protected by welded steel bars with bolts that are epoxy bolted into the brickwork. All other windows are blocked from the inside, but planning conditions prevented actual removal and bricking up of the windows. At both sites, researchers can be monitored in a dedicated research room; at Ludlow this is achieved via a window from an adjoining office, at Hereford via a recording CCTV link to the adjoining office.

Table 2. Description of Zones for security and environmental control.

Zone number	Accessed by	Degree of control	Functions
1	Public on a drop-in basis Staff	Comfort heating, no security	Entrance lobby Displays in show cases Public toilets
2a	Staff Public by request	Comfort heating Key control to rooms	Administration offices
2b	Staff Public by appointment or invitation from staff	Comfort heating Key control to rooms	Tea room/staff room Staff entrance Educational facilities
3a	Staff and volunteers, other visitors by appointment/authorisation of staff.	Comfort heating, environmental control not required Doors looked when not in use	Loading bay Staff toilets Plant rooms Staff offices
3b	Staff and volunteers, or for researchers and other visitors by appointment/authorisation of staff.	Within the range 45–60% RH fluctuations possible, needs to be stable, but does not need plumbed-in de-humidifiers/humidifiers Key control, doors looked when not in use	Exhibition crate storage Research room/library areas Documentation room Large (stable) object storage areas Packaging stores
3c	Staff and volunteers, or for researchers and other visitors by appointment/authorisation of staff.	Stable environment required within the range 45–60% RH fluctuations possible, but may need de-humidifiers Key control, doors locked when not in use	Volunteer work room Collection quarantine area Conservation laboratories Collection work rooms Education/handling collection store
4	Access by collection staff only	Doors always locked, strict key issue control. No windows, close environmental control determined by collection type in storage.	Collections stores

Procedures

Procedures are in place to vet researchers with differing levels of name and address or reference checks in place depending on the sensitivity of material that is requested. Both sites aim to offer public access to collection storage facilities. In Ludlow, this is possible via a route that allows visitors to inspect two stores from the mezzanine level and to inspect the conservation lab via a viewing window. In Hereford public access to date has been offered via guided behind the scenes tours for pre-booked groups, with ten visitors for every two members of staff and by a series of open days, three in the first year of opening, rising to ten per year in future. Additional changes to storage layout are planned in Hereford to ensure that the public can enter the stores and at least one of the compactor bays to gain a better understanding of the function of reserve collections. The best method to achieve this is being refined as we learn from our experiences.

Allocating each visitor with a giant object label on a piece of string to wear around their necks and only allowing sixteen visitors at a time has proved successful so far in restricting and monitoring the number of self-guided visitors on the site.

Fire

Building Features

The zoning concept at both sites has created a series of compartments arranged in compliance with UK building and fire regulations. Doors that allow two hours protection from fire divide the compartments. In Ludlow, there was a precedent of separate stores for each collection type and new stores were created in the same groupings, comprising geology, natural history, social history and fluid collection areas so that the risk of fire from fluid collections was minimized. In Hereford, collections have been arranged initially in larger rooms with the location governed by the size of object and the ideal environmental conditions. The original brief for the Ludlow project specified a sprinkler system. Investigations proved that there was insufficient water pressure to run such a system from the mains water supply, so we considered and then ruled out a system with its own water tank as this would have required a water tank the size of a large swimming pool to be located in the roof, thereby increasing the risk of water damage to an unacceptable level. Instead an inert gas (Inergen) system was installed to cover collection storage areas only; this system sounds a claxon and a flashing light before releasing an inert gas mixture into the room and starving the fire of oxygen. Both sites are covered by a fire detection system with automatic calling to the fire station. The Ludlow Fire Brigade, like many rural services in the United Kingdom, is a staffed by volunteers who respond to pager call-outs. Although the new site is closer to the fire station than the old collections store, attendance time is likely to be at least 10 minutes. Despite improving staff safety by upgrading the fire detection at the old store from a manual system, we were advised that in a fire we would probably lose the contents of whichever store the fire started in. A combination of lessons learned from Ludlow over water pressure, a restricted budget on the Hereford project and a view that we could minimise risk in this area meant that a traditional approach to fire detection and control had to be taken using an automatic detection and calling system and local fire extinguishers. Unlike Ludlow, Hereford has a permanent fire service and the fire station is less than half a mile from the site.

Fittings

At Hereford, original accession registers and collection histories are housed in fire resistant cabinets offering 2 hours protection, and most of the free standing cabinets are currently on palette bases for easy manoeuvring and evacuation.

Procedures

The principles at both sites are to minimize risks from fire with a no smoking policy, good housekeeping procedures with corridors, high visibility closed fire doors free from obstructions, backed up by the fire detection system with automatic calling of the fire brigade. English law requires an inspection by a fire officer on completion of a new building and in Hereford this has also been backed up with a Fire Brigade familiarization visit. Disaster plans are also in place.

Flood

Building Features

At both sites, it has been possible to minimize the risk of flood by preventing ingress with a sound building and by removing or minimizing water sources in collection areas. The old collections building at Ludlow suffered serious water ingress every time it rained hard, through the flat roof, through cracks and failed pointing in walls, perished window frames and leaking skylights. Removing or minimizing the risk of flood was successfully achieved at Ludlow through very careful planning of where functions and services were placed within the building. There are no water sources in the stores or above the stores. Electric heating is used in the collections zone and the air conditioning plant in the roof space, a possible water source, is located over the access corridor. The risk of water spreading across the top floor is minimized by a bund (low wall) and waterproof tanking across the floor and up the wall. At Hereford, the pre-existing building is located within the once in 100 years flood contour from the River Wye, although this risk is unlikely with the site at about 10 meters above river bank level. The site already had a small sump with a sump pump and a bund across the doorway into the basement store, and both features were retained. At Hereford, an existing hot water heating system was replaced with a new hot water system and was pressure tested before commissioning. In the event of a leak, the drop in pressure causes the heating pumps to turn off and prevents automatic topping up of the system. An alarm is also triggered that leads to staff callout. The combined de-humidifier and humidifiers in two of the stores have leak detection cables in a drip tray beneath the unit and also have an easily reached water shut off tap. The staff room with its sink (on the first floor) and toilets (on the ground floor) are grouped over each other at one end of the building. The Ludlow brief requested a drain to the outside from each store, but this proved impossible to create. At Hereford the ground floor nature of stores and the basement sump will allow water to be removed fairly easily.

Fittings

At Hereford, freestanding cabinets and most large items are raised above floor level on palette bases or on wide span shelving. At Ludlow, all large objects are stored on palettes.

Procedures

In order to avoid accidental small spills on objects, staff are permitted to drink water at their desks and hot drinks in the staff room, but no drinks are allowed anywhere else in the building. The officer in charge of the site is required to make occasional inspections inside and out in heavy rain checking for leaks and drips in particularly the down pipes and gutters.

Pests

Building Features

Both sites are surrounded by hard surfaces with no climbing plants permitted on walls to avoid attracting pests to the building. Entry points into both buildings are minimized and there are no windows in collection storage areas. Insect proof screens were requested on all opening windows at both sites but at Ludlow these were not installed, although mesh was installed behind ventilation grills in the roof space. However, the opening windows are remote from collection storage areas. In designing the new build and retrofit, the architects were also asked to avoid creating inaccessible voids in walls and ceilings.

Fittings

At both sites, exterior lighting was specified to be low UV emitting in order to avoid attracting insects. Both sites have a quarantine room close to the entrance with facilities for freezing incoming collections material. Kingsley et al. (2001) provided case studies and networking opportunities to discuss several possible de-infestation methods. Freezing to −30°C was selected as the most suitable method for cost and time reasons. The Thermolignum heating chamber with controlled relative humidity was also considered. Although quicker and requiring less preparation of items, the space needed for the unit to be cost effective and the capital cost for a unit on site, rather than one rented as required proved to be too high. At Ludlow, collections enter the facility via the loading bay door which can then be closed. The internal space is large enough to take a 7.5 tonne lorry or a shipping container. The largest size of removal lorry (a pantechnicon) can also reverse part way in. Collections are then unloaded into the quarantine area for inspection and if necessary frozen at −30°C for 72 hours in the 3 × 2 m walk-in freezer before being moved into the facility. At Hereford, the quarantine and freezing facility is currently more modest with a chest freezer large enough to take entomology drawers. Plans for the new-build extension include a walk-in freezer. The combination of a small chest freezer and a large walk-in freezer should give good flexibility over managing variable sized objects in quarantine and periodic large-scale de-infestation treatments in future.

Procedures

An integrated pest management (IPM) policy at both sites backs up the design of the building and fittings by a process of quarantining of incoming material, bagging and freezing infested material and trapping and monitoring in stores with sticky traps. All organic sections of the collection at Ludlow were frozen as part of the move process, using the built in freezer and a hired freezing container. This was planned following the procedure adopted for the bulk freeze of the Liverpool Museum Botany collections in 2001 (Young 2003). At Ludlow, the entire entomology collection had also been bagged, frozen, and frass removed during 1999 and 2000. Sticky traps showed that *Anthrenus,* dermestids, silver fish and book lice remained active in the collections at the old building. No insect pest activity has been noted in the new building since moving there in early 2003. In the past, both entomological collections had been protected with naphthalene. Citronella essential oil had also been trialed at Hereford with small glass vials containing the oil pinned into drawers and store boxes. Recent damage by *Anthrenus* to specimens despite the presence of a vial of essential oil proved that it had been ineffective and it is now being removed as part of a de-infestation and cleaning programme using the chest freezer. At both sites, eating food is allowed only in the staff room and food waste is limited to a waste bin in this area. The Hereford member of staff responsible for cleaning has embraced IPM with enthusiasm enabling staff to pinpoint entry points for pests and objects with active wood worm and deathwatch beetle infestations. These items, previously stored in very poor conditions, have since been transported to Ludlow for freezing and are no longer generating live beetles. It was not possible to carry out a freeze before moving collections at Hereford but as material is moved into the new build extension, it will be possible to undertake de-infestation in batches using the new walk-in freezer and then work retrospectively through collections in the existing building.

Pollutants

Building Features

In rural and non-industrial areas such as Ludlow and Hereford, the main external air pollutants are particulates. The risk of contamination has been minimized at both projects with a clean, new facility with no windows or exterior openings. In Ludlow, the site of the air intake for the air conditioning was carefully considered and is located at a sheltered second floor level. The air intake to the basement at Hereford is currently at ground floor level, though not causing a pollutant problem, it is providing ingress for insects. With the new build, the intake will be re-routed to first floor level.

Fittings

Neutral pH paint was specified for decorating and non off-gassing floor coverings at both facilities. Research on pollutants in mineral collections (Waller et al. 2000) indicates that metal collection furniture is preferable to wooden collection furniture in terms of the pH of the internal environment. Both sites therefore use metal collection storage furniture with the exception of entomological drawers and some retained antique cabinetry. Careful consideration was made to prevent dust ingress into collection furniture at Ludlow with compactors designed to close into dust proof units. Units housing variable depth drawers were planned to be loaded from the top downwards, so that each drawer became dust-tight by fitting closely to the base of the drawer above. Drawer sizes for the geological collection were selected after a survey of larger specimens to minimize the number that would not fit into drawers. Large specimens are stored on shelving protected by Tyvek® dust covers. Each bay of the mobile unit also has an overlapping flange to create a dust seal. Dust proofing was more difficult to achieve on the very high units at Hereford, but keeping bays closed as much as possible successfully reduced dust ingress during building work.

Procedures

A well specified schedule at Hereford with cleaning twice a week has helped to maintain the site following handover in a clean state. Stores at Ludlow are also regularly cleaned. At Hereford, collections remained in one store during the building work. A combination of inner lobbies, strict access control and keeping the mobile racking closed successfully prevented dust accumulation on collections.

Light and Radiation

Building Features

The problem of light damage has been removed at both sites. The stores have no windows and at Ludlow the lights function on a motion detector sensor. It is for this reason that the Hereford stores have light switches as Ludlow staff working in high racking at a distance from the passive infrared (PRI) motion detector heads have regularly been plunged into darkness, a problem that has been difficult to overcome.

Fittings

In the Hereford stores and offices, lighting is by polarized high frequency units manufactured by the Aura Corporation. These produce no UV, have a daylight colour temperature and are energy efficient. The improvement in light quality when these units were first commissioned after previously having fluorescent strip lights in the main store was dramatic. Light units run perpendicular to the mobile bays in order to prevent dark pockets developing as mobile bays are moved. At Hereford, all remaining windows were fitted with UV filtering film during the building conversion and UV filtering glass will be installed in the new-build extension.

Procedures

Lights are turned off when stores are unoccupied, either manually or by PIR motion detection system.

Incorrect Relative Humidity and Temperature

Building Features

Both projects are "heavy weight" highly insulated buildings with long thermal lags and minimal air exchange to the exterior through locating stores deep within the building and reducing the number of openings. The combination of these factors buffers the effect of fluctuating external conditions.

Fixtures

Two different means to control relative humidity and temperature were selected for the projects. At Ludlow, an air conditioning plant was deemed to be the only way to achieve the conditions specified in the brief with slightly different conditions for the different types of store and conservation lab. For example, although most of the stores are at 18°C the fluid collection store is cooler (14–16°C) to reduce alcohol evaporation rates. At Hereford 18 months of data from the building prior to the main refurbishment showed that acceptable environmental conditions were being achieved by constant heating to 18°C except for a few weeks in the spring and autumn of slightly too high or too low RH. The collection itself appeared to be providing some buffering effect too. A system of combined humidifier/dehumidifiers was proposed for the two stores requiring some humidification and in the low relative humidity store a system for de-humidification only. The stores comprise a low relative humidity store (40%RH), lower average relative humidity store 52% ± 5% RH for small and medium sized objects, 55% ± 5% RH higher average relative humidity store for medium to large objects (mainly furniture and wooden items) and a wheeled vehicle store with low level background heating to about 10°C only. After some initial teething problems this is now working well with less reliance on buffering by the collections and their packaging. A low budget precluded an air-conditioning approach.

Procedures

At Hereford, the heating system is controlled and monitored at a central council monitoring control room via a building management system. The heating in collection areas is on 24 hours a day once the temperature drops below 18. Local adjustments are made via thermostats. The office and collections areas are controlled separately. Cooling is not possible. Conditions are also monitored independently at both sites using Hanwell telemetric monitoring systems that include external sensors.

Disassociation

This agent had until recently been termed custodial neglect. The term disassociation has been introduced, to reflect the fact that the risk of a lack of care and responsibility for collection assets is not solely that of the immediate custodian.

Building Features

Both projects are a major improvement over the previous collection care conditions. At Hereford, the facility has replaced one store that flooded regularly, several overcrowded and inaccessible stores and collections spread over more than 15 locations. At Ludlow, overcrowding of the old facility was so severe that it was impossible to access many sections of the collections and public facilities were minimal. The old facility leaked whenever it rained, it was not particularly secure and had no environmental control. With newly completed state of the art facilities, there is now little obvious disassociation of collections from their data and functions at either facility and in fact a great deal of re-association has been possible.

Fixtures

Both sites benefit from appropriate new collection furniture with sufficient expansion space and flexibility to store objects systematically rather than by size. This has allowed many collections to be re-associated where previously, extreme restrictions on space meant that it was not always possible to store associated items together.

Procedures

Procedures at both new facilities started with the collection moves. In Ludlow, this move was undertaken by an in-house team since none of the four commercial companies approached wanted to take the job on. The physical strain on staff not used to the intensity of such tasks was high but the preparation for the move over the previous seven years meant that the process for the natural history collections at least was fairly straightforward. The Hereford move and temporary storage during the refurbishment was undertaken by a commercial company. Only one item (a glass dome) out of about 100,000 was broken. Both centres now enjoy a raised profile having achieved excellence in building facilities backed with good policies and procedures and service delivery. At Hereford this is being tackled via a Collections Management Plan, a full inventory of collections and their condition (Craig 2004) and work plans based on the risk analysis model. Both institutions were registered museums and are now preparing to apply for Accreditation, the new enhanced UK museum standards scheme.

Conclusions

Adopting the ten agents of deterioration framework linked to the zone concept for the design of these two collection facilities has created two highly effective resource centres. Risks from the ten agents are either removed or blocked, where possible at building level, but otherwise at portable fitting or procedures level. Standards of collection care are now considerably enhanced at both facilities and meet best practice at building and fittings level (Winsor 2002). Ensuring that procedures continue in future to meet best practice will be down to good collections management. With the restrictions of inadequate facilities removed, the opportunities for future use, public access and learning linked to collections are very exciting. Users clearly appreciate the new facilities with nearly 400 individual researchers visiting Hereford during the first years of operation since December 2004, over 300 visitors at open days, 350 on pre-booked behind-the-scenes tours and very high satisfaction rates. Similarly at Ludlow nearly 1,000 people have visited the centre for research, behind-the-scenes tours or adult learning sessions during April to October 2005.

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CLIMATE CONTROL IN AN UNCONTROLLABLE BUILDING

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Abstract.—The collections of the National Museum of Ireland, Natural History Division (NMINH), are held in a 2,100 m^2 converted mid-19th century army barracks, heated by the original closed-loop system of antiquated radiators. Monitoring of the collection environment (temperature and relative humidity) over three years, including phases of intervention and non-intervention by staff, provides a case study demonstrating the effectiveness of manual adjustment of temperature as a method of controlling the environment in an old building. Data from fourteen relative humidity and temperature transmitters distributed throughout the collections building were compared to external meteorological data to determine the relative impact of attempted internal controls. Fluctuations in building humidity were found to be significantly greater during periods of intervention, suggesting that in a poorly sealed building, with woefully inadequate levels of staffing, manual control of temperature in an effort to reduce fluctuations in humidity is detrimental to maintaining a stable internal environment, and is an inefficient use of human resources.

Introduction

Stability of internal climate (temperature in °C and relative humidity in %RH) in collections storage spaces is essential to collection integrity (e.g., Costain 1994, Michalski 1994, Rose and Hawks 1995). As a key factor to collections management, we expend significant human and financial resources on monitoring and controlling climate in museum environments. For example, in this study, around 15% of technical staff working hours are spent monitoring the collections environment using equipment worth in the region of 12,000 Euro. Monitoring programmes identify problems in the collection environment that may lead to damage of specimens. The data obtained from such programmes can enable curators and conservators to make informed decisions about protocols for the most appropriate use of available space (e.g., office/lab space versus long-term storage), or to develop arguments for the development of more extensive climate control systems (Waller 1995). Fundamentally, the temperature and humidity regimes of collections spaces are architectural issues, and it is the nature of the building in which collections are housed that will determine the levels of control able to be applied to the collections space (Padfield and Larsen 2004).

National Museum of Ireland Natural History Division (NMINH) collections are held in a dedicated off-site storage building that contains the majority of the Zoology Collection, the entirety of the mineralogical and palaeontological collections (Monaghan 2005), but not the Entomology Collection. The building is a converted British army barracks dating from the mid-nineteenth century, which became property of the Irish government after it gained political independence in the 20th Century. The total floor area is around 2,100 m^2 and the layout is effectively a series of cells with rooms connected by doors to either the next room or to a stairwell (Fig. 1). The building insulation is limited to thick limestone external walls, brick internal dividing walls and modern plasterboard ceilings with glass wool insulation of attic spaces. Black roller blinds are fitted to most windows in

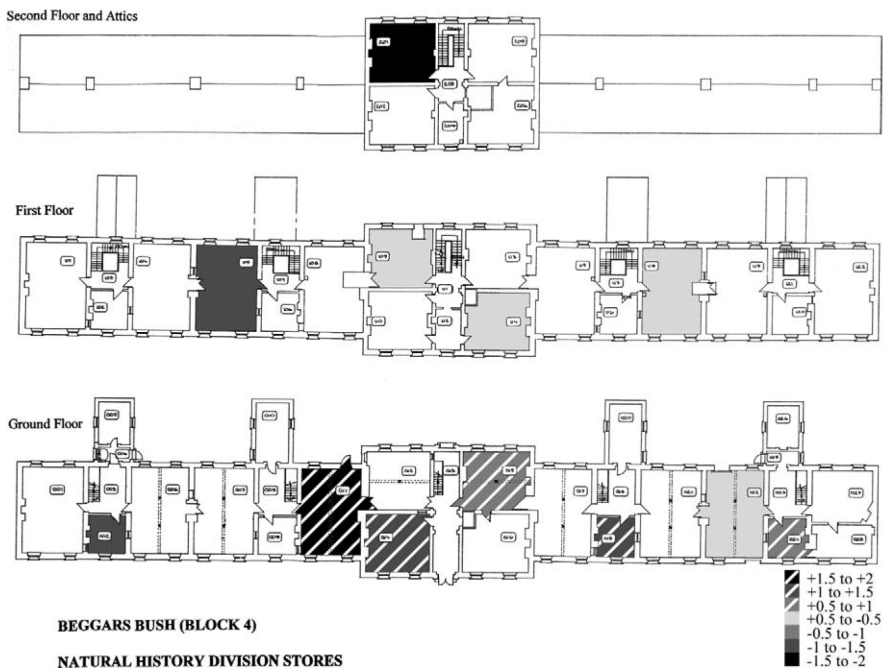


Figure 1. A generalised floor plan of the NMINH off-site collections storage building. Approximate total floor area on three levels is 2,100 m^2. Key indicates the temperature compared to overall building average in rooms containing sensors in the period from January 2005 to March 2005 (during climate intervention phase).

order to minimise solar gain and some windows (in the fluid-preserved zoological collection areas) are panelled with sheet steel for security purposes. Heating is provided by the original closed-loop system of 104 radiators, all controlled by old and faulty domestic thermostatic valves. The connecting pipes are fully insulated, so little heat is contributed from the large-bore pipework running around the building. A boiler at the southwest corner of the building sends hot water to radiators in series down the north longitudinal face of the building along the ground floor; the water flow turns up at the far (east) end and returns along the first floor (with a short section running in parallel up to the second floor in the centre of the building). At the west end of the building the pipe performs a U-turn before repeating the pattern through a second series of radiators on the south face of the building before returning to the boiler. A thermostat in the boiler compares the temperature of water as it returns, and adjusts the heat applied to water as it starts the loop, to maintain an acceptable temperature throughout. In practice, this means the building temperature is very much warmer at the southwest corner and the availability of hot water for heating the eastern end of the building and north face of some rooms is dissipated along the long circuit of pipework (Fig. 1). The building, still owned by the State, is considered a low priority for non-essential works. As a result, the fitting of automatic thermostatic valves has not been possible, making manual adjustment of the radiators in individual rooms the only available means of internal climate control.

The main renovation of the building took place when the Museum acquired the property in 1990. This consisted of fitting plasterboard ceilings to replace lath and plaster, complete rewiring, compartmentalisation of attics for fireproofing, and installation of security and fire alarm systems. At that stage the building was also fitted with internal doors throughout. It had most recently been used as a stationery storage building, with forklift trucks moving freely within a building where most internal doors had been removed. Steel grilles were fitted internally to all windows for security purposes, except in a zone at the eastern end where full steel plate was used to protect the fluid-preserved zoological collections.

Later additional work was carried out at various points to install toilets, telephones and re-slate the roof. In 2003 and 2005, Internet facilities were added. A programme of upgrading rooms has seen 12 of the 44 spaces painted and floors covered with linoleum. This has helped to seal flaking lime-washed walls, and to prevent air exchange and associated dust movement through the floorboards. Despite (and in some instances because of) the works carried out, the building has substantial ventilation between rooms due to holes in walls. In addition, substantial ventilation is provided to the outside of the building through airbricks (bricks with holes that are open to the outside), as well as vents, poorly blocked chimneys and decaying wooden sash windows. This is part of the original design in a building that has no damp-proof course and nothing under the ground floor floorboards, with the foundations limited to the areas under supporting walls. The ventilation was designed to maintain airflow to prevent damp and to provide clean air for a building inhabited by a large number of soldiers.

A number of disparate factors are known to influence and regulate climate within enclosed spaces. Of recognised importance is human activity. Use of electric lights can increase temperature, respiration can increase relative humidity and access can increase atmospheric exchange between rooms and the exterior. What is less clear is the nature of the relationship between temperature and humidity in a ‘‘leaky’’ system, such as a building that is not effectively insulated from the external environment. In these cases the impact of external climate fluctuation on temperature and humidity regime is expected to be much greater than the impact of localised variation due to human activity.

In this study we present our building as a case study demonstrating the effectiveness of attempts at climate control using limited resources in an antiquated building. Understanding and controlling fluctuations in building climate are essential to addressing issues related to climate-damaged specimens housed in this building. In common with many museums with limited staff resources, the NMINH does not have any on-staff conservation expertise. Technical and curatorial staff rely on advice from other personnel who are not at all familiar with the storage environment. Often technicians must make decisions through guesswork, personal experience, or, as in this study, retrospective analysis.

Our aims are to identify the impact of external climate fluctuation upon the internal climate of the collections storage areas, and to assess the effectiveness of attempts to control the internal climate by manual intervention. The second of these aims is important for estimating the value of the staff time investment required for manual intervention. This is a key factor for the NMINH since staffing levels are low, with just three full-time curatorial staff and one technician for a collection of more than two million specimens housed in two buildings. Furthermore, we intend to determine the reliability of earlier decisions made about

Table 1. Actions available for direct climate intervention, as implemented by technical staff during the attempted climate intervention period (January 2004–March 2005). Situations were interpreted from the central Meaco™ monitoring system, applied to each sensor in individual rooms.

Situation	Action
Temperature too high	Close radiator valve (decrease temperature)
Temperature too low	Open radiator valve (increase temperature)
RH too high	Open radiator valve (increase temperature)
RH too low	Close radiator valve (decrease temperature)
Contradictory actions, or radiator already fully open/closed	No action

building usage, particularly in light of specimen storage and researcher access. The majority of visitors to the collections building are researchers working through the Museum's partnership with University College Dublin Collections-based Biology in Dublin (CoB*i*D), and the establishment of effective, comfortable research space is of increasing priority.

Methods

Temperature and relative humidity data have been monitored continuously in the NMINH collections building since May 2002 using a Meaco™ Telemetric Environmental Monitoring System (Meaco 2006). Prior to this, relative humidity and temperature were monitored using Casella T9420 thermohygrographs in a small number of rooms during the early years of occupation of the building. Shortage of technical staff (there were four in 1990, only one today) limited environmental monitoring until the Meaco™ system was introduced. Our study period reported here ends in March 2005, although the system remains in place. Fifteen transmitters in a range of locations throughout the building record half-hourly measurements that are logged, via a radio telemetry system, by a central computer. All readings are stored electronically in a dedicated stand-alone computer. As part of the Meaco™ system software (version 5.00), each monitor is allocated an optimal temperature and humidity range, with an ''alarm'' and ''panic'' level identified as climate deviates from the optimum.

From January 2004, the NMINH's technician initiated a programme to moderate internal climate within the collections building, by responding to ''alarm'' and ''panic'' conditions identified by the Meaco™ system. An optimal range from 40% to 55% RH and from 15°C to 18°C represents the range of climate values chosen for the safe and stable storage of material throughout the building (based on information from Carter and Walker 1999). The ''alarm'' values ranged from anything outside these optimal values to extremes of 30% to 60% RH and from 12°C to 22°C. On two to three days per week the technician reviewed the readings from each monitor, and took action to adjust the internal climate in particular rooms when the immediate climate was found to be outside the pre-determined optima. The available actions are outlined in Table 1. Various staff in this post maintained this intervention programme for a period of 15 months until March 2005.

We compared the total internal building climate records with external weather climate conditions, to determine the degree of buffering offered by the building, and to identify whether efforts at control had made a significant impact on stabilising the collection environment. Weather data were supplied by the Irish National Meteorological Service (Met Éireann), including hourly records for temperature, humidity, precipitation, and evapotranspiration from the central Dublin area climate recording station at Dublin Airport (approximately 10 km to the northeast).

The data were divided into two phases: non-intervention and intervention. During the period of monitoring the collections building was heated between late October and mid-May. Although direct-action means to control room conditions were unavailable when the heating was turned off, the technician intervention programme also included a regime of electric lights being switched off when not in use (to prevent potential warming in collections spaces) and all doors between rooms were kept closed at all times. These collections space management strategies were implemented throughout the year.

Prior to, and during, the climate intervention programme, we know that at least some monitor units were moved an undetermined number of times between rooms during renovation works, making exact time-series comparisons on individual units impossible. Because some individual monitors were associated with a collection, rather than with a room within the building, monitors accompanied their collections when they were temporarily or permanently moved between parts of the building. In addition to these movements, some decisions were taken to concentrate monitoring on a particular collection or space for short periods of time, and unfortunately these placements were not consistently recorded. For analysis, average climate within the building as a whole was determined using the mean hourly temperature and RH across fourteen monitors, with results from one monitor excluded due to interference. Further details are given in the discussion. The average daily range was calculated as the mean difference between maximum and minimum temperature and RH recorded by each sensor over a 24-hour period. Time-series plots were visually examined for daily maxima and minima of temperature and RH (external and internal) to assess how much time the collections were outside the generalised optimal conditions imposed during the climate intervention programme.

The difference between daily maximum and minimum values (magnitude) of temperature and RH ranges in the "winter" (i.e., heated) periods during intervention and non-intervention phases was compared using pair-wise single factor analysis of variance (ANOVA) tests for external and internal climate data. Finally, the magnitude of internal daily fluctuations as a percentage of the external diurnal fluctuations was also compared.

Results and Discussion

As expected, the fluctuations in temperature within the collections building followed a distinctive seasonal pattern (Fig. 2). Humidity fluctuated even more dramatically, showing a complex relationship with temperature. Changes in humidity were often associated with rapid changes in temperature, although RH

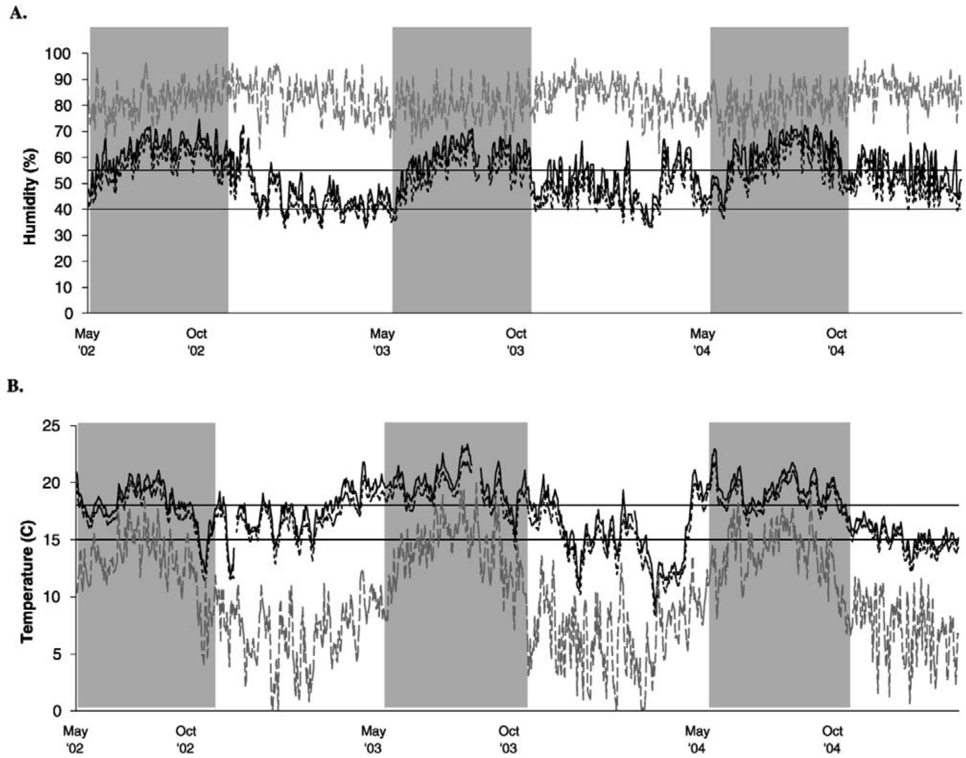


Figure 2. Internal climate in the NMINH collections building over the entire study period; black lines indicate internal daily maxima (solid) and minima (dashed), the lighter line shows average daily external conditions. Horizontal bars represent the smallest range of optimal conditions set to determine actions during the intervention period. The intervention period (not shown) ranged from January 2004 to March 2005. Shading indicates ''summer'' periods; unshaded regions are the ''winter'' periods when building was subject to scheduled heating. A. Relative humidity, optimal range 40–55%. B. Temperature, optimal range 15–18°C.

measurements did not correlate directly with temperature. This relationship is partly ascribed to the movement of frontal weather systems introducing warmer or cooler air with very different moisture contents, resulting in rapid change that stabilised over time. A strong seasonal influence was identified, where humidity lows were associated with temperature lows in the winter, but during the summer the relationship between precipitation and, more importantly evapotranspiration, resulted in a less clear-cut association between humidity and temperature.

Most interestingly, and more distressingly, the building climate rarely stayed within optimal conditions. Summer relative humidity regularly reached values of 70% RH inside the building and temperature reached a maximum of around 22°C. In the winter periods, whilst the building is heated, RH dropped to around 35% and temperatures fell to around 13°C. It should be noted that extreme low temperatures of down to 8°C have been experienced during periods when the heating system has failed. Correlations between temperature and RH values during extreme conditions inside the building are to be expected, but interestingly the temperature variation does not seem to have dramatic influence on the humidity regime.

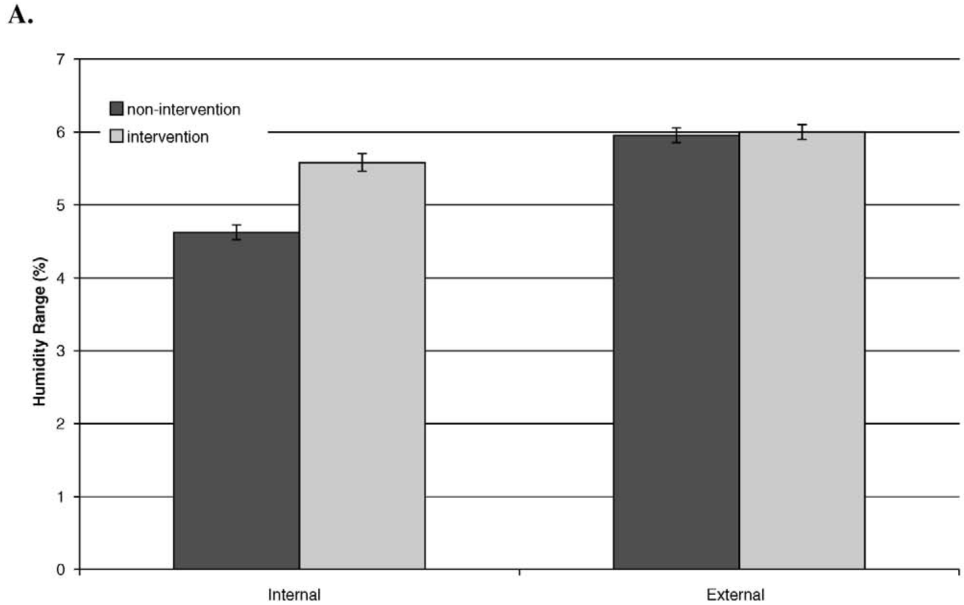
The daily building temperature has been outside the optimum maximum and minimum readings for 73% of the time since 2002, and the RH for 70% of the time. Mostly the RH is above the upper part of the range and only drops below the maximum humidity (55% RH) for 32% of the time. However, the temperature varies dramatically over the three-year period, spending in total 13% of the time with the minimum daily temperature exceeding 18°C and 17% of the time with the maximum daily temperature staying below 15°C.

Comparing the periods with and without intervention, the programme has had a limited effect on narrowing the internal temperature range, with measurements falling outside the optimal range for 35% of time during the non-intervention period, compared to 26% of time with intervention. However, the climate intervention programme has had dramatic negative results on the building humidity regime, with measurements falling outside the optimum values for 74% of time, compared to 58% of time before intervention. What is also visible from plots of the RH measurements is that the oscillations within the building become more extreme during the period of intervention. Examining the fluctuations in temperature and RH as a percentage of the external daily range, we note that during the period of intervention the magnitude of fluctuations in internal humidity exceed external fluctuations more often, and are generally greater during the intervention period.

The time when the building heating was turned on is critical for analysis, as this is the period when direct actions on climate control were possible. During the winter, the building environment is well buffered from fluctuations in outside temperature; it is less well insulated from fluctuations in external humidity (Fig. 3). The average daily range (fluctuation) of temperatures has decreased slightly, but statistically significantly, during the intervention phase from a difference of 1°C to a difference of 0.9°C (ANOVA comparing 249 data points, $F = 11.99$, $P = 0.0006$). However, the range of humidity fluctuation has increased significantly during the intervention period, from a range of 4.6% to 5.6% ($F = 11.09$, $P = 0.0009$). These changes in the internal climate occur irrespective of external climate, since there is no difference in external range between the years compared.

These data paint a rather negative picture of the impact of manual intervention in climate control on the collections environment in Dublin. Stable humidity is the most important factor for object conservation (Rose and Hawks 1995), and although the intervention programme aimed to control humidity via temperature regulation, the intervention efforts have actually exacerbated humidity fluctuations. Long-term exposure to unstable humidity are the presumed cause for visible damage to our collection of Giant Irish Deer (*Megaloceros giganteus*), where several examples of these famously large antler sets are suffering cracking and flaking. This collection, of particular importance to the museum, is obviously one example of material we are working hard to protect from exactly the kind of environmental phenomena that the intervention programme inadvertently worsened.

Such patterns of rapid oscillations in humidity have been reported previously in similar environments with attempted control of humidity by warming, with the conclusion that such buildings must be controlled by direct dehumidification (Padfield and Jensen 1990, Padfield 1996). The natural buffering provided by the building material and the thick walls create an unpredictable and uncontrollable



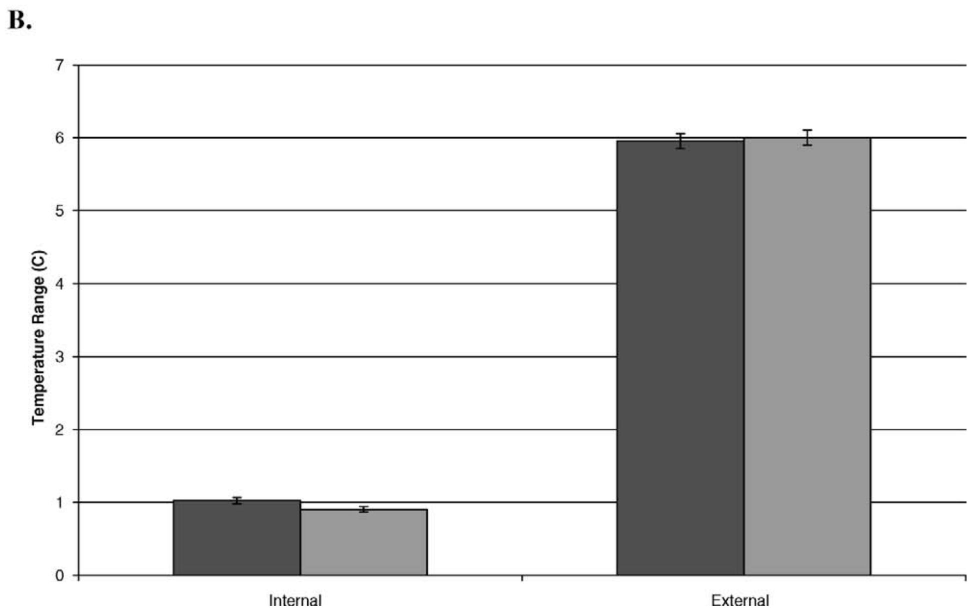


Figure 3. Comparison of average daily range (daily maximum minus daily minimum) for internal and external climate data during periods of non-intervention (left) and intervention (right); error bars represent plus or minus standard error. A. Relative humidity (%). B. Temperature (°C).

internal climate as the building responds to the external environment. The building materials in this case are probably the best regulator of humidity, as the natural porosity of limestone buffers internal humidity (Eshoj and Padfield 1993). However, we have noted that during a period of heating failure, in wet Irish winters, cold and wet conditions led to ‘‘rising damp’’ as groundwater seeped up into the stone wall bases of the building. It seems unlikely that in the absence of heating this could be practically controlled by dehumidification in the large space of this building. Therefore, controlling humidity by heating is essential. In light of these results, we have concluded that attempts to fine-tune the climate to affect the collection environment must be abandoned.

Footfall has increased over the whole study period, as the CoB*i*D partnership has increased accessibility of the collections to university researchers and students, as well as other scientific visitors. However, this access has been limited to very specific areas of the collection, and the rooms used do not all have monitor devices. Since this analysis reflects an average of readings across all monitors, all of which were subject to the climate intervention programme, the human traffic cannot account for the variability we find. In addition, human activity would be expected to increase internal relative humidity (Padfield 1999), yet we do not see such an increase in RH. Finally, user activity cannot account for the reduction in temperature fluctuations seen, one success of this intervention programme. It is clear that increased footfall has therefore not been a determining factor in the outcome of this study. Rather than being detrimental to the collections environment, we believe that increased traffic is of overall benefit, for example in improving our ability to monitor climate experientially if not experimentally in areas not covered by monitors.

Temperature changes within various rooms followed the same generalised patterns of oscillation on weekly, monthly and annual scales. However, diurnal fluctuations substantially varied in magnitude between rooms with individual monitors. This reflects the sensitivity of different room volumes, locations and response to external atmospheric influence, and not the success of staff intervention in localised spaces. Although a cursory inspection of data readouts may appear to correlate with daily building activities (e.g., fire doors being left open between rooms, electric lights being left on), it is clear that the larger-scale, external climate patterns are the only issue of importance; the effects of internal activities cannot be safely gauged in isolation. Rooms with relatively smaller volume are prone to heat up quickly from radiant heating on the outside wall of the building. The effects of black-painted steel plates covering 26 of the 100 windows are not known, but it is likely that they act as radiant heaters, especially on the south aspect of the building. Given the overwhelming effects of the external climate, the protocols of keeping doors closed and lights off in all rooms probably does not impact internal climate. Keeping individual rooms isolated by shutting all doors may not result in predictable climate, because of the building’s ‘‘leaky’’ architecture, and because individual radiators have been observed to spontaneously fail and start, as air-locks move through the closed-loop heating system. However, limiting the exchange of dust, and providing a potential barrier to fire are sufficient motivation for keeping doors shut in areas not involved in active work, and it is good practice to extinguish lights in areas not involved in work or foot traffic. We will maintain these policies during times when workers are not present.

Evapotranspiration rather than rainfall seems to determine external and thus internal humidity. This is unsurprising given that rainfall is more or less constant throughout the year in Ireland, while evapotranspiration shows a seasonal trend

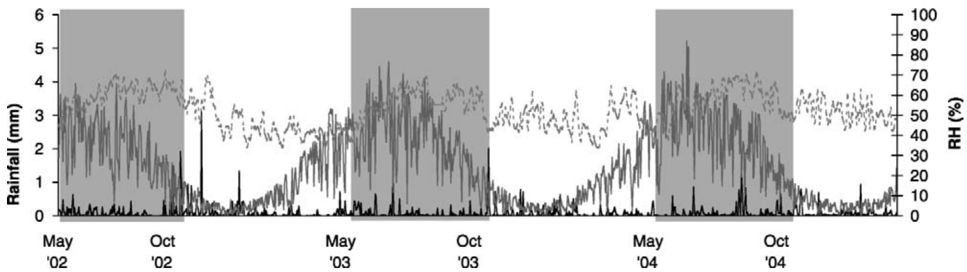


Figure 4. External climate data illustrating relationship between precipitation (black line, bottom), evapotranspiration (grey line), and external humidity (dashed line). Data are from the Irish National Meteorological Service (Met Éireann) climate monitoring stations in Dublin Airport, approximately 10 km northeast of the NMINH collection building. Shading indicates ''summer'' periods; unshaded regions are the ''winter'' periods, when internal conditions in the building (not shown) were subject to scheduled heating.

(Fig. 4). The period during which the building is heated (late October through mid-May) corresponds to the seasonally decreasing evapotranspiration phase of the winter. Heating is off during the increasing phase of summer and autumn. The urban setting of the building may be directly beneficial, as there is a relatively low density of vegetation surrounding it, which may result in lower local humidity. The environment, although far from ideal, is not dire. Low levels of seasonal fluctuations in the Irish climate mean that temperature and humidity regimes operate in a relatively narrow, sub-optimal band.

The importance of storage furniture in reducing the climatic fluctuations experienced by specimens was illustrated when one monitor was placed in a sealed drawer at a point during this study. The data from this monitor were not included in the building average, since the monitor was not subject to the same conditions as the other devices, but it is interesting to note that the buffering offered by the closed unit reduced climate fluctuations dramatically. A quantitative study to investigate this effect is currently underway. The specimens of *Megaloceros* mentioned above are currently stored on open shelving because of their size. However, these data provide additional motivation to acquire large-scale enclosed cabinetry to improve their local environment. Ensuring that specimens throughout the collections are maintained in sealed cabinetry that provides an additional envelope of protection, we can maintain adequate environmental standards for our collections.

Conclusions

In a poorly sealed building with inadequate levels of staffing, manual control of temperature in an effort to reduce fluctuations in humidity is an inefficient and ineffective use of human resources. The manual control of radiators as a means of controlling climate in this building was found to have less influence than fluctuations due to changes in weather. Furthermore, any changes caused by radiators may occur more slowly than diurnal fluctuations, thereby amplifying the fluctuations occurring over the course of the day. The natural architectural climate buffer offers the best protection to the collections housed in this building. The way forward in caring for collections in this building is through building modifications and at a small scale by using control of specimen microenvironments.

Intervention has made the storage environment measurably worse in the NMINH storage building. Without the ability to control climate differentially in different areas of the building, the natural tendencies of the environment must be the guide for usage decisions. Maintaining the rigorously low temperatures appropriate for some collections is not a universal solution, and is detrimental to the health and morale of visitors, workers, and volunteers. Human activities within the collections do not negatively impact the collections environment, and can be of active benefit to monitoring climate, as well as other conservation issues such as pest management. There is too much work to be done in this museum, to continue attempts to control an uncontrollable situation; time can be better spent on other duties.

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LEVELS OF IPM CONTROL: MATCHING CONDITIONS TO PERFORMANCE AND EFFORT

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Abstract.—A scale in order of increasing improvement of pest control is presented to cover a wide range of situations from 'no resistance to pests' to 'comprehensive control'. Seven levels of IPM control are developed from this scale and for each level there are subsequently described appropriate remedial integrated pest management (IPM) solutions to the more significant vulnerabilities. These are intended to be a good starting point for IPM planning or instruction. Threshold 'Plan B' details have also been identified for each level, so the user can achieve the basics first and look to improve standards in the future. The levels provide an important benchmark for assessing long-term movements up, down or within the scale of standards. A prognosis is given for each level, forecasting the course of pest infestation and estimating rates of deterioration, which are discussed for obdurate, robust, soft and delicate materials. This provides a useful framework during collections surveying for classifying risks to collections from pest activities.

Introduction

The basic concepts and strategies of IPM for museums are well described in recent literature (Åkerlund et al. 1998, Kigawa 1999, Kingsley et al. 2001, Pinniger 2001, Strang 1999). Basic pest management can be rationalized around five stages of control: avoid, block, detect, respond and recover (CCI 1994, Strang 1999). Yet we have many questions attached to real situations such as: ''Our building's seals are far from tight,'' ''We don't have any money for IPM this year,'' ''We don't have enough staff for activities beyond basic running of the museum,'' ''It is sitting outside because it is really big.''

These questions arise from institutions with differing qualities of building, staffing levels and budgets. To respond to inquiries, we must characterize the background situation before offering a helpful strategy. The answers are not mechanistic, clear-cut, or without risk of failure.

This paper models a breadth of situations from outdoor exposure to the inside of a perfectly sealed container within a modern collection preservation building. Readers can estimate which level is closest to their situation and use the progression as a prototype for designing IPM strategies with the simple goal of establishing a 'generally good level of protection' for each situation.

IPM Strategies

In developing an IPM workshop for collection managers, the authors wanted to establish a rough guide to IPM strategies that gave essential details. When people make changes to protect an object or collection, they should have assurance of what they will achieve or forestall. We called this approach 'Plan B' in jesting reference to the observation that we rarely get what we really want due to constraints such as time and money. When Plan B proves functional, other concerns can take the fore and Plan B becomes the operational norm. Plan B is tied to performance expectations of the level in which it is described, and incorporates appropriate elements from the previous lower levels of control.

The authors have long advocated IPM as a layered approach as it creates greater resilience against single point failure when protecting collections. While some features will stand out as highly significant, others reduce pressures and lower risk through their filtering effects against pest attraction, colonization, and uncontrolled growth. Pests are generally defined as deleterious fungi, insects, rodents, and other adventitious annoyances.

The recent Natural History Museum (London, UK) initiative to zone for IPM purposes, recognizes that not all portions of the very large area of their urban museum are sensitive to pest attack, so they developed a tiered 'level of concern' designation for different sections of the building (A. Doyle pers. comm.). Subdividing into regions of appropriate behaviour and response avoids having to impose unnecessary regimes on staff that may never get near a sensitive collection. Focus can then be placed on collections that are most vulnerable. However, their proposal relies on IPM being applied overall to reduce internal threats to the more sensitive zones (NHM 2006). As a result, over 420 staff were trained in basic IPM principles and practices (D. Pinniger and P. Ackery pers. comm.). This 'building as gradient' approach is tacit acknowledgement that an old large building will never be free of pests, but equally it acknowledges that with some vigilance, people make a significant positive difference. This is a similar approach to the consultative work of the authors, adapting the spectrum of IPM tools and approaches to what is reasonable for people to accomplish in a spectrum of individual situations.

Another method is to propose an IPM standard commensurate with a general situation. Standards should by nature be achievable and flexible enough to allow solutions that will show measurable prevention of pest damage.

Pest management strategies sometimes fall foul of several fallacies. If you have no pests it is not necessarily due to the system in place; you may just be lucky so far (pragmatic fallacy). Natural fluctuations in insect numbers can lead to a belief that changes made in the system are having an effect on the pest population (regressive fallacy). Post hoc reasoning, that one change caused another, can lack direct evidence. All this argues for controlled experimental measures for each IPM proposal. The advice given often follows other studies such as food safety engineering, (Imholte 1984) or efficacy studies like using bags as barriers to pests (Bry et al., 1972). Advice is also given using 'common sense' (e.g., beating carpets because insect eggs are fragile) or cultural practice (e.g., tight construction of cedar chests block pests with the cedar oil acting as a mild repellent).

A recent example of IPM moving into the area of standards is the April 2003 change to the Japanese statute governing the sanitation and environmental health in public buildings over 3000 square meters of floor space. By default this will include national and most prefectural museums. It can be considered a standard that increases the priority of IPM in the annual operation of these public spaces containing valuable items. The statute was amended to include the following:

1. Inspect the buildings for pest resistance, plan countermeasures for addressing the weaknesses.
2. Monitoring for pests at least semi-annually (instead of just routinely applying

chemicals) and when finding pests, cope with them using appropriate countermeasures.
3. In addition to routine cleaning, do thorough cleaning throughout the facilities twice a year. This cleaning must be done to inhibit or discourage pest inhabitation and activities.

Development of the Levels of Control

Living organisms respond to environments and are selective, or at least tolerant of conditions around them. The first step was to create a scale that reflects increments in environment generally associated with heritage objects that are progressively more resistant to debilitating pest problems. Groups of IPM details within each level were then established from a non-existent to an ideal contribution. In setting a standard, threshold details (things you should not be without) have to be identified, so the user can achieve the basics first and the niceties later.

Establishing levels started with endpoint calibration: 'no resistance' and 'comprehensive control'. These are relatively easy to see and immediately get the scale going. Setting the relative position of intermediate levels was more difficult but was done based on the previous experience of the authors.

Physical Barriers

The sizes of openings that allow pests to infiltrate are a dominant characteristic of the level designations. Level 0 is completely outside (opening is infinite). By adding a roof or tarpaulin (level 1) there may be some ineffectual protection against most pests. By levels 2 and 3, decimetre to centimetre sized openings dominate and centimetre to millimetre sized openings are characteristic of levels 4 to 6, with 7 being a hermetic or clean-room ideal. The concept of enclosure spans from outdoors, through buildings to sealed vials.

Intervention

No building stays pest free if left unattended with no cleaning or maintenance. Improving just the passive features can temporarily raise a situation a level, but can fail if a situation is ignored for too long. Invoking higher level detection and response procedures may significantly raise an institution's preservation level following the maxim of early detection, early cure. However, when the porosity of the structure and fittings greatly adds to the labour cost through increased incidence of pests, the attempt to control by strictly human intervention may ultimately fail. Appropriate structural changes would have been the more germane choice.

With the exception of parthenogenic insect pests, most animals have need of sexual reproduction, or social structure for their success. This can be turned into a weakness, using pheromone lures, and removing or poisoning nests. Fungi, insects, and rodents need oxygen to survive, although some microbes and insects can survive short-term anaerobic environments. Anaerobic burial environments can effect very long preservation times for soft organics, with some microbial induced change. Time and experience will determine if we develop a similar attitude toward any changes from deliberate anoxic storage such as those seen by Kenjo (1980) or Griesser et al. (2004) when it is used for IPM followed by long term protective storage.

Appendices 1a and 1b contain the scales in order of increasing improvement of pest control elements. These scales were then developed into the levels of control described in detail in Appendices 2a–f.

Quantification of Deterioration

In order to develop prognoses for the levels of control (Appendix 2), we chose to discuss four classes of material listed below. However, it must be remembered that these classes are not exclusive to a pest, but degrees of a scale. For example, a rodent will chew anything if it wishes to maintain its teeth. Obviously, pests are most debilitating when they destroy outright (e.g. rodents shredding textiles, dermestids consuming specimens) or compromise the integrity of difficult to restore objects (e.g. structural pests in buildings, fine furniture, ornate carvings). But there is a significant amount of damage needed to get to this endpoint and a continuum from the first bite to the last burp. How much are pest effects forestalled by the situation or IPM practice in the control levels? We have ventured some qualitative estimates in Appendix 2, modelling from our experiences.

Obdurate Items

Many mineral, stone, metal, and ceramic objects are obdurate. While recognizing there are some soft rocks and friable ceramics, which may be stained or damaged in outdoor locations, this class is relatively hard and unattractive to pests.

An example is vegetation on stone. Dissolution of a cubic millimetre of mineral in pH 5, 25°C water ranges from 0.6 years for calcite to 3.4×10^7 years for quartz (Drever 1994). In trying to model rates, biological activity is recognized as accelerative; for example, the calcite dissolution rate increases tenfold with each 1 pH decrease (Drever 1994), so a 10 to 100 fold acceleration is easily possible from biological source acidity on susceptible minerals. However, these rates are rarely quantified in situ and biological films are sometimes considered decelerating if not benign. Ivy vines shelter surfaces, but also cause severe disruption to masonry structures in a century once their roots mature. Surface dwelling (epilithic) lichens may shelter details from weathering for nearly two centuries compared to uncolonised areas while penetrating (endolithic) lichen damages stone. However, applicable rate data is sparse (Schaffer 1932). Centuries of survival in the face of biodeterioration is not uncommon.

Robust Items

But what is the baseline for survival for robust items like wood posts, plank built objects and framing? Probably the oldest wood buildings on earth still exposed in their original state are in the Horyu-ji complex built outside Nara, Japan in the 8th Century (ICOMOS 1993). Revered within a relatively stable religious environment, these have survived the threats of fire, earthquake, and warfare that claimed many other such structures. Similar incidence of longevity is seen in the stave-churches of Norway. The reported fire risk in cultural institutions in Canada is greater than 1% per year, with average damage per fire exceeding $800,000 (P. Baril pers. comm.). So one could propose these elderly structures are exhibiting a rough tenfold survival over the norm to significant non-biodeterioration hazards.

Termite attack is one of the most aggressive wood pest scenarios. Termite destruction rate is not a simple estimate and their local distribution is most important in assessing hazard (Edwards and Mill 1986). Based on measurement of 83 milligrams of wood consumed per 1000 *Reticulitermes flavipes* individuals per day (Haverty 1976) an average colony of a quarter of a million individuals consumes 38 cubic centimetres per day (Edwards and Mill 1986). From U.S. state surveys on termite attacks in 1975 to1980, crawl spaces increased risk by a factor of two to six times, and increased the likelihood of supporting dry wood termite species (Edwards and Mill 1986). Buried construction waste is also a high risk factor for termite attack.

Two areas of concern arise, biodeterioration threat to mechanical properties of structural timbers, and hazard to aesthetic elements (e.g. surface carving). Many strength properties are roughly proportional to wood density. Aesthetic integrity will depend roughly on how the surviving matter approximates its original shape.

Definitive microscopic evidence of decay is only visible upward from 5% to 10% mass loss; prior to that it is termed 'early stage decay' (Wilcox 1977). Wood toughness to withstand shock loading is most sensitive to this region of early decay with 50% loss of toughness by one percent mass loss, and 60% to 85% toughness loss by ten percent mass loss. Commonly, wood exhibits 50% loss of mechanical property by two percent loss of mass (static bending, impact bending strength) while axial compression (pole load bearing strength) is roughly halved by a nine percent mass loss due to brown rot, and axial tension strength is roughly halved by a two percent mass loss. White rot is less severe than brown rot up to a rough factor of two (Wilcox 1977) due to the lessened effect on cellulose fibre by white rot.

Biodeterioration of outdoor exposed untreated timber species has been extensively measured in Australia. Decaying to 95% mass loss (defined as "specimen life"), Mackensen et al. (2003) liberally defined service life as more than 60% to 75% loss of cross section (median specimen life compared to durability studies) for timber in ground contact and not infested with termites. While this is definition is counter to Wilcox's finding, Mackensen et al. are concerned with presence of wood waste on the forest floor (akin to a measure of survival of an object's form) not structural integrity under load. Lifespan for 76 species falls between seven and 373 years, with a median of 49 years, and average of 92 years. Temperature is a significant controlling factor, and very high rainfall prolonging lifetime through lumen saturation inhibition of fungal decay (Mackensen et al. 2003). From this picture we see that life beyond a century for exposed structural wood greatly depends on avoiding soil contact and maintenance of the sheltering roof, or burial in a waterlogged environment. For this reason we set the proposed biodeterioration survival of robust wood objects to be equivalent to the overall survival of the structure in which they are housed beyond the period of a century excepting wet-site archaeological materials.

Soft Items

Coarse natural fabrics (coir, hemp, bast), gourds, baskets and shelved books are easily attacked by aggressive insects like *Lasioderma serricorne.* Sheltered, their preservation is often better than loss to outdoor exposure (e.g., weeks for flower tissues, years for conifer needles). Wool fabrics and animal hides can be attacked by protein consuming pests. A flensed animal can be stripped to the bone by dermestid colonies in two to three hours (shrew), one to two days (opossum) or five to ten days (horse) (J. Jacobs pers. comm.). Even indigestible synthetic fabrics are vulnerable as rodent nesting material.

Delicate Items

The previous category could be the final one, but a further designation of delicate was desired to include such objects as distinct hairs on tiny animal specimens, insect specimens, fine botanical specimens, fine natural fabrics, fusuma-e, and Nihon-ga style paintings on paper and silk. These become prey to clothes moth, dermestids, silverfish and cockroach grazing. Vulnerability is greatly enhanced when the fabric of the object is closely matched by the size of the pest's mouth, this category was set as a warning of high vulnerability.

Conclusions

The scales and levels approach to IPM presented here (Appendices 1, 2) enable an institution to embark on self-assessment. Examining the corresponding levels and 'Plan B' improvements make the concepts of IPM accessible in a more relevant way for a broad range of situations. The impact of the changes made, through examining incident data, can then be assessed against this standard.

Moving from the matching description to Plan B is a possible 'standard' for action, while moving from level to level is a 'standard' for progression as collection facilities upgrade through time.

A prognosis is given for each level forecasting the course of pest infestation. Measured rates are discussed in this paper and mentioned where possible in Appendices 1 and 2, and we hope more will be forthcoming from the risk assessment approach now under way in the collections care profession (Waller 2003).

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Appendix 1A. Progressive scales of IPM components.

Column headings are activities, and structure concerns that affect IPM in collection facilities.

Level and situation	Examples	Environment	Site	Object condition	Food waste	Lighting	Plants	Sanitation
[0] Outside	Totem pole, farm machine	Local climate and weather	No modification	Infested	Strewn throughout interior and around exterior	Ambient natural or city lighting	Nearby flowering plants and deadwood sources of pest insects	No cleaning except by natural weathering and wind
[1] Roof, tarp	Shrines, under eaves	Sheltered from rain and sun	Possible elevation, roof drainage		Consolidated in open containers		Encroaching foliage cut back (reduce moisture damage)	Dry sweeping raises dusts but may damage insects
[2] Roof and walls	Temples, sheds, barns	Sheltered from some windblown dirt and snow	Simple foundation drainage	Cleaned	Consolidated in lidded containers	Some interior lighting	Cut back encroaching trees (reduce root damage)	Clutter provides harbourage interfering with inspection
[3] Basic habitation	Historic homes, churches, temples	Protected from weather, may have winter heating	Subterranean foundation drainage	Sanitary	Hauled away weekly from exterior containers	Few lights mounted on exterior	Avoid cut wild flowers or inspect for insects before bringing indoors	Household vacuum and damp mop to capture dust and insects
[4] Commercial adapted	Civic archives, private gallery	Climate controlled by HVAC to eliminate extremes		Disinfected	Removed daily from interior, hauled away weekly from exterior lidded container	Mandated security lighting over doors	Restrictive policy includes inspection, treatment or ban of high risk (primarily local cut wild flowers)	Clutter localized into designated workrooms

Appendix 1A. Continued.

Column headings are activities, and structure concerns that affect IPM in collection facilities.

Level and situation	Examples	Environment	Site	Object condition	Food waste	Lighting	Plants	Sanitation
[5] Purpose built	Provincial and national museums from last century	Climate controlled by HVAC to year round human occupancy requirements	Site wide flood water drainage		Exterior compactor (rodent proofed)	Low pest attraction lights (UV poor) on exterior	Nearby exterior: only non-flowering plants. Interior: only greenhouse cut-flowers or healthy house plants in sterilized soil	Built-in vacuum system (bag room) isolates dust and captured insects
[6] Preservation designed	Collection preservation centres	Climate controlled by HVAC to debilitate pests, yet meets object needs	Designed to manage 100 year weather extremes		Well sealed interior garbage room (cooled) to control rodent and insect access	Attractive light draws insects from exterior walls and openings, light traps near entrance ways		HEPA vacuum (portable units or built in filtration)
[7] Ultimate		Optimal for all objects		Sterile	No food waste production		No plants that can be utilized by pests	Clean room air supply

Appendix 1B. Progressive scales of IPM components (continued).

Level	Physical barrier	Physical resistance	Object enclosures	Object shelving	Detection	Maintenance	Suppression response	Recovery
[0]	No barriers to pests	Intrinsic	Intrinsic	Objects on ground	No inspection	No maintenance	Predators, disease, weather	No recovery, no accounting of cost
[1]	Structure may encourage bird roosting			May sit on plinths, pallets	Annual visitation	Replace roofing, replace tarp	Residual pesticide, fumigant application to entire collection	
[2]	Perforations may allow rats, birds access	Building sheathing easily infiltrated	Cardboard boxes	Gravel, concrete slab	Adventitious observation during use	Repair structural failures as found	Tactical pesticide application	
[3]	Perforations may allow mice access, window and door screens block insect access	Sheathing gnawed by rodents and insects	Chests, fabric bags, jars, dressers, cupboards, gaping cabinets	Pantry shelves, sit on wood floor, carpet	Daily familiarity, inspections associated with incidence	Repair exterior seal failures as found	Low temperature, easy to obtain (control moisture risk, refrigerant leak hazard)	Thorough cleaning after infestation is treated to reset for future inspection program
[4]	Perforations may allow large insects access	Some mineral sheathing less prone to rodent or insect attack	Sealed wood cabinets, adopted commercial display cases. Insect resistant bags (polyethylene)	Sealed wood or metal racking elevating objects from floor	Periodic inspection of exterior and interior. Incoming objects quarantined and visually inspected	Repair interior seal failures and interior building fabric to support preservation needs including pest exclusion	Controlled atmosphere fumigation, increases volume (assume high pressure gas supply hazard)	Managerial analysis of pest control problems. Accounting of basic capital and contract costs

Appendix 1B. Continued.

Level	Physical barrier	Physical resistance	Object enclosures	Object shelving	Detection	Maintenance	Suppression response	Recovery
[5]	Perforations may allow small insects access	Mineral or metal sheathing impedes rodents and insects	Some tight metal cabinets, rest wood with loose seals	Metal racking elevating objects from sealed concrete floor	Systematic use of rodent and insect traps to map problem areas, vulnerable objects inspected	Improve exterior building fabric to support preservation needs	Elevated temperature treatment, increases throughput (controlled incremental thermal aging above natural rate)	Make physical improvements through capital planning (passive features)
[6]	Perimeter control blocks insects (perimeter corridor increases detection)	Near seamless sheathing is resistant to rodent or insect attack	All metal cabinets, tight seals. Compactor system allows total floor cleaning	Compactor shelving	Sensitive collections visually inspected annually	Replace aging components before failure		Make procedural improvements (active features). Accounting of all internal labour costs
[7]	Hermetic	Metal can	All metal cabinets, vials, hermetic seals	High density, robotic retrieval warehousing	All objects visually inspected annually			

Appendix 2A. Level 0—Outdoors with unbridled access by deleterious agents.

Common circumstance	Plan B
Examples: Building exterior, totem pole, public sculpture.	
Site: Outdoors, rural or urban, may be sheltered by trees, buildings, landforms. May be well or poorly drained. May be windswept or sheltered. Urban sites are likely public spaces, rural sites may be remote with little visitation.	Some environmental modification may be considered if site is clearly deleterious: e.g., cutting back encroaching growth that physically disrupts, shelters pests, induces higher moisture content through casting shade, clinging vines that disfigure, obscure, present fire risk etc.
Building: No exterior enclosure, fully exposed to year round weathering, object sitting directly on ground.	There is considerable preservation justification for moving objects under shelter. If that is not possible, in situ techniques should be considered. Use bird netting or sheet material closures if the object is open to weather and collecting detritus or housing animals (e.g., large machinery, derelict buildings). Angled rain-caps used where possible to reduce roosting and bird detritus inducing rot (e.g., on pole tops, exposed beam ends).
Portable fittings: None.	Separate rot-prone objects from the soil they are resting on, use gravel, paved surfaces, a fungicide/insecticide treated wood shoring, short concrete plinth, or a self-draining moisture barrier (metal sheet fixture) to: reduce ground contact, slow fungal attack, force exposure of termite tubes to easy detection.
Procedure: None. Abandoned to fate.	Routinely remove grime, soil pockets (foundation for rapid biological activity), and all surface growths: lichen, mould, moss etc. Examine for insect infestations, especially wood borers that can lead to structural collapse. Likely use of residual pesticides or fungicides when warranted. Water-sealing wood to reduce moisture absorption is most effective on smooth surface, minimally weathered new wood. Deteriorated surfaces allow easy paths for water into the interior, supporting systemic fungal attack. All surface treatments need maintenance coats as the surface weathers. Borate fungicide and insecticide treatments are susceptible to water elution, but migrate effectively with moisture. Preservative fungicides and insecticides may colour surfaces unduly, test first. Subterranean portions near soil surface can be excavated, approved fungicide applied and surface drainage improved as the fastest attack generally occurs here (just above the water table, still oxygenated). Thank people for their contribution when they detect problems.
Prognosis: Maximum algal, fungal, rodent, and insect attack. Chronic bird and bat roosting. Systemic effects by all pests attacking the materials to which they are adapted to use.	Restrained algal, fungal, rodent, insect attack, and bird roosting. Surface to systemic effects still expected due to high exposure to the elements, but lowered extent of damage through detection and remediation.
Expected deterioration: Noticeable effect or damage in one season, as fast as to a dead tree, mammal, insect, or leaf. Colonization of obdurate items by algae, moss, fungi and plants in a few years. Forestalled effects showing in a few years for robust items, and a few days for delicate items. Self-sheltered parts of object will retain features as in level 1 (below) but eventually fail.	Noticeable effect or damage in one season. Forestalled effects showing within a decade for robust items, few days for delicate items. Self-sheltering parts of object will retain features as in level 1 but eventually fail.

Appendix 2B. Level 1—Roof or tarp only.

Provides basic shelter from rain and overhead sun, either from an architectural element, applied covering or self-sheltering part of the exposed object. Include appropriate elements from previous Plan B.

Common circumstance	Plan B
Examples: Poor enclosure in wind-way, car-port, shed-roof, tarpaulin cover.	
Site: Outdoors, rural or urban, may be windswept or sheltered by trees, buildings, landforms. May be well or poorly drained.	Some environmental modification may be considered if it is clearly deleterious. (e.g. cutting back encroaching growth that shelters pests, induces higher moisture content through casting shade, clinging vine cover that disfigures.) Eliminate obvious nearby pest attractors such as open garbage containers. Ensure roof closure is capable of rebuffing maximum snow and wind load.
Building: A roof or tarpaulin overhead with no complete wall. Structure protects from direct rainfall, preventing extensive fungal attack and limits any mould-requiring boring insect attack. However, structure will attract nesting birds, rodents, insects seeking shelter. Does not stop rodent, bird or insect access.	Roof must extend over the object to protect against slanting rain. Encapsulating with tarpaulins must allow ridge ventilation to protect against prolonged entrapment of high humidity which avoids making an inverted cup when enclosed to the ground. Bird netting, or spikes used where possible to reduce roosting detritus on rest of structure or sheltered objects. Coordinate construction of enclosing wire screens or cages with physical protection needs. Treat timber in soil contact with fungicides.
Portable fittings: None, contents of enclosure resting directly on earth, gravel or semi buried.	Where possible, separate objects from soil or gravel surface with a short plinth, or insert a moisture barrier to reduce moisture from contact with soil. Ensure the barrier drains properly so as not to cause a local puddle against the object.
Procedure: No pest control procedures other than beneficial contributions of original construction (e.g. mineral shingles, paint). Little site sanitation other than through wind and weathering processes.	Consider improvements in level 0 Plan B.
Prognosis: Rodent or bird contamination in one year, structural insect attack in under ten years, surface mildew within ten years. Many deleterious pests can still have widespread access to sheltered objects.	Noticeable extension in lifetime of smaller dimension timbers with remedial fungicide treatment, or break with soil, especially rapid deteriorating species. Reduction in disfiguring animal nests and some wood boring insects. Elimination of most structural fungal attack due to low moisture content of sheltered objects. Surface mildew, moss, lichen, algae still present as a risk in humid environments.
Expected deterioration: Noticeable effect or damage in one season. Forestalled effects showing within a decade to century for robust items, several years for soft, months for delicate. Self-sheltering parts of object will retain features as in level 2.	Noticeable extension in lifetime of timbers with remedial fungicide treatment. Several years for soft, months for delicate. Self-sheltering parts of object will retain features as in level 2.

Appendix 2C. Level 2—Roof, walls, and loose fitting doors.

This level provides more complete shelter from the elements. Contents may have exposure to wind driven rain, oblique sun, excessive wind and windblown soil, snow, spores and seeds. Include appropriate elements from previous levels.

Common circumstance	Plan B
Examples: Poor to fair enclosure: outbuilding, shed, poorly maintained house.	
Site: Commonly rural, sometimes urban. Drainage may have been improved by small rise in elevation under or against foundations. Subterranean foundation leaky. Structure may be sound if roof has been maintained, otherwise structural damage expected.	Where possible, clearing of vegetation away from walls to reduce moisture damage and root jacking of foundations. Removal of nearby dead timber to lower local incidence of wood boring pests and dead-fall hazards to structure. Improve drainage if ponding of water against foundation or inside is seen after any rainfall.
Building: Walls, wood, porous cladding, basic doors with gaps, floor of rammed earth, planks, plywood, gravel, asphalt, or separate concrete pad. Will not stop determined burrowing or gnawing pests as structural materials and wall construction is easily compromised. Protects against wind driven precipitation, thus halting major fungal attack. Does not bar insects due to gaps in structure. May limit large rodent and bird ingress but gaps let small animals take advantage of building as shelter. May attract roosting and nesting birds into eaves and insects into the building fabric.	Bird netting eaves or wire caging openings where possible to reduce animal ingress and subsequent detritus. Coordinate construction of enclosure with physical protection needs. Improve or fix exterior sheathing if it has been compromised.
Portable fittings: Contents resting on hard floor can become damp from permeating ground moisture and support fungi.	Rudimentary shelving limits moisture transfer from ground. Shelving lowers chance encounters with some pests. If appropriate shelving is not available, at least use preservative treated pallets, or wood wrapped in plastic sheeting to raise objects from earth contact. Large heavy items sited off the ground, resting securely on concrete pads, or baulks of treated timber.
Procedure: Animal nests removed, grounds-keeping around building consists of annual to monthly cutting back grass and foliage.	Routine sweeping of interior space to eliminate wind blown detritus and spider nests. Immediate removal of wasp nests, bird nests. Use fabric (moisture permeable) tarpaulins as drapes over complex, hard to clean objects, to reduce dust accumulation, block flies from spotting surfaces, and allow moisture permeation (drying) after humid periods and constrain surface mould.
Prognosis: Expect fly specks, rodent invasion, insects grazing, or crawling over stored materials, especially in cluttered, static, unexamined areas. Water-staining and possible fungal attack after heavy rain with winds. Pests have free range, so all contents can be affected.	Reduction in disfiguring animal nests, early remediation of pest attack by removal or targeted pesticide use.
Expected deterioration: Forestalled effects showing within a century for robust objects, decade for soft and year for delicate.	Reduction in frequency of many insect attacks compared to lesser sheltered situations. Minimum structural microbial activity, and greatly reduced surface activity.

Appendix 2D. Level 3—Basic Habitation.

Human housing with reasonable protection from climate, and coarse control of the interior environment with basic heating or ventilation. Include appropriate elements from previous levels.

Common circumstance	Plan B
Examples: Fair enclosure: western housing into last century, public buildings like churches, palaces. Average maintained historic civic buildings, temples, and shrines.	
Site: Garden landscapes, walkways, lanes, streets. Drainage to open ditches, roadways, rudimentary sewer.	Limit growth of trees and shrubs against structure to protect vulnerable foundations against root-jacking.
Building: Reasonable attempt at full enclosure from bad weather to make a liveable building with some comfort through annual climate cycle. Gaps generally small if building has basic heating, but exterior cladding may allow determined or intermittent rodent access. Has single doors for egress, loose fitting sash windows, possibly no screens. Internal partition walls exhibit crevices along floor that can house insect life. Open fireplaces, flues, hypocausts, rough attics allow bird, rodent and insect access into structural voids. Some natural ventilation is possible to alter interior temperature or humidity, but there is no air conditioning system.	Use of screen doors and windows to reduce insect ingress and allow ventilation. Reducing structural gaps and spaces around habitually used openings (doors, windows) to half a centimetre to limit rodents. Ensure eaves trough has outflow pipes to carry water well away from foundations, reducing mould. Screen unused flues at roof level to block bird and insect access. Use heavy gauge plastic sheet 'soil covers' over enclosed earth-floor crawl spaces. Ensure good screened ventilation of this space to further reduce humidity, otherwise wood structural piles are prone to fungal and insect attack.
Portable fittings: Exhibited objects are inside the building as originally used (historic interior), but other objects are stored in closed rooms on shelves, within open or gaping boxes. Some contents may be in cabinets for security, but insect resistance of enclosures is generally poor.	Place vulnerable objects in well sealed display or storage cabinets (gaps less than 0.1 mm to 0.3 mm). Consider portable dehumidifiers to restrict humidity under 75% in short damp season (i.e., two months), and under 65% in year-round high humidity climates. Consider using polyethylene bag enclosures (enclosed during dry season), or fabric covers for soft items in storage to reduce pest incidence. Delicate items placed in lidded boxes or cabinets.
Procedure: Spring and fall cleaning, household vacuuming, dusting of exhibits may also occur when build up of dirt noticed.	Do not place things in underground levels if you cannot ensure good ventilation and flood control. Animal inspection of attic and basement areas for severe pest problems, these are often more open and fulfilling of pest's needs than the inhabited floors.
Prognosis: Multiple rooms can be affected, chronic outbreaks of paper and fabric pests could be supported. Storage in damp basements or attics are a retrograde choice.	Lessened chronic fly and dermestid problems with increased control over attic space. Lessened silverfish and mouse problems with increased control over basement and crawl spaces.
Expected deterioration: Forestalled effects equivalent to building lifetime for robust objects, decades to century for soft and years for delicate.	Lessened rodent, insect and fungal damage with increased building closure and routine sanitation activity.

Appendix 2E. Level 4—Commercial adapted.

Adapted civic structures built to handle large scale inhabitation, industrial process, project social status. Include appropriate elements from previous levels.

Common circumstance	Plan B
Examples: Good enclosure: basic professional, commercial, or civic building adapted to museum archive or gallery use.	
Site: Drainage ensured close to foundation walls, but overall site may not yet be adapted to 100 year weather extreme, or is affected by adverse elements from neighbouring properties (strong attractors).	Consider flood hazard and rodent habitat reduction in site development planning.
Building: Commonly has a mineral exterior surface. Has multiple doors to stage egress to the exterior, a mudroom, or a divided entrance hall. Single layer of doors such as emergency exits are sealed tightly against pests with brush strips, rubber blades, rodent proof metal doors. Structure has HVAC system for air conditioning, heating, forced air movement.	Improve sealing of doors, windows, and other perforations, to prevent pest access. Interior partitions should be improved to limit rodent travel through reduced gaps under doors and screening accessible perforations.
Portable fittings: Exterior garbage bins or designed loading bay garbage collection area (bay is inside one exterior door, but has a well fitting inner door to cut it off from corridor). More extensive use of display cabinets, may not all be insect proof, but greatly lower incidence of insect infiltration. All collections on shelving, or palletized. May not have easy access throughout storeroom for pest inspections due to over-crowding. Hallways also used as overflow storage.	Create an enclosed space for quarantine of incoming goods, artefacts and for disinfestation treatments of new acquisitions. Obtain chest freezer, cool fumigation bubble or nitrogen treatment chamber and train several staff in proper and safe use complying with regulations. Include inspection needs in collection rehousing activities.
Procedures: Basic visual inspection of collection from familiarity through use, few traps used in areas with major exterior openings. Annual storage room sanitation limited to vacuuming, but only in corridor spaces, not under lower shelves. Gallery cleaning more frequent, but does not keep up with dust, litter, hair, etc. that is depositing in restricted spaces.	Annual cleaning reduce clutter, vacuum under shelving, view rarely accessed collections. Quarantine and eradicate pests before objects introduced to collections. With an established IPM program and low internal pest incidence, new collections are the highest risk for introducing infestation, along with used packaging and food service activities. Disposing garbage (especially foods) on a daily basis and immediately clean spills. Contract pest control operator (PCO) for public food areas. PCO activity in collection areas only if heavily infested and needing remedial action (baseboard sprays only, avoid area fumigation or pesticide application to objects). Trapping program to detect pests. With reasonably tight enclosure of the building trapping will tell more about what is going on in collections than what is crawling through the building that day.

Appendix 2E. Level 4—Continued.

Adapted civic structures built to handle large scale inhabitation, industrial process, project social status. Include appropriate elements from previous levels.	
Common circumstance	Plan B
Prognosis: Expect local outbreaks of pests, derived from importing pests with objects more than from building infiltrations, less chance of rodent damage, more from insects.	Reduction in chronic textile, fur and skin pests. Annual levels may be chronic but should become low in incidence and severity.
Expected deterioration: Forestalled effects equivalent to building for robust, century for soft, and decades for delicate.	Less frequent infestation by insects than previous level.

Appendix 2F. Level 5—Purpose built.

Designed as museum, gallery, or archive with increased planning that integrates policies and features to include pest control with control of other deteriorating agents. Include appropriate elements from previous levels.

Common circumstance	Plan B
Examples: Purposely designed as museum, archive, or gallery. Improved enclosure for preservation requirements, enhanced commercial construction.	
Site: Site planning includes perimeter control of neighbouring risks, through environmental modification (e.g., creation of buffer zones, controlled ponding of water and pruning of dense foliage to lower fire hazard.)	
Building: Designed with consideration for pest control such as fumigation room to support freezers, controlled atmosphere chamber and quarantine needs. Smooth flooring, coved junctions to walls for easy sanitation. Light coloured finishes and good lighting to assist detection. Pest resistant exterior wall materials and reduction of crevices in construction to lower HVAC losses and reduce wall moisture issues.	Crevices discovered to be housing insects are remedially caulked with appropriate sealant. Exterior window seals maintained promptly to exclude wall moisture risk, and improvements made in sealing of all exterior doors as flawed installation is discovered or materials fail. Improve HVAC filtration to ''MERV 9'' to eliminate mould spore and pollen transport via HVAC system.
Portable fittings: Intensive use of protective cabinets increases need for planned visual inspection. Many objects not regularly seen so there is a delay in finding outbreaks without deliberate inspection. Little consideration taken for cleaning underneath displays over the long term of a static gallery's life, high traffic brings accumulating littler, some of which can support pest life. Enclosed exhibits constructed to a level of tightness that excludes insects (0.1 mm to 0.3 mm). Possesses fumigation capability either as toxic gas, controlled atmosphere, or walk-in freezers (−25°C to −30°C) of sufficient size to handle routine volumes of artifacts.	Extensive gallery and modern exhibit techniques will have lots of pest hiding places adjacent to visitor traffic, so consider reducing this long term hazard through designed ease of access. Prompt removal of food garbage, which should all be in closed containers and emptied daily to reduce support for mice.

Appendix 2F. Level 5—Continued.

Designed as museum, gallery, or archive with increased planning that integrates policies and features to include pest control with control of other deteriorating agents. Include appropriate elements from previous levels.

Common circumstance	Plan B
Procedure: Comprehensive trapping for insect detection with adhesive traps, bird proofing of structure. Will have commercial PCO for on-site restaurant. Permanent cleaning staff and security not trained in IPM concerns. All new acquisitions subject to quarantine, inspection, and pest eradication processes. International loans of objects must not include packaging that is in contravention of current import/export restrictions to limit the spread of wood pests, use only certified use wood (heat treated).	In larger institutions consider using a zoned IPM system to emphasize most vulnerable areas needing special precautions and protection against pests. Annual visual inspection of most sensitive and valuable objects. Give all permanent staff basic IPM training to sensitize them to pest problems and methods. Elevated degree of store room sanitation recognized as pest reduction activity. Annual cleaning of non-traffic areas including under-shelf spaces in storage rooms.
Prognosis: Sporadic outbreaks associated with non-collections areas and events. Older storage cabinets may continue to show higher incidence of infestation due to their porous structure, and pests living within monolith arrangements of cabinets.	Sporadic pest problems with new collections and returning loans.
Expected deterioration: Forestalled events equivalent for robust and soft objects, century for delicate.	Same as left or less frequency of sporadic issues due to early intervention and effective remediation.

Appendix 2G. Level 6—Preservation designed.

Collections facility with primary function of long term preservation. Provides excellent enclosure, with multiple-layers to intercept routine hazards and engineered to reduce calamities. Include appropriate elements from previous level.

Common circumstance	Plan B
Examples: Purpose-designed preservation enclosure; full spectrum of pest reducing features incorporated such as cool temperature herbarium collection building, refrigerated ethnographic fur storage room, extensive use of tightly sealed cabinetry for all collections.	
Site: Preparation conforms with need to fully manage expected 100 year weather extremes. Exterior plantings controlled, sanitary perimeter managed as Level 0, plan B. Use food processing plant techniques such as gravel borders on geo-textile to lower rodent pressure (see Imholte 1984). Manage exterior wall under protective eaves as Level 1 plan B.	
Building: Design process based on collection preservation needs. Construction phase monitored by people cognizant of collection needs. Perimeter corridor buffers storerooms. Poured concrete, slab/wall junctions sealed and maintained. Separate storage from high human occupancy operations. Floor sweep on interior doors restricts insect motion. Pipe and wiring chases minimize wall perforations, holes sealed with appropriate means to retain room to room quarantine. Built-in vacuum limits dust redeposition, or portable HEPA units used. Tightly sealed cabinets throughout. HVAC designed to eliminate particulate contaminants and reduce chemical pollutants if there is significant storage on open shelving lowers mould spore loading. Pest control facility near loading bay provides quarantine and treatment including sufficient room to store exhibit packaging. Cooled food waste and garbage storeroom.	Well filtered HVAC (MERV 13+) to eliminate particulate contaminants including dust mite faeces. Plan cool room storage to inhibit insect motion and lower chemical deterioration rate (e.g., rooms at 15 degrees C). Requires careful design and commitment to maintenance and energy use. Construction project managed with strict control of details such as vapour barriers due to high performance expectations of the building envelope. Structure and contents disinfested prior to occupation, requires coordination of pest control operations in collection move phase.

Appendix 2G. Level 6—Continued.

Collections facility with primary function of long term preservation. Provides excellent enclosure, with multiple-layers to intercept routine hazards and engineered to reduce calamities. Include appropriate elements from previous level.

Common circumstance	Plan B
Portable fittings: Light traps to draw insects out of loading bay. Bird curtains or shrouds connected to truck trailers block most pest access when doors are open. Appropriate system (−20 degrees C to −30 degrees C freezer, controlled atmosphere fumigation, heat chamber) for eradicating infestation of new acquisitions.	Cabinet integrity protected with annual inspection and maintenance plan. Near hermetic storage (e.g., film canisters) can be used for most valuable and vulnerable items in long term storage. All disinfested object sealed in pest resistant enclosures, possibly refrigerated, possibly with altered storage atmosphere. Walk-in storage freezers with redundant power supply used for routine pest control.
Procedure: Structural flaws promptly maintained, harbourage caulked. Routine trapping near openings of each room and vulnerable collections databased and mapped for long term analysis. Annual visual inspection of susceptible collections. For human comfort temperature storage: contents sanitized, sterilized, fumigated, cleaned before being hermetically sealed or deposited in tight pest resistant containers. Bagged, vials, boxed artifacts all placed in pest resistant cabinets. Visual inspections to confirm integrity of seals, and absence of pests on annual basis. For refrigerated storage: all contents prepared sealed against refrigeration failure and moisture movement, have recovery plan for mechanical failure. Train new staff in IPM policies and methods. Maintain work relationships through IPM committee and informal connections with staff who encounter pests (security, maintenance, food services).	
Prognosis: Few pest issues in storage environment, more found by floor trapping than cabinet visual inspection. Incidental pests in gallery spaces due to human traffic and food service.	Sporadic pest problem, mostly with new collections and returning loans.
Expected deterioration: Forestalled events equivalent to structure for robust to delicate objects. Long term object survival tied to cultural survival (available energy or interest remains).	

JAPANESE TISSUES: USES IN REPAIRING NATURAL SCIENCE SPECIMENS

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Abstract.—Japanese tissues are widely used by conservators, especially those who work with paper. Until recently Natural Science conservators have not used them. This article shows how they can be used to create tidy, effective, strong repairs and gap fills for the repair of taxidermy specimens. Guidelines are provided for their use with examples shown of repairs to mounted birds and fishes, Lepidoptera and molluscs.

INTRODUCTION

There are three principal shrub-like plants used in the manufacture of Japanese tissues*: Kozo, Mitsumata* and *Gampi.* These plants are grown, harvested and processed in small villages in provinces after which the tissues are named. The fibres in the bark are exceptionally long and strong which gives the tissues their characteristic strength. Additives such as powdered shell and clay can result in some lengthy compound names for some of these tissues. The pulp from these plants is skilfully agitated and laid, using the finest of purpose-made wicker baskets, aligning as much of the fibre as possible and creating tissues of varying grades and weights, expressed as grams per square metre (gsm). The basket-layering process aligns most of the plant fibres (Fig. 1a) and the paper is extremely strong. The critical tearing mass (breaking strain across the grain) of a 1 cm wide length

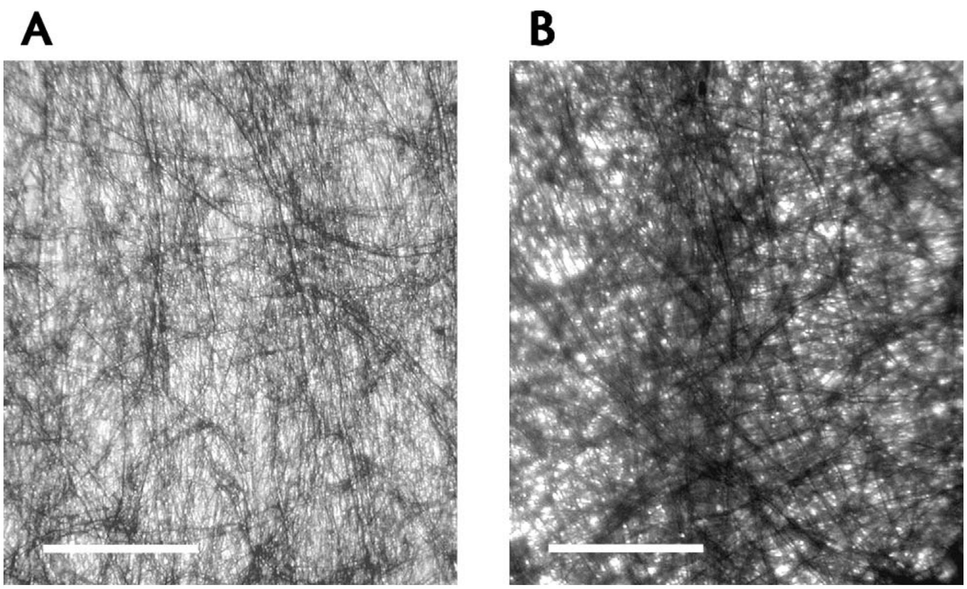

Figure 1. a. Traditionally-made 9 gsm (grams per square metre) Gampi tissue. Note how most of the fibres are in the same alignment. b. Mass-produced Philippine 20 gsm Gampi tissue. The fibres are randomly aligned and give much less strength *pro-rata.* Magnification of both papers × 360.

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Table 1. Dry tissue strength.

Tissue type	Weight (gsm)	Breaking mass (g)
Acid-free wrapping	9.85	346
Gampi	9	2,015
Gampi (sulphite-free Silk tissue)	10	1,845
Gampi	14	2,544
Philippine Gampi	20	2,620
Sekishi Kozo	15	4,580
Kozo	12.25	5,705
Usumino Kozo	8.5	3,960

of 9 gsm Gampi, one of the thinnest papers, is an amazing 2.015 kilograms (Table 1). The paper can also be torn by hand in a perfectly straight line along the grain. These handmade papers are produced by a traditional craft industry that has been active for centuries, with some papers existing that are 1,200 years old. Unfortunately the next generation is less interested in such tradition so the craft is gradually being subsumed by mass production of inferior tissues from Thailand and the Philippines. Although cheaper, these do not possess the same physical properties as the more expensive but superior hand-laid papers. Holding a sheet of poorer quality paper up to the light reveals undesirable knots of fibres, unwanted particles of plant material and a poorly aligned grain structure (Fig. 1b). Although a single large sheet of traditionally made paper (1,400 × 915 mm) can cost £16, a great many repairs can be made using the one sheet. Used extensively in paper conservation (e.g., Walker 1991) for their combination of fineness and strength, Japanese tissues have a place in taxidermy conservation and have already spread into other areas of natural science conservation. This paper shows examples of how these tissues have been used to repair birds, fishes, Lepidoptera and molluscs.

Advantages of Using Japanese Tissues

A strong tissue (Table 1), whose structure does not break down into a tangle of fibres when wet or in contact with an aqueous adhesive, is ideal for all sorts of repair work. The tissue and adhesive act as a strong and stable bridge between the preserved protein/amino acids or cellulose-based structure of animal or plant tissue without forming any sort of irreversible molecular cross-linkage since the composition of both the bridge and the damaged tissues are chemically incompatible. The adhesive must penetrate deeply into the tissue, so must be quite fluid, fairly slow-setting and should have a neutral pH. Neutral pH PVA is used in this context and bonds strongly with the micro-fibrous surface of the tissue.

Japanese tissue can also be used as a gap-fill, replacing more traditional resin fills that could either compromise the proteinaceous tissues to be joined or were irreversible. The adhesive join is reversible using warm water. These paper gap-fills can either be used as a simple surface cover that can be textured with a sharp point before painting, or as a deeper level fill. The resulting fill is similar to *papier-mâché* but has a harder finish, which is also advantageous as it can be textured to blend in with surrounding tissues.

Figure 2. a. Damaged kingfisher feathers, from a historic specimen, mounted, barb-by-barb, onto 9 gsm Gampi tissue. b. Feather patched with strips of tissue, which will adopt the natural curvature of the feather.

General Tips for Using Japanese Tissues

If repairs are going to be visible, ensure that all strips of tissue are torn and not cut. This is because straight cut edges can still be seen even if subsequently painted. Heavier weights of tissue provide stronger joins but need to be well moistened with adhesive. Heavier tissues are also better for internal repairs. Each fill layer should be no more than 3mm thick or the process becomes difficult to manage. Lighter tissues will start to curl as soon as they become moist. If this effect is undesirable ensure that at least part of the tissue is held flat under a small sheet of glass.

Examples of Applications

Bird Feathers

Applications include rebuilding pest-shredded bird feathers and re-mounting detached bird feathers (Fig. 2). Bird feather re-building requires time and patience and is only carried out on specimens of great rarity or importance. The process is outlined below:

1. Barbs need to be graded, using a low-power microscope and kept in a draught

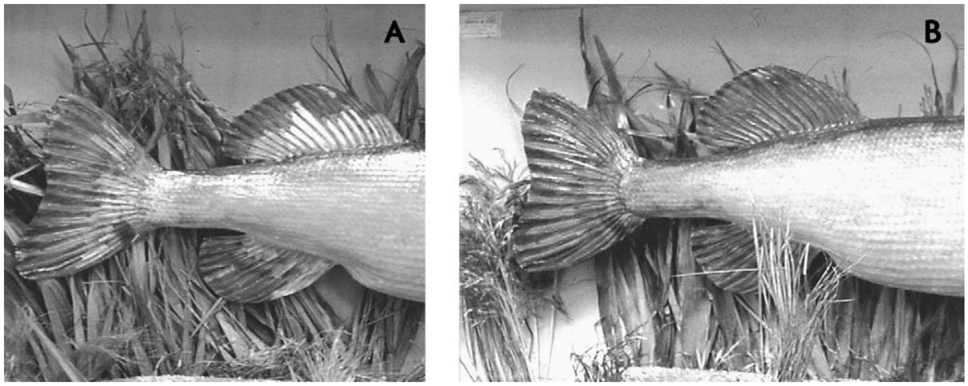

Figure 3. a. The fins of a pike have been partly eaten away by larvae of the varied carpet beetle *Anthrenus verbasci.* Fins lined with 14 gsm Kozo tissue applied as torn strips and adhered to the rear side of fins. Neutral pH PVA painted onto both sides of the tissue infill dries to a consistency similar to fish skin. b. The tissue gap-fills have been painted and lacquered with shellac.

free, lidded container. An airtight container will cause a small internal draught each time the lid is removed.

2. The barbs are then individually glued, using a tiny amount of 50% PVA (diluted in deionised water) onto a strip of 9 gsm Gampi (Fig. 2a). The adhesive is applied using an eyelash glued onto a small glass rod. Ensure that the tissue is partly placed under a strip of 2–3mm glass to prevent it from curling as it comes into contact with the water-based adhesive. Should the barbs adhere to the glass, this adhesion can be broken later using a wedge-shaped scalpel blade (Swann-Morton No. 25).
3. After about 15 minutes the next barb can be glued.
4. Before replacement, the re-built feather may lie rather flat. Brushing a small amount of deionised water onto the back of the tissue will help the feather regain its natural curvature (Fig. 2b).
5. Once the feather has been rebuilt, the shaft base is wrapped in some tissue with PVA to increase the surface area of adhesion. Shaft bases are often brittle and this obviates recurrence of feather drop. Where the bird skin has been eaten away by *Anthrenus* or other pest larvae, Japanese tissue can be used as a replacement skin with feathers added to it in swatches.

Fish Mount Fins

Fish fins are often prone to being attacked by pest larvae resulting in unsightly holes. If the relative humidity level of the storage or display area falls below 45% then fins and skin can start to split and crack. Japanese tissue provides a suitable strong, yet aesthetic, medium for gap filling (Fig. 3).

Lepidopteran Wings

Stored and displayed insect specimens are also prone to pest infestation and ensuing damage. If the damage is not total, 9 gsm Gampi tissue provides a lightweight but strong enough backing that can be painted if necessary (Fig. 4). Some skill is required since the specimen is fragile and will not allow for a ‘second chance’ should the first paper application fail. The Gampi is torn to the correct

Figure 4. Gampi (9 gsm) has been used beneath the lower left wing to repair this Swallowtail butterfly.

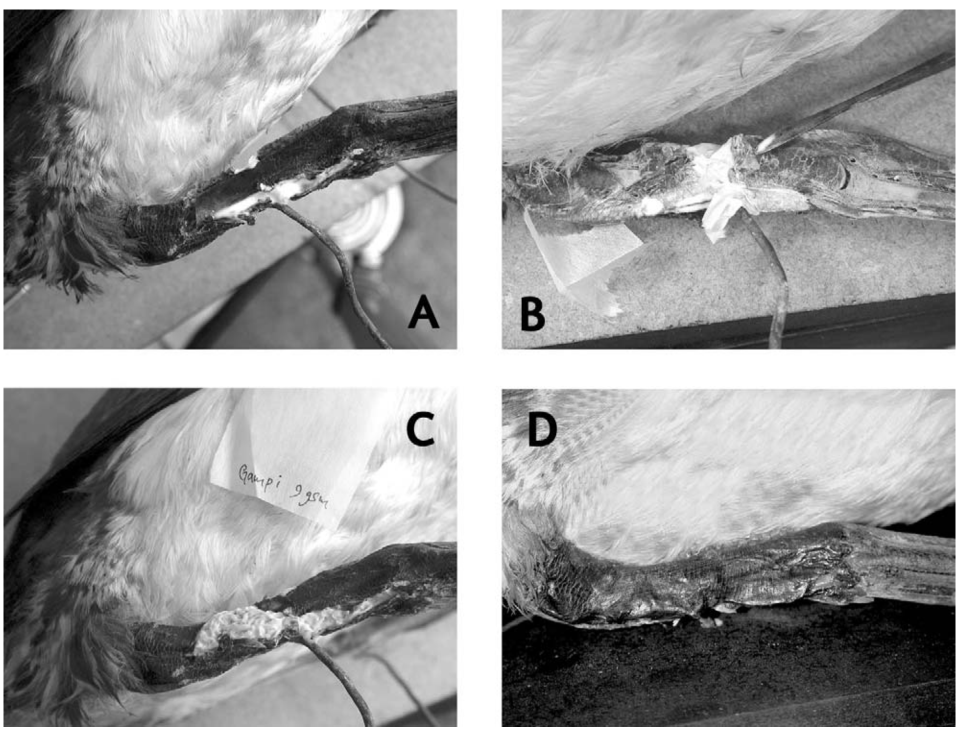

Figure 5. a. Multiple fractures to the right leg of a little grebe. The bone is re-aligned and glued into place. b. Adhesive-impregnated tissue plug is tucked into place. c. The plug surface is deckled with a spatula point. D. Once dry, the gap-fill is textured using a sharp point and lacquered with shellac. The adhesive and tissue have become like a new skin layer as well as providing a strong join.

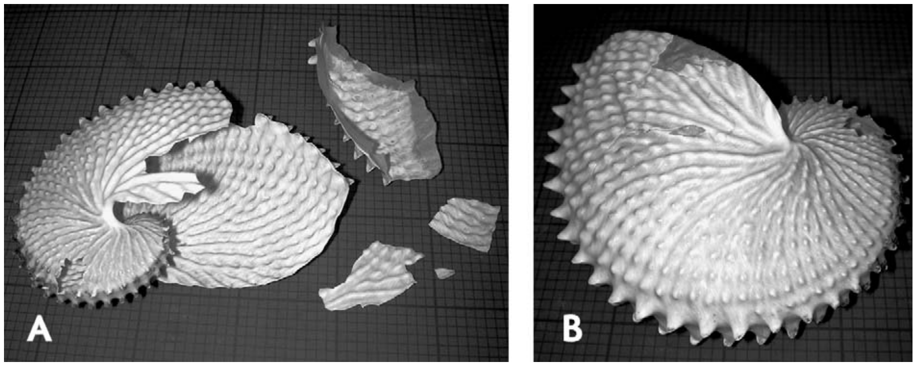

Figure 6. a. Broken *Argonauta* (paper nautilus) shell. b. The shell has almost been repaired and the internal lining of the tissue is visible. The repair is so strong that the shell is currently being used in the handling collection at Basildon Park (UK National Trust).

size and held across the join with fine forceps. A small amount of PVA is brushed onto the attachment surface of the paper and the paper immediately applied to the wing before it can start to curl. It is brushed down onto the wing using a small camelhair brush. The other half of the tissue is similarly coated with glue and brushed into place. Once dry, the tissue can be painted if required.

Gap Fills

With surface gap-fills, the strips of tissue must be torn along the grain so that the edges will blend into the background. Textured gap-fills require the Japanese tissue to be coated in adhesive beforehand, so that it can be folded in on itself. The folded plug of tissue is then inserted, shaped and the surface moistened with neutral pH PVA. After about 20 minutes the surface can then be deckled or textured using a pointed spatula until the desired effect is achieved (Fig. 5). Various types and gsm grades of tissue can be used for this work depending on the area to be covered and the type of animal tissue. Always experiment with a small piece of tissue first if you are unsure, even though the process is reversible.

Mollusc Shells

The tissue acts as a bridge between the thin edges of the paper nautilus shell and forms a reinforcing plate internally so that the shell can be more safely handled (Fig. 6).

Conclusions

Japanese tissues are an effective medium to support and strengthen adhesive-protein joints for a wide range of deteriorated taxidermy and other natural science specimens, including birds and fishes, mollusc shells and lepidoptera. Although not covered in this paper, they have potential for the repair of damaged herbarium specimens and other natural history objects. The range of weights and tissue types means that they are versatile materials for natural science conservation repair work. As with all repair media, knowledge of their composition and their possible limitations (ageing, possible discolouration, breaking strain) is useful. Practise with use of these tissues is recommended before attempting any delicate repairs.

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THE EFFECTS OF TANNING AND FIXING PROCESSES ON THE PROPERTIES OF TAXIDERMY SKINS

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Abstract.—The effect of different tanning and fixing processes on the mechanical properties of taxidermy skins was investigated using a screw driven tensile machine. Tanning treatments were potash alum powder, salt and a bath (salt, potash alum, and water) used at the Muséum National d'Histoire Naturelle in Paris. Fixing was with formalin or alcohols (methanol, ethanol, and 2-propanol). Stress vs strain plots using results from air-dried skin as control show that air dried skins are least flexible, squirrel skins are significantly stiffer than deer skins but that all the skins tested show elastic properties, except skins fixed in formalin. The MNHN bath produces stronger and more flexible treatments than using potash alum or salt powder on their own. There were no significant differences between ethanol and 2-propanol treated skins at similar concentrations but methanol, ethanol and 2-propanol have increasing flexibility. Increasing ethanol concentration makes the skin more flexible. Even small amounts of formalin increase flexibility and large amounts of formalin are not needed to make a useful skin for taxidermy. Differences of bonding between collagen fibers in the skins account for the differing mechanical properties and suggest ethanol is better than formaldehyde for future preparations. Knowledge of preparation technique is vital when considering future conservation strategies.

INTRODUCTION

In taxidermy, the first step is to treat the skin as soon as possible before it deteriorates after animal death, with tanning the most widely used technique. It can be performed with either vegetable tannins or minerals. Some of these treatments such as tanning with arsenical soap, potash alum, salt (sodium chloride) or chromium compounds, proved popular. Another method to preserve skin of any degradation is to fix it. According to Stoddard (1989), fixation is the first preparation step in the preparation of wet collections to arrest the physical and chemical changes that could appear after death. The most common fixative is formalin, a mixture of water and 37% formaldehyde by weight. Alcohols such as ethanol or propanol have also been employed to fix vertebrate specimens. Since the 18th century, over 140 preservation treatments for mammalian taxidermy collections have been described (Williams and Hawks 1987, Péquignot 2002). The effects of these treatments on the elasticity and flexibility of skin were not known except that they helped to preserve the specimen. During taxidermy, after skins have been tanned or fixed, they undergo some stress during the stuffing and mounting on the mannequin. The elasticity and flexibility of skin is vital during this process and also when mounted skins are removed and stuffed as study skins and *vice versa.* Flexibility is also important when wet and fixed specimens are mounted or stuffed in dry conditions. Ageing taxidermy mounts in damp environments may cause skin to shrink and tear. Hanacziwskyj et al. (1991) studied the effects of tanning on the strength, stiffness or flexibility, and elastic or plastic properties of skin. This paper looks at the same properties but compares tanning with a number of different fixing processes.

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MATERIALS AND METHODS

Samples and Preparation

Fresh squirrel and deer skins were stored frozen. Before treatment, the skins were cleaned, fleshed and washed with soap, and then cut into 1.5 cm × 15 cm strips for tensile testing. The cutting was done on the underside of the skin where the Langer's lines (lines of tension within the animal skin) are parallel to the length of the skin in order to standardize the results of the tensile tests. Each skin strip was subjected to a treatment described below and then laid out flat and allowed to dry at room temperature. From the many potential preservation treatments, we selected the ''basic'' and the most common treatments used during the long history of taxidermy. The aim was to simulate many past and possibly current treatments of skins.

Air Dried Skin

Air-drying is one of the oldest methods used by taxidermists to prepare skins for natural history collections. Réaumur (1748) and Mauduit de la Varenne (1773) used the ''méthode du four'' (oven method) or sun drying which also killed any pests present. In our experiment, the skin received no chemical treatment and was dried at room temperature in desiccators containing thymol crystals to prevent any bacterial or fungal activity. The dried skin acted as a ''control'' in our tensile tests.

Mineral Tanning (Salt, Potash Alum, and MNHN Bath)

Salt (NaCl) and potash alum ($KAl(S0_4)_2.12(H_2O)$) have been used in taxidermy since the 17th century to tan skins and to preserve small to medium mammal skins in natural history museums (Kuckhan 1770). In two separate treatments, salt or potash alum in powdered form was applied to both sides of the skin. The skin was completely covered and then allowed to dry at room temperature. Since the 19th century, the Muséum National d'Histoire Naturelle in Paris (MNHM) has used a tanning bath of salt and potash alum. This has been a successful procedure for tanning small and medium sized mammals such as rats, wolves and dogs. A solution was made by dissolving 5.5 mg of sodium chloride and 11.11 mg of potash alum per 100ml distilled water.

Protein-denaturing Agents (Methanol, Ethanol, and 2-propanol)

Methanol, ethanol, and 2-propanol are generally the only alcohols that have been employed as pseudo-fixatives to preserve specimens. By the 17th century, European naturalists used ''spirit'' or ''spirit of wine'' to fix and preserve vertebrate skins (Boyle 1665, Davies 1770, Réaumur 1748). At present, museums use 70% ethanol (C_2H_5OH) as a fixative in the field or before any other wet preservation. Ethanol (70%) is well known to kill bacteria, and is used when the recovery of DNA, RNA, and protein in wet skin collections is required. Some other museums prefer to use 60% to75% 2-propanol (iso-propanol, C_3H_7OH). In this study, skins were soaked in 100ml of solution before examination. The following solutions were used on separate deer skins: 70% methanol; ethanol at 70%, 75%, and 100%; and 2-propanol at 70 % and 75%. Both squirrel and deer skins were treated with 70% ethanol.

Aldehyde (Formalin)

Formaldehyde (also known as methanal) is a gas that is very soluble in water at room temperature. It is commonly sold as a 37% solution in water with a little methyl alcohol to prevent any polymerisation, and called by the trade name Formalin. For the last 100 years it has been the most widely used fixative in museums to preserve vertebrate and invertebrate wet collections. This method has associated health and safety problems and is no longer used in the natural history museum community (Carter and Walker 1999). Solutions of 1%, 5% and 10% formalin (ten percent formalin was prepared by adding 10 ml 37% formaldehyde to 90ml distilled water) were used for three separate treatments.

Tensile Testing

After chemical treatment for four days, the samples were dried at 22°C and ambient relative humidity for two days and then stabilized at 45% relative humidity and 22°C for three days. The skins were not de-haired so they could remain in a condition typical of a museum taxidermy specimen. All tests were conducted in chambers that provided a controlled temperature (20°C) and relative humidity (45–50%). Conditioned silica gel was used to maintain a buffered environment. Mechanical testing was performed using the screw driven tensile machine described by Mecklenburg and Tumosa (1991). Tensile tests were performed to stretch the strips of skin. Every 30 seconds a small increment of tension was applied so that there was time for the test skin to equilibrate and for the strain output and the force applied to be measured. The skins were not stretched to failure, as these are not normal conditions for taxidermy specimens. The experiment was stopped before the strain indicator on the screw driven tensile machine read 3500–4000 "strain units."

The mechanical properties of materials can be defined by different parameters. For example, stiffness is related to the amount of deformation (δ) (the stretched length L, minus the unstretched L_0), that a material undergoes when it is subjected to a force (F). To get around the problem of comparing the mechanical properties of different samples, the mechanical properties were "normalized" by dividing the specimen deformation (δ) by the unstretched $L_{0.}$ This is defined as the strain (ε).

$$\varepsilon = (L - L_0)/L_0 = \delta/L_0$$

The stress (σ) is the measurement of the intensity of force per unit area and is defined as:

$$\sigma = F/A$$

where the force (F) is the tensile force applied and (A) is the cross-sectional area measured of the skin. The data were plotted, and the relative stiffness and flexibility of each sample observed from the tensile test plot.

Results

Tensile test plots of squirrel skins fixed in 70% ethanol showed characteristic elastic behaviour. When the force was removed within the elastic region of the plot, the treated skin returned to its original shape (Fig. 1). It should also be noted in this case the behaviour is non-linear but nevertheless elastic. Even if all treat-

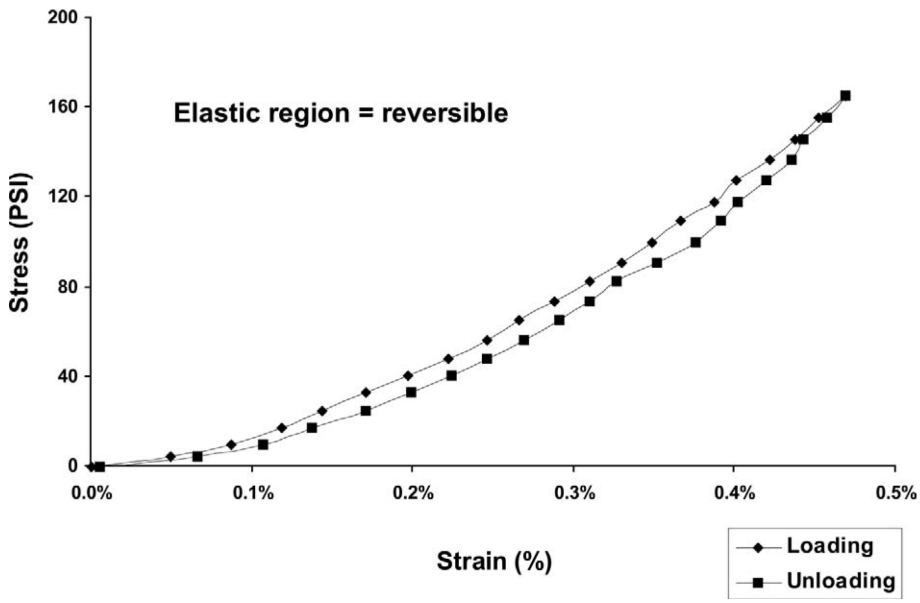

Figure 1. Tensile test plot showing reversibility within the elastic region for squirrel skin fixed in 70% ethanol. There is no measurable distortion.

ment goals are to fix or preserve tissue, tensile test results show clearly that there are significant effects on the properties of skin caused by using different tanning or fixing methods (Fig. 2). When both skins (deer and squirrel) treated in 70% ethanol are loaded (Figs. 1, 2), the first observation is that squirrel skins are significantly stiffer than deer skins as a stress of 40 pounds per square inch (PSI) for the deer skin is needed to produce a strain around 0.3% while it needs 80 PSI for the squirrel skin. In the deer skin test, air dried skin is the stiffest material while the 10% formalin skin is the most flexible (Fig. 2). When the magnitude of the stress is small (zero to 100 PSI), all tensile tests plots showed a general linear behavior with applied force, typical of elastic behavior. When the skin is in the early stages of loading (stress between zero and 50 PSI), some plots show a sigmoidal shape for example the MNHN bath (Fig. 2). This is similar to the squirrel tests with a stress between zero and 120 PSI, but this was shown to be part of the elastic region (Fig. 1). Even at low strains below two per cent, the difference between the skins is already significant and is even more marked when the force increases (Figs. 2–5). The air dried skin is the strongest one while the 10% formalin one sustains deformation at around three per cent (Fig. 5). For a stress of 30 PSI, dried skin, the MNHN bath skin, 70% ethanol, salt and potash alum treatments show a strain in the same range (less than 0.5–1.0%) while 10% formalin treatment has a strain around two per cent (Fig. 2). At higher stresses (150 to 300 PSI), tensile testing experiments revealed two different behaviours. Dried skin, mineral tanning and alcohol treated skins, showed a characteristic elastic linear relationship (Fig. 2). Mineral treatments such as salt, potash alum and the MNHN bath formula keep the skin almost as strong as dried skin and those treated with 70% ethanol (Fig. 2). The effect of different alcohols and alcohol concentrations on the mechanical properties of skins are shown in Figure

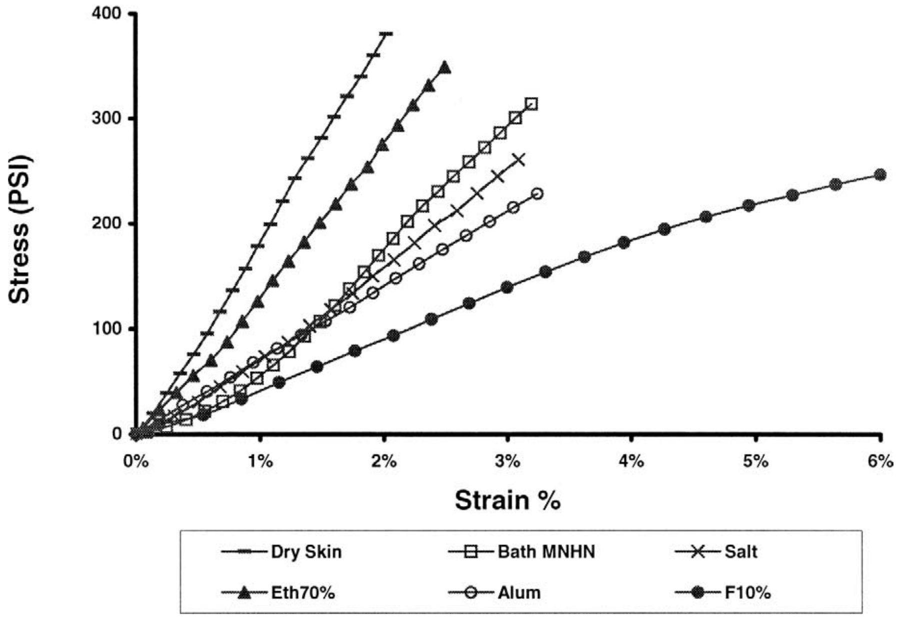

Figure 2. Tensile test plots of deer skins treated with alum, salt, MNHN bath, 70% ethanol and 10% formalin.

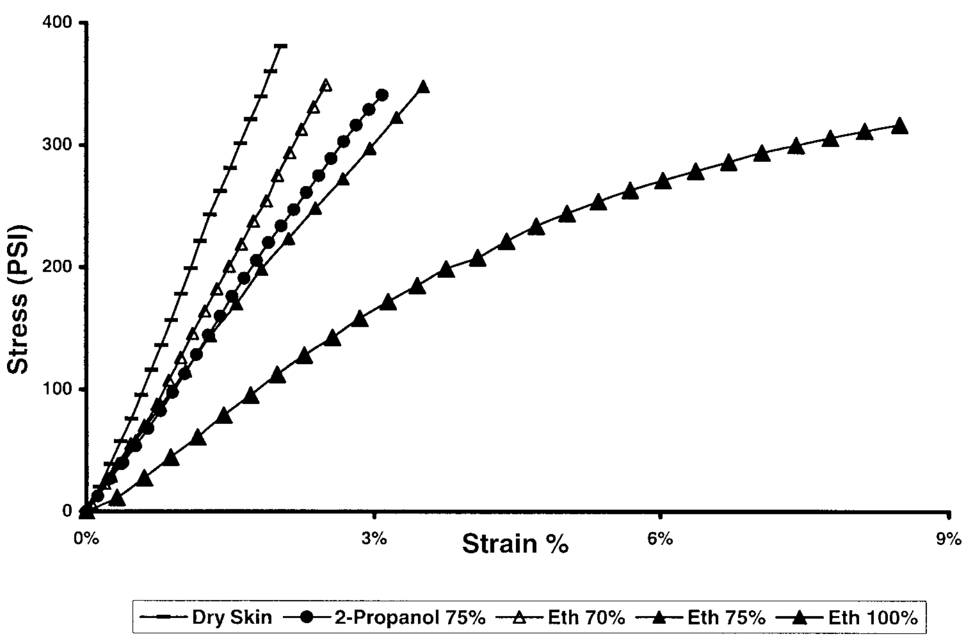

Figure 3. Tensile test plots showing the effects of ethanol and 2-propanol on the flexibility of deer skins.

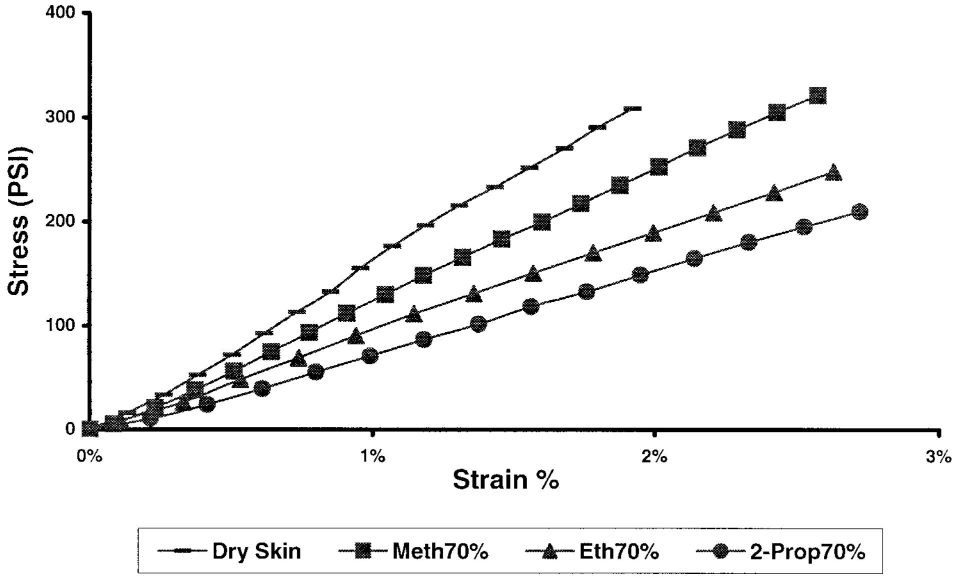

Figure 4. The effects of different alcohols (methanol, ethanol and 2-propanol) at 70% on the flexibility of deer skins.

3. The result shows that there is no significant difference between ethanol and 2-propanol treated skins at similar concentrations. But the variation of ethanol concentration clearly affects the skin's mechanical behaviour with an increase in ethanol concentration making the skin more flexible (Fig. 3). To observe the effect of different alcohols on skin, methanol, ethanol, and 2-propanol at 70% were plotted (Fig. 4). Skin flexibility increases with longer alkyl chains so skins treated with methanol, ethanol,and 2-propanol have increasing flexibility. Tests on skins treated with formalin at one per cent, five per cent, and ten per cent (Fig. 5) show

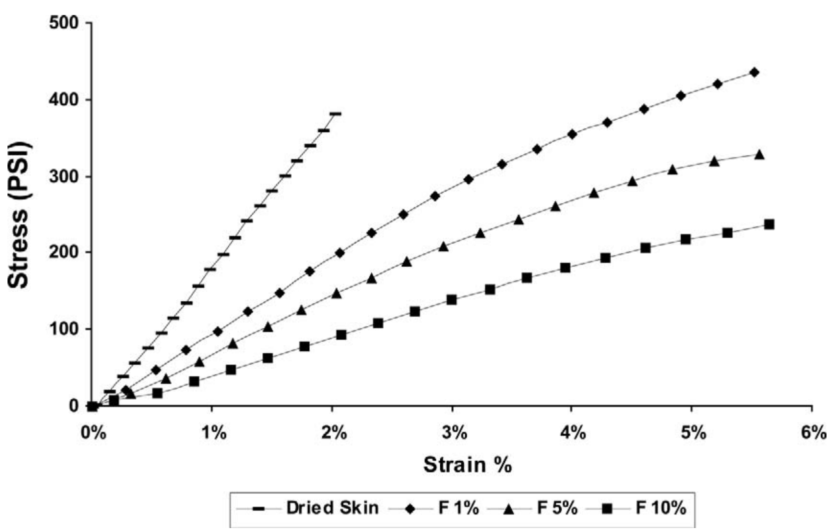

Figure 5. The effects of different formalin concentrations on the tensile test plots of deer skins.

that flexibility increases gradually with formalin concentration. Even small amounts of formalin increase flexibility and large amounts of formalin are not needed to make a useful skin for taxidermy.

Structure of Skin

In order to discuss the significance of the tensile test results, some background on the structure of skin is needed. A brief review is provided below. Mammalian skin is composed of two distinct layers. The outermost layer, called the epidermis, is the thinner of the two layers and is responsible for keeping water in the body and keeping other harmful chemicals and pathogens out. The second layer of skin, called the dermis, is closely connected to the epidermis. The dermis can be split into the papillary and reticular layers. The papillary layer is outermost and extends into the dermis to supply it with vessels. It is composed of the fibrous proteins collagen and elastin, which form a thin and dense network supporting the various hair follicles, sebaceous, and sweat glands, nerves, lymph and blood vessels found there. This fibrous network layer is composed primarily of collagen (70%), arranged in long fibrous bundles that vary in diameter from about one to 200 microns. Collagen fibres give structural toughness and strength. Within the papillary dermis, elastin fibres are loosely arranged in all directions and give elasticity to the skin. The reticular layer is more dense and is continuous with the hypodermis. It contains the bulk of the structures (such as sweat glands). The reticular layer is composed of irregularly arranged fibres and resists stretching. When skin is removed from the body, it undergoes a process called autolysis that starts soon after cell death when intracellular enzymes cause a breakdown of proteins. Deterioration and loosening of hair is an early indication that cellular degradation has started. Ultimately, the deterioration processes include structural damage to the collagen finally resulting in the conversion of collagen to gelatin. Bacteria in dead tissue can also speed decomposition and produce changes in tissue behaviour as well (Rose and Von Endt 1984).

Collagen is a fibrous protein in which linear polypeptide chains align themselves more or less parallel to each other. Collagen is the structural protein of connective tissues and is the most abundant protein in mammals and fish. It has great tensile strength, it is the main component of tendons and ligaments and it responsible for skin elasticity. Collagen fibres consist of globular units of the collagen sub-unit called tropocollagen. Three separate protein strands are each coiled with one another in α-helix configuration. They are rigidly held together in one overall complex by strong intra-chain and H-bonding interaction between the hydroxyl of the hydroxyproline and the amino hydrogens adjacent to glycine units or water molecules (Rose and von Endt 1984).

Discussion of Tensile Test Results

The tensile test results showed that the type of treatment chosen significantly affects the properties of skin. The air-dried skin was the stiffest while alcohol (with a limit of concentration around 70% to 75%) and mineral tanning showed a higher degree of flexibility. These results confirm a previous experiment by Hanacziwskyj et al. (1991), which covered just the effects of tanning and showed that air-dried skin was stiffer. The common elastic behavior of skins treated by air drying, mineral salt and ethanol could be explained by the common action of removing water from the skin. At a molecular level, fresh skin contains 62 to 65% of water (Rose and von Endt, 1984). Water is a strong hydrogen bonding (H-bonding) solvent (Barton 1991) and forms clusters around the collagen that prevents H-bonding between collagen peptides. In dried skin, water breaks the interpeptide bonds due to its higher H-bonding capacity, plasticizing the collagen fibrils and filling the space between the fibrils. Interpeptide H-bonding is important for maintaining the α-helical structure of collagen (Lee 1986). During dehydration, collagen fibrils are brought into closer contact, allowing bonding between polypeptide chains stabilizing the structure of dried skin and making it stiffer. Salt, potash alum, and the MNHN bath treatments work on the principle of dehydration and prevent the pelt from swelling. In the MNHN bath formula (mixed of salt and potash alum), the salt permits the swelling and allows the potash alum to penetrate better into the skin. The solid salt also crystallizes between the fibers when the skin dries and acts as a solid spacer between the fibers, maintaining flexibility. This would explain why the MNHN bath seems to produce stronger and more flexible treatments than using potash alum or salt powder on their own.

Alcohols such as ethanol and 2-propanol are also well known for their ability to dehydrate specimens and this loss of water can significantly alter the mechanical properties. Methanol is closely related in structure to water and it competes almost as effectively as the latter for hydrogen bonds. Ethanol is also closely related in structure and both replace water molecules in the tissues, unbound as well as bound, during fixing. This replacement should affect the hydrogen bonds of collagen fibres, and the structure of other proteins as well. Hydrogen bonds can arise with ethanol because the area around the oxygen atom is relatively rich in electrons and can attract hydroxyl hydrogen from neighboring ethanol molecules. The structure of protein is largely dependent on the arrangement of covalent bonds in the sequence of amino acids forming the peptide chain (primary structure), and hydrogen bonding between the components of the peptide chain itself and side chains (secondary structure). The tertiary structure results from electrostatic or ionic bonds between the acidic and basic amino-acid residues of peptides, disulphide bonds and hydrophobic bonds that are preferentially situated in the relatively water-free interior of the protein molecule. These bonds contribute to the exclusion of water from the peptide backbone and are protected from reagents dissolved in the medium. Alteration of the structure of proteins brought about by methanol and ethanol is primarily due to disruption of the hydrophobic bonds, which contribute to the maintenance of the tertiary structure of proteins. Hydrogen bonds appear to be more stable in methanol and ethanol than in water so that while affecting the tertiary structure of proteins, these alcohols may preserve their secondary structure. We suggest that methanol and ethanol are the only alcohols that could have a role as fixatives.

Formaldehyde and other aldehydes, such as glutaraldehyde, are well known to form cross-links between proteins, creating a gel, and retaining cellular structure. In this process, soluble proteins are fixed to structural proteins and may be rendered insoluble. The cross-links are formed between protein molecules containing the basic amino acid, lysine, although other groups such as imino, amido, peptide, guanidyl, hydroxyl, carboxyl, and aromatic ring structures may also be involved.

The increase in flexibility of the skins with the addition of formalin could be due to chemical degradation.

Preservation

All treatments tested in this paper have been used for preservation, so the results could be applied to help conservation of any taxidermy collection. Since leather and tanned skin are organic material, deterioration occurs by misuse or adverse storage conditions. Regardless of age or origin, these collections are highly susceptible to deterioration caused by relative humidity, temperature, light, air pollution, insects, rodents, and micro-organisms. Hydrolic deterioration of leathers can be due to humidity and temperature interactions, perspiration, microbial growths, and acidic ambient environments. As has been shown here, skin property varies greatly depending on the amount of moisture present and preservation technique used. If the preservation technique is known then a suitable treatment can chosen to treat skin that is too dry or suffering from lack of flexibility. This is often needed during taxidermy restoration or dismantling of specimens. For example, a mounted specimen could be rehydrated with humid linen before removal from the mannequin and preparation as study skin. Since tanning minerals are very reactive with water, the re-hydration should be done carefully, taking care not to re-initiate bacterial or fungal activity.

The results also highlight the importance of choosing the correct fixative for preparation of wet collection specimens. The fixing of mammal skins with alcohol (especially 70% ethanol) is better than formalin for the conservation of mechanical properties of skin and subsequently specimen shape. This may explain in part the problems of deformation of specimens when preserved in fluid for long periods. This is an important issue for wet collections and their use in morphological studies or DNA recovery. In addition, skins fixed with alcohol should be more easily re-hydrated than skins fixed with formalin, which causes significant cross-linking between proteins in the collagen.

Conclusions

Tensile tests made on skins treated by salts, alcohols and formalin show that the untreated skin has the least flexibility, treatment with salts increases flexibility to about the same amount as alcohol treatments and, finally, that formalin treatments give the most flexible skins.

All the skins tested were elastic up to 0.5% without introducing any permanent deformation and have very little deformation when stretched several percent.

The MNHN bath seems to produce stronger and more flexible treatments than using potash alum or salt powder on their own.

With different alcohols there is no significant difference between ethanol and 2-propanol treated skins at similar concentrations but skin flexibility increases slightly with longer alkyl chains so methanol, ethanol and 2-propanol have increasing flexibility.

The variation of ethanol concentration clearly affects the skin's mechanical behaviour with an increase in ethanol concentration making the skin more flexible.

Even small amounts of formalin increase flexibility and large amounts of formalin are not needed to make a useful skin for taxidermy.

Differences of bonding between collagen fibres produce the variation in results between the different techniques. The nature of these bonds needs to be considered when choosing a method for conservation of historical taxidermy specimens and choosing new techniques for future preparations.

Acknowledgments

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ARSENIC IN TAXIDERMY COLLECTIONS: HISTORY, DETECTION, AND MANAGEMENT

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Abstract.—An historical review of taxidermy treatments shows that arsenic has been used in the preparation and conservation of specimens from the 18th century until recent times. Two spot tests for arsenic detection have been tested and compared: the Weber's test and a kit developed by Macherey-Nagel. Stuffed birds from the Muséum National d'Histoire Naturelle, Paris and standard arsenical solutions were spot tested and results compared with those using Inductively Coupled Plasma Spectrometry (ICPMS). The spot tests compared well to the results using expensive equipment, are freely available, inexpensive and provide an adequate level of detection down to 20 ppm. All specimens should be monitored even those that test negative first time round. Institutions should be responsible for monitoring levels of arsenic in collections, use appropriate protection when handling all specimens and regularly update health and safety records.

Introduction

Pesticides have been used in museum collections for a long time. Many of these compounds are toxic to human beings and can be a potential danger to individuals who are in contact with these collections. In taxidermy, arsenic was one of the principal substances used in the preparation of skins. In different taxidermy handbooks, arsenic, realgar, and orpiment were used in preservative recipes. Taxidermists usually use arsenic as arsenical soap, which was applied to the inner side of the specimen skin to preserve it from bio-deterioration and insect attack.

Today curators, conservators, scientists and technicians have to deal with the hazardous effects of this element. Different analytical techniques such as XRF, ICPMS, and SEM-EDS can be used to detect arsenic in collections. Most museums do not have the access to this technology, but this is not always necessary as spot tests provide an alternative method to detect the presence of arsenic.

This study aims to compare two different arsenic spot test methods, provide further information concerning their limits of detection and recommendations for arsenic detection in taxidermy collections.

Arsenic in Taxidermy: A Long History

By the middle of the 18th century, collectors of natural history specimens were experiencing problems with preserving their collections and at that time produced a vast amount of literature on the subject. They used the generic term *Preservative* to describe the products used for skin tanning and conserving. Boitard (1881) defined it as "an antiseptic substance that possesses [several] conservative properties." Specimens were often dried and preserved with salt, herbs, alum, spices, or tobacco. These "recipes" were only effective for a short period of time causing the specimens to smell unpleasant. Naturalists then decided to try new techniques for preserving bird and mammal skins. They substituted techniques that had been used in dried collections for a new group of very strong and effective poisons, for example, mercuric chloride dissolved in water, corrosive sublimate, or arsenic.

Arsenic compounds have been used as therapeutic agents since the 5th century BC, when arsenic sulfide was recommended for the treatment of ulcerated abscesses. Arsenic was isolated in ca. 1250 by the German physicist and alchemist Albertus Magnus (ca. 1200–1280). While heating arsenic sulfide (As_2S_3) with soap he sublimated arsenic. From the eighteenth and up until the nineteenth centuries, arsenic was prescribed for disorders, such as tuberculosis, rheumatism and syphilis (Anonymous 1752, Bescherelle 1856).

Arsenic is mainly present in two forms: organic (when associated with carbon and hydrogen) and inorganic (combined with chlorine and sulfur), the inorganic form being more toxic. Its principal ores are mispickel (FeAsS), realgar (As_2S_2), orpiment (As_2S_3), and loellingite ($FeAs_2$). When exposed to humid air, arsenic tarnishes with trioxide of diarsenic (As_2O_3), a very toxic powder often used as rat poison. Realgar has long been used in medicine, and alchemists experimented with it until the Middle Ages. This is a very fragile red mineral that with extended exposure to light causes the crystals to decompose to a yellow-orange powder (arsenolite and orpiment).

In different taxidermy handbooks, arsenic, realgar, and orpiment were used in preservative recipes. As early as the 18th century, taxidermists employed a mixture of realgar and orpiment dissolved in water with lime or *vert-de-gris* (copper acetate) for the conservation of skins. Another technique used involved the covering of skins with a terebenthine and camphor varnish. At the moment of the mounting, the interiors were then covered with a mixture of arsenic and aloe. During the stuffing of the skin, a dry mixture of corrosive sublimate ($HgCl_2$), arsenic, alum, camphor, and occasionally cinnamon (to give it a good smell), was used. Apart from being used as a tanning agent, arsenic was also employed as an insecticide. Its smell was considered better than that of sulfur, which caused specimens to change from red to yellow, darkened blue specimens and occasionally caused them to burn. In taxidermy, arsenic is better known for the preservative arsenical soap, invented by the French Jean-Baptiste Bécoeur (1718–1777). During his lifetime, Bécoeur kept the composition of his miraculous product a secret and it was not revealed until 1800 (Dufresne 1800). The preservative was composed of camphor, arsenic oxide, carbonate of potash, soap and lime powder. This composition has been fairly constant through the centuries (Péquignot 2002). At the end of the 19th century, arsenical soap was indexed in the *Codex Medicamentarius* (Anonymous 1866), and was under strict regulation in France, under the *Loi sur la vente des substances vénéneuses du 19 juillet 1845,* and under the *Ordonnance royale portant Réglement sur la vente des substances vénéneuses du 29 octobre 1846.* The formula was arsenic (320 g), carbonate of potash (120 g), distilled water (320 g), soap (320 g), lime (40 g) and camphor (10 g). At the time, arsenical soap was a real advance in the art of taxidermy and at the end of 19th century many handbook authors recognized Bécoeur as the inventor and an important player in the history of taxidermy. His arsenical soap was employed until the 1980s in different museums around the world (Hawks and Williams 1986, McCann 1995, Knapp 2000). Because of its toxicity (Le Dimet and Jullien 2002), the use of arsenic is now prohibited in the museum community.

Detect to Protect

The history of taxidermy shows us that the vast majority of stuffed animals found in museum collections may have been prepared with arsenic. This does not only cover ''ancient specimens'' as arsenic has been used in more recent times (Hawks and Williams 1986, Knapp 2000). Knowing which specimens are contaminated is vital so that preventative measures can be taken to protect the health of individuals in contact with collections. This includes taxidermists, researchers, and even the general public as some of these objects are still exhibited.

First it is necessary to visually inspect the specimens for the presence of characteristic white arsenic dust. These powdery or crystalline deposits are normally found at the base of hairs and feathers, around eyes, in or at the base of ears, around mouths or bills, and on foot pads. In addition to this examination, some knowledge of the object's history will be helpful to determine when, and by whom it was collected and prepared, and if arsenic was used in that period. Then it is necessary to test specimens for arsenic, as the absence of white powder does not mean the absence of arsenic. For that purpose there are several available techniques. Sirois and Sansoucy (2001) presented different techniques available to detect arsenic in collections. Because many museums may not have the opportunity to use high-technology (XRF, ICPMS or SEM-EDS), but they still need to detect the presence of arsenic, spot tests are a good alternative. We decided to test and to compare three different methods on a skin sample prepared by arsenic: the Weber's test, a kit developed by Macherey-Nagel sold commercially, and the ICPMS (Inductively Coupled Plasma Mass Spectrometry). We prepared and tested a set of standard solutions, as well as a set of samples of arsenic tanned skin from the Muséum National d'Histoire Naturelle, Paris.

Weber's test is commonly used in American museums (see for example Found and Helwig 1995, Hawks and Williams 1986, Sirois and Taylor 1989). This test was devised by Stephen Weber (University of Pittsburg) and is based on the Gutzeit method developed in Germany in the 1920s (Vogel 1965). In this process, the arsenic compounds react with hydrogen produced from the reaction between zinc and acid (hydrochloric or sulfuric). The hydrogen reduces the arsenic compounds to arsine (AsH_3), a poisonous gas. The arsine is then exposed to a paper treated with mercuric chloride solution to produce a yellow to brown color, depending on the concentration of arsenic. The limit of sensitivity commonly accepted is 20 μg per drop of standard arsenic (Hawks and Williams 1986, Sirois and Taylor 1989). This limit was chosen as it is the ''background'' level of arsenic in soil and water that is the result of leaching from natural sources and from two centuries of applying arsenic in agriculture. It is assumed that when the tests are carried out on water and soil, at least 20 μg will be present per drop of sample after dilution. This background level defines the detection limit when using the tests for these purposes. The detection limit is therefore estimated to be around 400 ppm.

The *Arsenic Paper Test* kit manufactured by the Macherey-Nagel Corporation (USA) and recommended by Odegaard et al. (2000) and Odegaard and Sadongei (2005) is a modification of the Weber's test. Arsenic present in the sample is reduced to arsine gas, which turns the test white paper (containing 1.9% mercuric (II) bromide) lemon yellow to brown according to the concentration. The detection limit stated by the company, is 0.1 ppm of arsenic for a 5 ml sample (20 ppm) and a box of 200 strips (Art-Nr. 907 62) costs approximately $25 at the time of writing. The procedure involves careful physical removal of some crystalline powder residues or rolling fine cotton swabs dampened with distilled water over the specimen (Fig. 1). The cotton swab is then broken off and placed in an Erlenmeyer flask with 25 ml of distilled water. After an hour, 5 ml of this solution is placed in a test tube and 10 drops of concentrated chlorydric acid and around 0.5 g of zinc powder are added. The test paper is quickly introduced and the tube closed with a laboratory wrapping film (Parafilm™) cap. After 30 minutes the paper test can be read.

We also tested the sensitivity and accuracy of these two procedures against results from the Perkin Elmer Elan 6000 Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) at the Smithsonian Center for Materials Research and Education (USA). The ICP-MS was connected to a cross flow nebulizer sample introduction device. The parameters of the ICP-MS were optimized to ensure a stable signal with a maximum intensity over the full range of masses of the elements and to minimize oxides and double ionized species formation ($XO+/X+$ and $X{+}{+}/X+ < 3$ %). The nebulizer gas flow, lens voltage, detector analog stage voltage and detector pulse stage voltage were adjusted to achieve this. A dual detector calibration was applied to match the analog and pulse detector stages and was required to measure major, minor and trace elements at the same time.

We tested both paper methods on the specimen samples and then on the arsenic solutions. We used the ICP-MS to determine arsenic concentrations for the specimen samples and arsenic solutions. Skin and feathers from the samples, were tested in different areas of the specimen. They were prepared by acid digestion in 70% nitric acid (HNO_3) since chloride reacts with argon interfering with the readings. Digestion was conducted in a microwave at a pressure of 30b, a temperature of 260°C, for 15 min at 400W and then 30 min at 800W. ICP-MS analyses revealed an arsenic concentration of 935 ppb (0.935 mg/L) for skin samples and 173 ppb (0.173 mg/L) for feather samples. For the Weber's Test and the Arsenic Test Paper we removed some crystalline residues by rolling fine cotton swabs dampened with distilled water and followed each test procedure. Both tests gave a positive result with a stronger signal for the Weber's test than for the Arsenic Test Paper.

The results show that the Weber's test and the arsenic paper test are positive at 200 ppm concentration of arsenic, as there is a strong black/brown coloration. The reaction still clearly appears at 100 ppm for both tests, and two tests still react at 20 ppm. At 7 ppm, no reaction was observed in the Weber's Test and it is very difficult to read a positive answer in the Arsenic Paper Test (Fig. 2). We can observe positive results for Weber's test below the 400 ppm sensitivity previously estimated (but results should be taken with caution when concentrations are lower than 400 ppm). Results for the Arsenic Paper Test are consistent with the 20 ppm limit stated by the supplier. Both tests are very sensitive and are suitable for arsenic detection. From the practical point of view, the Weber's test gives a very quick answer but it requires previous training in the handling of chemical compounds. The Arsenic Paper Test is easier to use but the process

Figure 1. Rolling a cotton swab on a bird specimen for an Arsenic Spot Test at the Muséum National d'Histoire Naturelle, Paris.

takes longer, as 30 minutes are needed before readings can be taken. Spots tests can be use to determine the presence of arsenic in taxidermy specimens when proper and careful sampling is practiced. It is essential to test several areas as negative results can be obtained from some parts of contaminated specimens.

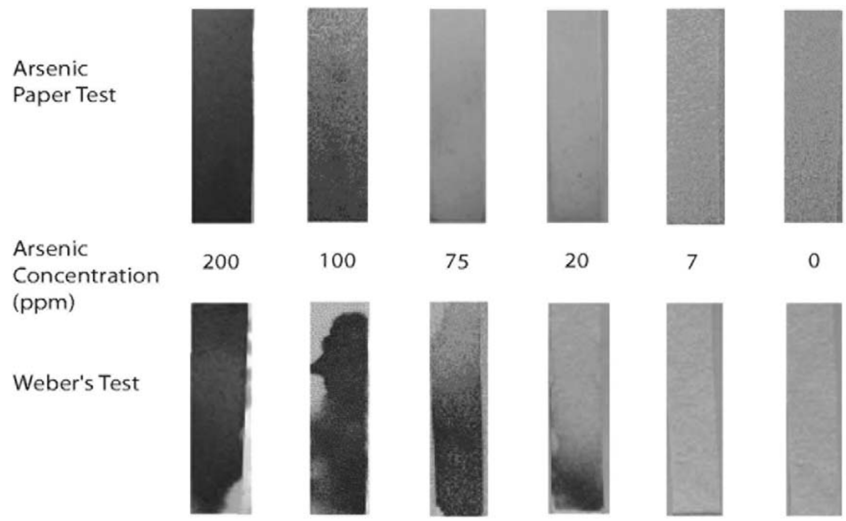

Figure 2. Results from Weber's Test and the Arsenic Paper Test on the solutions at different arsenic concentrations (7, 20, 75, 100 and 200 ppm).

Arsenic Management

Arsenic when present in museum collections requires an appropriate level of management, as does management of the information associated with the contaminated specimens. It is important for institutions to develop a protocol for handling arsenic contaminated objects that covers not just employees but also researchers and visitors. Specimens known, or suspected to contain arsenic should never be handled without appropriate protection. Nitrile gloves and a protective smock or apron, as well as a respirator, are necessary in dealing with these objects. These supplies should be disposed of in an appropriate way similar to other hazardous materials. Specimens testing positive for arsenic must have ''Arsenic contaminated'' clearly visible on their labels (Knapp 2000). This information must also be added to the museum paper and/or computer catalog. It should be noted that objects that tested negative might still contain arsenic (Palmer 2001). These objects should be inspected and tested every two to three years, as arsenic may migrate from the interior of the specimen. Each test result, whether positive or negative, must be recorded in the specimen's computer and/or paper catalog entry. These specimens should be stored separately whenever possible. Objects that are contaminated with arsenic should not be exhibited without appropriate conditions and/or decontamination to reduce the risk of exposure. A High-Efficiency Particulate Air (HEPA) vacuum could be used to absorb at least part of the arsenic powder on the specimen (Knapp 2000). This method may have restricted application in taxidermy because arsenic or arsenical soap was usually applied as a paste on the inner side of the specimen skin.

Conclusions

Spot tests such as the Weber's test and the Macherey-Nagel paper are freely available and inexpensive methods that can identify arsenic in taxidermy collections and help to manage this contamination problem. These two spot tests were successfully calibrated against ICP-MS results on arsenic standard solutions and bird specimens. The spot test methods are sensitive enough to detect even background levels of arsenic. However, specimens that give negative results should be re-tested every two to three years. It is the responsibility of museums to identify those objects that are contaminated and to provide a safe environment to their staff and visitors.

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A CONTRIBUTION TO STANDARDS FOR FREEZING AS A PEST CONTROL METHOD FOR MUSEUMS

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Abstract.—The mortality of larvae of *Anthrenus museorum* (L.), *Anthrenus verbasci* (L.), *Attagenus smirnovi* Zhantiev, *Attagenus woodroffei* Hallstead and Green, *Reesa vespulae* (Milliron), *Trogoderma angustum* (Solier) (Coleoptera: Dermestidae) and *Tineola bisselliella* (Hummel) (Lepidoptera: Tineidae) was studied in freezing experiments at −18° to −20°C. An infestation by these pests was simulated inside heavy woollen material and upholstered furniture, i.e., in wood enclosed in heavy material. It is vitally important that air can circulate around the treated objects in the freezer. Times necessary for the temperature to reach equilibrium were 20 and 36 hours, respectively. Larvae that had been exposed to temperatures lower than −17.6°C for about 50 hours had all died, either immediately or as observed several months later. Freezing procedures using moderate temperatures must be based on time-temperature-mortality relationships for different stages of the relevant species. Previous conclusions that *A. museorum* is more resistant to low temperatures than several other dermestids are confirmed and acclimatisation suggested as the reason. Further investigations on the biochemical processes occurring in the insects during exposure to low temperatures could elucidate this further.

Introduction

Freezing is a widely used method for eradication of pest insects in museum collections. In the literature, recommendations for freezing times and temperatures vary. Florian (1986) reports on freezing procedures used in museums with temperature/time relationships ranging from −12°C for 48 hours to −40°C for 24 hours. Pinniger (2003) suggests using either −30°C for three days or −18°C for at least 14 days. Many museums and private collections do not have access to low temperature freezers with temperature ranges down to −30°C. Consequently there is a need for data on lethal exposure times for a number of pest species and stages exposed to moderate low temperatures (around −20°C).

Table 1 shows the results of several studies on the effect of freezing at moderate low temperatures on common museum pests. These investigations were conducted with freely exposed specimens. Not much is known about the effect of freezing when dealing with insects inside large dimensions of wood or upholstered furniture.

The present paper reports investigations into the possibilities of controlling larvae of seven insect species that are important pests in Scandinavian museums. The tests were conducted in two configurations intended to simulate an infestation of pests inside i) heavy woollen material and ii) upholstered furniture, i.e., in wood enclosed in heavy woollen material.

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Table 1. References describing investigations of exposure times required to kill insect pests in museums at −20°C.

Pest	Stage	Temp.	Time	% mortality	Reference
Anthrenus verbasci	All	−20°C	3 hours	100	Linnie 1999
Reesa vespulae	Larvae	−20°C	1 hour	100	Arevad 1974
Anthrenus verbasci	Eggs/pupae/adults	−20°C	2 hours	100	Arevad 1979
Anthrenus museorum	Larvae	−20°C	2 hours	<100	Arevad 1974
Tineola bisselliella	Adults	−20°C	0.5 hour	100	Brokerhof et al. 1993
	Larvae/pupae	−20°C	1 hour	100	
	Eggs	−20°C	30 hours	100	
Common museum pests	All	−20°C	48 hours to 2–3 weeks	100	Review by Strang 1992

Materials and Methods

Experiment 1

The following species were used: *Anthrenus museorum* (L.), *Anthrenus verbasci* (L.), *Attagenus smirnovi* Zhantiev, *Attagenus woodroffei* Halstead and Green, *Reesa vespulae* (Milliron), and *Trogoderma angustum* (Solier) (all Coleoptera: Dermestidae). The insects had been maintained under laboratory conditions at the Danish Pest Infestation Laboratory (DPIL) for a minimum of two years. Middle-sized larvae of the insects used in the tests were sent by surface post from Copenhagen to Stockholm (duration: 48 h). A temperature logger was included in the package to check that the larvae were not exposed to extreme temperatures during dispatch. They were transferred to the test boxes using pliable tweezers immediately before the treatment.

The test specimens were placed in 76 × 55 × 22 mm plastic boxes, one box for each species. The boxes were wrapped in heavy Swedish Army woollen blankets (density 770 g/m^2) at four distances from the upper surface to the middle approximately 2, 4, 8, and 16 cm from the surface (Fig. 1). Temperature sensors connected to a Squirrel® data logger were placed close to each box. The blankets were wrapped in plastic film and the whole package was placed in a Cylinda AFB 500® chest freezer at a temperature of approximately −20°C. Control larvae of each species were stored at room temperature.

In experiments 1A and 1B the package was placed directly on the bottom of the freezer without allowing any air circulation around the package. In experiment 1C an additional box was placed beneath the blankets; a wooden frame below the blankets and wooden laths placed vertically along the sides made air circulation possible. In experiment 1A all six species were tested, in 1B only *T. angustum, R. vespulae* and *A. museorum,* and in experiment 1C the test species was *A. museorum.* In experiment 1A the exposure time was 24 hours and in experiment 1B and 1C the insects were treated for 72 hours. In experiment 1A three replicates in time were performed, in experiment 1B and 1C the number of replicates was four, all with 15 specimens of each species. After freezing the test specimens were placed at room temperature and survival was checked after one and three or four days. Larvae that moved when exposed to a gentle push with a soft brush or when gently breathed upon were classified as living. Survival was

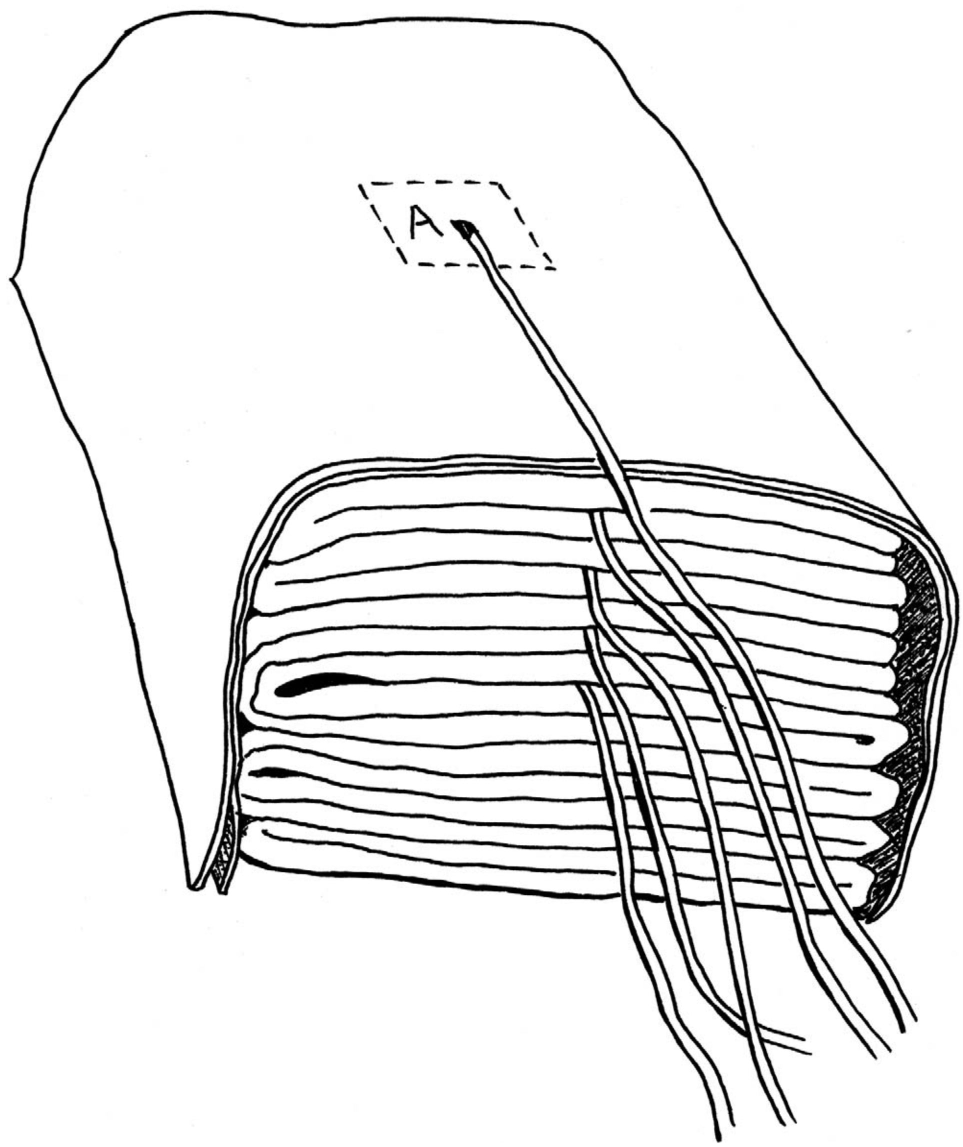

Figure 1. Experimental bundle showing sensor wires protruding from woolen wrapping.

also checked after several months, during which period no additional food was provided.

Experiment 2

The same species were used as for Experiment 1 with the addition of *Tineola bisselliella* (Hummel) (Lepidoptera: Tineidae). Three or four repeat experiments were carried out, each with 10 test specimens of middle-sized larvae. Test specimens were transferred with a soft brush or pliable tweezers to 5 ml glass test vials. The vials were kept at room temperature for 24 hours until being used in the experiments.

The tests were conducted in 20 × 20 × 20 cm blocks of seasoned oak wood (*Quercus* sp.). Each block had been divided into half and a 9 × 9 × 9 cm central cavity made, in which the test specimens were placed. The distance from the exterior to internal cavity was thus 5.5 cm on all sides of the cavity. Two narrow channels were made in the block so that wires from thermocouples placed in the cavity could pass to the outside. Temperatures inside an extra glass vial in the block as well as in the freezer were recorded by Testo K-type thermocouples (made in Lenzkirch, Germany) connected to a Quatech QTM-8018 thermocouple signal-conditioning module (made in Akron, Ohio, USA). The holes around the wires were sealed using rubber or adhesive gum. The two adjoining sides of the block halves were carefully planed, leaving a minimal crack when the block was assembled.

The wooden block was wrapped in a 5.5 cm thick layer of heavy woollen blankets of the same type as used in experiment 1. The block with blanket was placed in a Gram F 600 upright freezer in which a fan ensured ventilation at approximately −18°C for 24 or 72 hours. Untreated control specimens were placed in a block wrapped in blankets in a refrigerator at 2.4° to 5.0°C. Survival of treated and untreated specimens was checked after 24 hours (24-hour treatments) or two hours (72-hour treatments). Between checks for survival the glass vials were kept at room temperature in the laboratory.

Results

Experiment 1

The mortality three to four days after exposure and final temperatures are shown in Tables 2, 3 and 4.

The outer layer temperature reached −10°C after 5.5 hours (cooling rate of 5.5°C/h) and the middle layer after 12 hours (cooling rate of 2.5°C/hr). However, after 24 hours the temperature of the middle layer was not lower than −14.8°C (Table 2) and prolonging the treatment to 72 hours did not change this situation (Table 3). Not even after five weeks did the temperatures decrease further. Only after air circulation in the freezer had been improved as attempted for experiment 1C, did the middle layer reach temperatures of approximately −20°C (Table 4) after 20 hours. The exposure time at this temperature was thus 50 hours rather than 72.

Observations three to four days after treatment showed that *At. smirnovi* and *At. woodroffei* were killed at all temperatures. In the rest mortality was highest at the lowest temperatures. Full mortality was not obtained in *T. angustum, A. verbasci* or *A. museorum.*

A check after one year of experiment 1A (24 hour treatment) showed that *T. angustum* and *A. verbasci* had a 100 % mortality, while survival or traces of a new generation occurred in *R. vespulae* at −13.6°C, and in *A. museorum* at −13.6°, −15.3° and −17.3°C. In experiment 1B (72 hour treatment) *T. angustum* and *R. vespulae* showed 100 % mortality, while some survival and reproduction was seen in *A. museorum* at temperatures above −17.6°C. At a check of experiment 1C (*A. museorum* 72 hour treatment) after three months, all larvae were dead. In all cases the control insects had produced offspring and/or were alive. The check after several months revealed that many of the treated larvae had died

Table 2. Mortality of larvae of museum pests placed at different depths within wool and exposed to −20°C for 24 hours, ventilation limited (Experiment 1A), $n = 15$, three replicates.

Temperature[a,b] (max/min)	−19.1 ± 0.6°C (−18.8/−19.8°C)		−17.4 ± 0.2°C (−17.3/−18.0°C)		−15.4 ± 0.2°C (−15.3/−15.7°C)		−14.4 ± 0.7°C (−13.6/−14.8°C)		Untreated controls (+22.7/+23.9°C)	
	No. dead[b]	Mortality	No. dead[b]	Mortality	No. dead	Mortality	No. dead	Mortality	No. dead	Mortality
A. museorum	2.0 ± 1.0	13%	1.7 ± 1.2	11%	0.0 ± 0.0	0%	0.3 ± 0.6	0%	0.0 ± 0.0	0%
A. verbasci	14.0 ± 1.0	93%	12.7 ± 2.5	85%	9.7 ± 2.3	65%	2.3 ± 2.1	15%	0.3 ± 0.6	2%
At. smirnovi	15.0 ± 0.0	100%	15.0 ± 0.0	100%	15.0 ± 0.0	100%	15.0 ± 0.0	100%	1.0 ± 1.0	7%
At. woodroffei	13.3[c]	100%	13.3[c]	100%	13.3[c]	100%	13.3[c]	100%	0.3 ± 0.6	2%
R. vespulae	12.3 ± 2.1	80%	6.3 ± 3.2	42%	1.0 ± 1.0	7%	1.7 ± 1.2	11%	0.0 ± 0.0	0%
T. angustum	13.7 ± 1.2	91%	9.7 ± 1.5	65%	10.0 ± 1.7	67%	3.7 ± 3.8	24%	0.0 ± 0.0	0%

[a] Adjacent to test specimens inside blanket.
[b] Mean ± SD.
[c] $n = 10; 15; 15$; SD not calculated.

Table 3. Mortality of larvae of museum pests placed at different depths within wool and exposed to −20°C for 72 hours, ventilation limited (Experiment 1B), $n = 15$, four replicates.

Temperature[a,b] (max/min)	−19.5 ± 0.1°C (−19.4/−19.6°C)		−18.1 ± 0.3°C (−17.8/−18.4°C)		−16.2 ± 0.9 (−15.6/−17.6°C)		−14.2 ± 0.4 (−13.9/−14.8°C)		Untreated controls (+22.6/+23.8°C)	
	No. dead	Mortality	No. dead	Mortality	No. dead	Mortality	No. dead	Mortality	No. dead	Mortality
A. museorum	10.5 ± 1.7	70%	5.3 ± 4.8	35%	0.3 ± 0.5	2%	0.3 ± 0.5	2%	0.0 ± 0.0	0%
R. vespulae	15.0 ± 0.0	100%	15.0 ± 0.0	100%	15.0 ± 0.0	100%	15.0 ± 0.0	100%	0.0 ± 0.0	0%
T. angustum	14.2 ± 0.1	95%	14.8[c]	100%	14.5 ± 1.0	97%	12.0 ± 3.6	80%	0.3 ± 0.5	2%

[a] Adjacent to test specimens inside blanket.
[b] Mean ± SD.
[c] $n = 15; 15; 14; 15$; SD not calculated.

Table 4. Mortality of larvae of museum pests placed at different depths within wool and exposed to −20°C for 72 hours, ventilation (Experiment 1C), $n = 15$, four replicates.

Temperature[a,b] (max/min)	−19.7 ± 0.3°C (−18.9/−19.1°C)		−20.1 ± 0.3°C (−20.2/−20.9°C)		−20.1 ± 0.7°C (−19.1/−20.7°C)		−20.6 ± 0.3°C (−19.7/−20.4°C)		−19.1 ± 0.1°C (−19.4/−20.0°C)		Untreated controls (+21.1/+23.4°C)	
	No. dead	Mortality	No. dead	Mortality	No. dead	Mortality	No. dead	Mortality	No. dead	Mortality	No. dead	Mortality
A. museorum	14.5 ± 0.6	97%	14.3 ± 1.5	95%	14.3 ± 1.0	95%	14.8 ± 0.5	98%	13.8 ± 1.5	92%	0.0	0%

[a] Adjacent to test specimens inside blanket.
[b] Mean ± SD.

Table 5. Mortality of larvae of museums pests placed inside wooden blocks and woollen blankets and exposed to −18°C (Experiment 2).

Temperature[a,b] (max/min)	Treatment: 24 hours		Untreated controls		Treatment 72 hours		Untreated controls	
	(n = 10, 4 replicates)				(n = 10, 3 replicates)			
	−11.8 ± 2.1°C (−9.0/−14.2°C)		7.7 ± 0.8°C (6.9/8.4°C)		−18.1 ± 0.4°C (−17.7/−18.5°C)		4.5 ± 1.3°C (3.6/5.9°C)	
	No. dead[b]	Mortality	No. dead[b]	Mortality	No. dead[b]	Mortality	No. dead[b]	Mortality
A. museorum	0.8[c]	8%	0.3 ± 0.5	3%	10.0 ± 0.0	100%	0.0 ± 0.0	0%
A. verbasci	3.0 ± 4.7	30%	0.8 ± 1.0	8%	10.0 ± 0.0	100%	0.0 ± 0.0	0%
At. smirnovi	9.8 ± 0.5	98%	0.0 ± 0.0	0%	10.0 ± 0.0	100%	0.0 ± 0.0	0%
At. woodroffei	—	—	—	—	10.0 ± 0.0	100%	0.0 ± 0.0	0%
R. vespulae	0.5 ± 0.6	5%	0.8[d]	8%	10.0 ± 0.0	100%	2.0 ± 2.0	20%
T. angustum	0.8 ± 1.0	8%	0.5 ± 0.6	5%	10.0 ± 0.0	100%	0.0 ± 0.0	0%
Ti. bisselliella	9.8 ± 0.5	98%	1.5 ± 1.7	15%	10.0 ± 0.0	100%	2.0 ± 1.0	20%

[a] Adjacent to test specimens inside wooden block.
[b] Mean ± SD.
[c] n = 10; 10; 10; 8; SD not calculated.
[d] n = 10; 10; 11; 11; SD not calculated.

during the moulting process. Moulting was observed to have occurred in specimens of the following species exposed to temperatures higher than −14°C (*A. verbasci*), −15°C (*R. vespulae*), and −20°C (*A. museorum*).

Experiment 2

The final temperatures and the mortality observations are shown in Table 5. Temperatures reached −10°C after 21 hours with a cooling rate of 1.5°C/h. Despite freezer temperatures of approximately −18°C, the temperature inside the blocks only reached −12°C after 24 hours, and mortality was incomplete in all tested species. Treatment for 72 hours led to 100 % mortality in all species; in this case temperatures inside the blocks reached equilibrium at −18°C after approximately 36 hours, resulting in an exposure time of 36 hours. Mortality in the untreated specimens was generally low, except for *T. bisselliella,* which is generally known to be delicate. *R. vespulae* also suffered some mortality, but the overall mortality level in the untreated specimens is considered acceptable.

Discussion and Conclusions

Two species, *At. smirnovi* and *At. woodroffei,* are very susceptible to low temperature treatment. They both have tropical origins (Zhantiev 1973, Halstead and Green 1979). The most resistant species, *A. museorum,* is naturally distributed all over the holarctic region (Mroczkowski 1968), and can thus be expected to be adapted to low temperatures. There are small differences in the lowest temperature for survival between the different experiments. This especially applies for *A. museorum,* in which full mortality was achieved at −18.1°C in experiment 2, but not at several of the temperatures used in experiment 1, extending down to −20.9°C. This is even more surprising as the cooling rate in experiment 1 is higher than in experiment 2; a higher cooling rate is generally considered to be a more severe treatment. The different results may be related to the temperatures that the test specimens in experiment 1 experienced during shipment (lowest value 6°C, duration about one hour). This may have triggered an acclimatisation reaction in *A. museorum,* which may explain the survival in experiment 1 as opposed to experiment 2. The same may be the case with the small differences between experiments 1 and 2 observed in *T. angustum.* In addition, random variation between individuals could contribute to part of the differences.

The available literature on this subject deals with treatment of freely exposed larvae. Arevad (1974) concluded that *A. museorum* is more resistant to low temperatures than several other dermestids and suggested that acclimatisation could be the reason. The present investigations seem to support this theory. Not much information exists on acclimatisation in museum pests. Further investigations on the biochemical processes occurring in the insects during exposure to low temperatures could elucidate this further.

Despite the wide range of supercooling points in *T. bisselliella* (−5.5°C to −24.5°C) (Vannier 1994), all larvae were dead after exposure to −18.7°C for approximately 36 hours in the present study. Thus, for some species, full control can be obtained at temperatures above the lowest super cooling point. This confirms that in order to design freezing procedures using moderate temperatures, time-temperature-mortality relationships must be determined for different stages of the relevant species.

The observation of most importance for freezing procedures in museums is the fact that larvae that had been exposed to temperatures lower than −17.6°C for about 50 hours had all died, either immediately or within the following months.

It took 20 hours for the centre of the blanket to reach −19°C (experiment 1C, with air circulation), and 36 hours for the core temperature in the wooden blocks wrapped in blankets (experiment 2) to reach equilibrium with the freezer temperature. Thus, exposure times in the present study were approximately 50 and 36 hours. These experiments illustrate the insulating properties of heavy material such as wood and/or wool.

It seems to be possible to design freezing procedures using moderate temperatures (-20°C) to control insect pests concealed within objects of large dimensions. However, information on time-temperature-mortality relationships for all stages of important pest species must be available. For control of pests in large dimensions the necessary exposure times are much longer than when dealing with freely exposed individuals. Furthermore, it is of utmost importance that the objects are placed in the freezer in such a way that air circulation is possible. Several papers report on the possible effects of freezing on museum artefacts (e.g., Björdal 1998, Carrlee 2003, Florian 1986, Peacock 1998, Strang 1995). Prior to freezing of valuable artefacts it is advisable to consult the literature and the expertise of conservators.

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TIE IT TO THE TRAY! SAFELY SHIPPING NATIVE AMERICAN ARTIFACTS

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Abstract.—In August 2004, the Conservation Department at the Science Museum of Minnesota agreed to work on a loan of 101 Native American ethnographic artifacts for an exhibition in the Basque Region of Spain due to open in November 2004. These included birch bark baskets, bone tools, wooden tools, and articles of glass beaded hide and fabric ranging in age from the mid-19th century to the 1980s. The system of crates, trays, ties, blocking, wrapping and padding used to prepare the loan for shipping and exhibition is described here. The value of teamwork between conservators, packers, interns and volunteers is emphasized and it is recommended that the same staff be present during packing, unpacking and repacking of exhibition loan material. It is vital that enough time be set aside for exhibition loans to allow for revising packing procedures during large projects, for loans to be properly packed on return and for associated digital images to be well curated and cross referenced. Clear visual packing instructions help the repacking process immensely, with photographs of both finished wrapped appearance and unwrapped appearance useful to help orient each artifact.

INTRODUCTION

Preparing objects for loan and exhibition is a normal activity for a conservation department in a museum. There are well-defined standards for the process (e.g., Buck et al. 1998, Raphael 1999, Stolow 1987) with common techniques and preferred materials well described (e.g., Piechota and Hansen 1982, Von Endt et al. 1995), as are standards for documentation for the condition of the objects to be lent (Buck et al. 1998).

Under ideal conditions, the preparation of objects for loan will have sufficient lead-time for all parties involved to complete the required tasks to the necessary standard. A partial list of tasks includes:

- Curatorial and collections management staff choose collections according to the exhibition theme, research the objects, and document the results.
- The registrar manages paper work for the loan, makes shipping arrangements, gathers any necessary permits, and ensures that the objects will be returned upon completion of the loan.
- Conservators document the condition of the objects, treat objects as needed and advise on display mounts and shipping containers.

The conservator must work closely with collections managers and curatorial staff to fine-tune the object loan list by determining if objects are stable enough, or can be made stable enough to be safely shipped and displayed. The conservator examines the objects, providing detailed condition reports with associated documentation and treatments as needed. The conservator works closely with the exhibit builders, providing standards for environmental conditions for the exhibit and expertise on the design and construction of display mounts and shipping containers.

This is a team effort in a process that can easily take two or more years, depending on the complexity of the exhibition and condition of the objects being considered for loan.

Unfortunately in the real world, ideal conditions rarely exist. In this paper, we will examine the condition reporting, preparation, packing, and shipping of a recent international loan from the conservation point of view. As is so often the case, external parameters presented challenges that required creative solutions to meet standards.

The Project

In August 2004, the Conservation Department at the Science Museum of Minnesota agreed to work on a loan of 101 Native American ethnographic artifacts to Kultur Basauri, a museum and cultural center administrated by the Basauri City Council in the Basque Region of Spain. The objects were to be part of a large exhibit and cultural exchange entitled *Indians.* The exhibit was due to feature historic Native American objects, contemporary work from Native American artists, and live music and dance performances. Joe D. Horse Capture, Associate Curator of Africa, Oceania, and the Americas at the Minneapolis Institute of Art curated the exhibition. The artifacts chosen for this loan represent some of the finest items in the Science Museum of Minnesota's Native American collection. Drawing heavily on the collections from Plains and Woodlands tribes, the group of artifacts consisted of some very diverse materials. These included birch bark baskets, bone tools, wooden tools, and articles of glass beaded hide and fabric. The artifacts span a time period from the mid-19th century to the 1980s. We chose artifacts that could be shipped as safely as possible and ranged from fair to excellent in condition.

The exhibition was scheduled to open in Basauri on 26 November 2004, which presented the first challenge as there was a short time frame in which to prepare. However, the opportunity to participate in such a unique international event far outweighed any obstacles. A project of this scope should have been allowed a minimum of six months for the amount of conservation work that was required. Instead, two months was available for planning and a total of six weeks for treatments, condition documentation, packing development and implementation. Planning needed to be detailed and execution efficient.

The final object list was completed by 1 October 2004, and the first artifacts were delivered to the lab. The Conservation Department had cleared the schedule of all other work so that the following six weeks could be exclusively dedicated to the project. The Conservator developed a plan that included working closely with curatorial/collection management staff and trained volunteers and interns. A local art packing company, Museum Services, was contracted to pack the artifacts in order to alleviate the workload and facilitate shipping.

Conservation Department staff had sufficient experience to handle the project as the two staff members at that time had over thirty years of combined experience in packing objects safely for shipping. The Department has worked closely with the Exhibits Division of the museum on every objects-based traveling exhibition produced by the Science Museum of Minnesota to ensure that the display, packing and shipping systems are safe for the artifacts and the condition documentation is easy to use. In addition, the Conservation Department was instrumental in moving the entire museum collection to a new building in 1999. Staff designed and prototyped packing and storage systems for the 1.75 million objects and also supervised the packing. The experiences of the Conservation Department, along with the collections and curatorial staff, were published in Benson et al. (2001). Many of the techniques used were adapted from Rose et al. (1992), and from various traditional packing methods observed through previous experience.

For the Basauri loan, the Conservation Department was involved solely with the physical care of the artifacts, preparing them for travel and verifying their condition upon return. The scope of the artifact care included: completing condition reports with diagrams and photographic documentation for 101 artifacts; performing stabilizing treatments on 18 artifacts; building internal display mounts for 30 artifacts; and designing and supervising the construction of the shipping system. Conservation Department volunteers and interns also helped with the project.

It was imperative that the objects were well documented and packed safely. Since this was an international loan to a non-English speaking region, the packing instructions and condition reports had to be as clear as possible to avoid confusion. The documentation on this project was very thorough. Each artifact had a written condition report, a line drawing indicating condition issues, and digital photos from at least two views. Each tray was digitally imaged as was each individual object. A package containing the image of the tray full of objects, images of each object and related condition reports was placed in the crate with the tray. A CD containing electronic files of all documentation traveled with the artifacts. Each tray of artifacts was photographed prior to shipping with the image printed and packed inside the crate to aid in unpacking and repacking. A listing of the objects in each tray was also included. The short time frame of this project demanded the development of a quick and easy, yet safe packing system.

Packing Methodology

Three employees from Museum Services worked on packing in the Science Museum's Conservation Lab for ten days, under the supervision of the Conservator. Together, the team applied their collective knowledge of packing and shipping and developed the techniques described below. One single packing method was not suitable for all the pieces. Traditionally, sensitive and fragile artifacts are packed in padded and lined custom carved wells or cavities. Often artifacts will be packed in individual containers to prevent them from bumping into each other. The artifacts must also be secured from moving around, but not held down so tightly that they are damaged. This method is labor intensive and requires a large amount of packing material. The challenge was to provide similarly safe packing without needing the intensive work required for individual custom cavities. The materials used were standardized for cost efficiency and ease of use. All materials were purchased at the beginning of the project (Table 1).

Trays and Crates

Artifacts were tied to modular trays in a variety of ways and the trays stacked upon each other in exterior grade plywood crates. Some large objects and particularly fragile objects were individually boxed. The goal was to be as systematic and consistent as possible, using variations on a theme throughout the system.

Table 1. Materials used.

White acid-free cardboard
Grey acid-free cardboard
Coroplast®
Ethafoam®
Zotefoam®
Tyvek®
Cotton twill tape
Acid-free blotter paper
Polyester batting
Acrylic felt
3M Jet Melt Adhesive 3764®
3M window sealing tape® (double stick tape)
Polyester (polar) fleece
Cotton stockinette
Polyethylene foam rod (backer rod and Tri-rod®)
IDenti™Pen

Criteria included maximum safety for the artifacts and speed and ease of packing. The crates were designed to fit through a normal door, and were opened from the top. They were shallow enough for two people to easily remove the bottom tray. One-inch Ethafoam® spacer strips were placed in the bottom, sides and top of the crate to hold the trays in place and to buffer vibration.

The bottom of each tray consisted of two layers of acid-free corrugated cardboard held together with hot melt adhesive. After pulling ties (see below) for the artifacts through the cardboard, a layer of corrugated polyethylene (Coroplast®) was attached to the bottom of the tray with double sided sticky tape. This bottom layer of Coroplast® helped strengthen the tray and protect the ties from being snagged from underneath. The sides of the trays were made from strips of one inch thick polyethylene foam (Ethafoam®) adhered with hot melt glue. The height of the foam strips varied between trays to accommodate objects of differing heights. Handhold cutouts provided easy access for lifting the tray above. The bottom interior was lined with ¼-inch thick Ethafoam® sheet. Hot melt adhesive was used to bond the foam to the cardboard. Outlines, diagrams, and object numbers clearly indicating the locations of the artifacts were drawn on the bottom of each tray with a felt tip marker with water based permanent ink (IDenti™Pen) (Fig. 1). The trays and crates were constructed at Museum Services Headquarters. They were fitted for specific objects and packed in the Conservation Lab.

Ties

Objects were tied directly to the trays or mounts with cotton twill tape. Cotton twill tape was threaded through the bottom of the tray and secured with hot melt glue on the bottom side. Tie down locations corresponded with the most stable areas of the objects and strips of blotter paper distributed stress from knots (Fig. 2). The tie was threaded through a hole at one end of the strip and slipped into a slit at the other end. This allowed the object to be removed from packing once the tie was loosened, without having to remove the strip completely from the tie. This also helped to prevent loss of the strips during unpacking. Larger sheets of blotter paper were used with the same system to secure and tie down the fringe on several artifacts (Fig. 2). Ties were often used in combination with the blocking, padding and wrapping systems, described below.

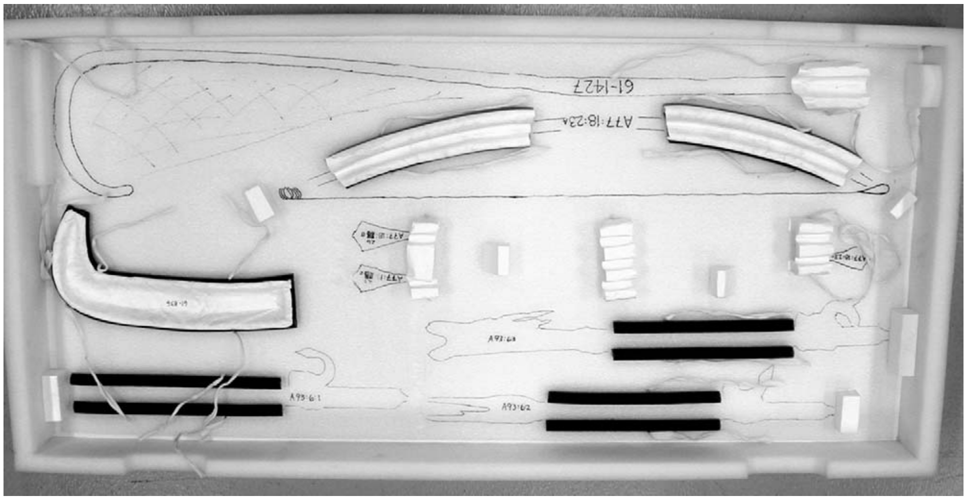

Figure 1. A completed tray, ready for packing.

Blocking

When possible, objects were blocked in place with Ethafoam® to prevent movement (Fuller 1992, Waller 1992) and the foam covered with Tyvek® to prevent abrasion. Polyethylene backer rod was used to create form-fitting cavities for the objects. Backer rod pegs held rigid objects in place (Fig. 3). Hot melt adhesive was used as an adhesive for the foam. Some small flexible objects were packed on individual padded acid-free corrugated cardboard mounts. These mounts now serve as permanent storage mounts in the collections storage area of the museum. The mounts and blocked areas were clearly marked with catalog numbers and outlines of objects (Fig. 1).

Figure 2. Gun case, 1-766. The gun case was tied to a padded board with blotter paper strips used to distribute stress.

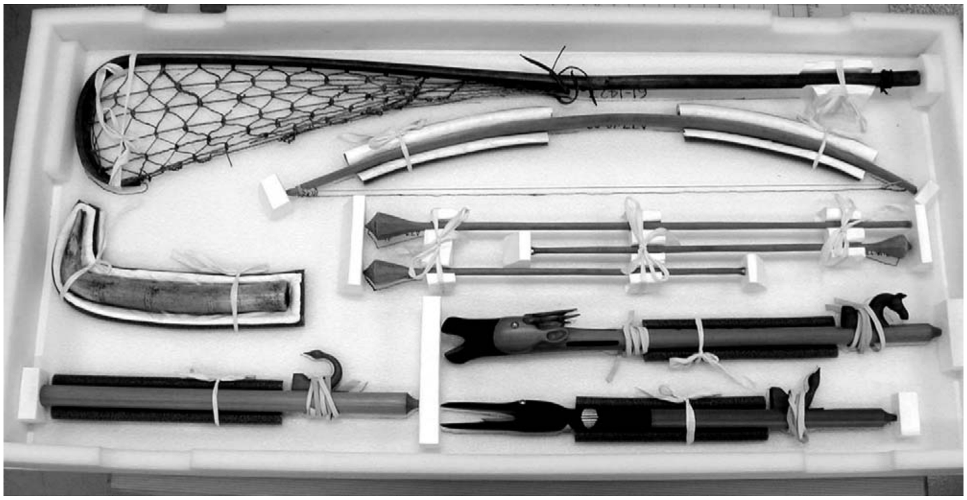

Figure 3. Objects are blocked and tied into place in the tray.

Wrapping and Padding

Objects with fragile surfaces and all objects with beadwork were wrapped in Tyvek® before they were tied down to the trays. The Tyvek® reduced the risk of abrasion and would also contain loose beads, should they happen to fall off. The Tyvek® packets closed on the top of the object, so nothing would have to be turned over while unwrapping. All wrappings were labeled with the object number. Each packet was tied to the tray with cotton tape with blotter paper strips to spread the pressure from the ties and knots (Fig. 4).

Soft padding served the dual purposes of internal support and protection for the objects in the trays. After the artifacts were secured, the tray was covered with a sheet of Tyvek® and a layer of polyester batting for protection. The Tyvek®

Figure 4. Beaded objects wrapped in tyvek packages, tied to the tray and ready to ship.

served as a barrier layer between the artifacts and the batting. The batting acted as a cushion and space filler preventing the artifacts from shifting in the event they should break loose. This system of using soft padding to keep objects from shifting was used extensively when Science Museum of Minnesota collections were moved to the new facility in 1999 (Anderson 2001).

Cotton stockinette tubes filled with polyester batting padded folds in hide and cloth materials, like shirts and bandolier bags. This prevented creasing and lessened the stress on fragile beadwork (Anderson 2001). Internal supports for vests and saddlebags were made from carved Ethafoam®. The foam form was covered with polyester batting and cotton stockinette. Internal padded mounts supported the artifacts and lent them some shape for display. Where the mount was visible, it was covered with polar fleece for aesthetic reasons.

Special Cases

Especially fragile objects, for example birch bark baskets, were packed in individual boxes, tied to their permanent storage mounts, blocked into place with Ethafoam® plank and then packed in the crates. Fragile pieces, like a small birch bark cone solidly filled with maple sugar, were wrapped in Tyvek®, tied to a padded mount, and secured into an individual box with foam planks wedged along the sides to prevent the board from shifting (Odegaard 1992). The eight boxes with individual artifacts in them were arranged into a single crate in the same manner as the trays. All the packing material was clearly labeled with the object numbers.

Very fragile and flexible artifacts had multi-purpose shipping, display and storage mounts constructed for them. The mounts consisted of acid-free corrugated cardboard, padded with 1/4 inch Ethafoam® covered in polyester fleece. The objects were tied or sewn to the mount, using cotton embroidery floss, or in one case silk thread. The mounted objects were wrapped in a Tyvek® envelope and the entire package was tied to the tray as described above. One artifact treated in this manner was a small 19th century bandolier bag. The bag was a concern because of its fragile beadwork and deteriorating silk. The padded board stabilized the piece sufficiently to safely ship it and to display it on a steep slant. The bag sustained no damage from shipping or exhibition.

Successes

The artifacts traveled to Spain and back without damage. Everyone on the project understood what their role was and was part of a real team effort. It worked well that the Registrar and the Assistant Curator/Collections Manager for Ethnographic Collections, acted as couriers and oversaw both the unpacking and installation. The Assistant Curator/Collections Manager for Ethnographic Collections also returned to Spain to oversee de-installation and preparations for the return shipment. This provided a standardized level of control over the artifacts. Members of TTI International, installation and exhibition specialists, who work throughout Europe, installed and de-installed the exhibition. Science Museum collections staff members that were at the installation and de-installation determined the level of packing documentation that was done, and also provided the Conservation Department with valuable feedback on how the packing systems functioned.

The collaboration with Museum Services (the art packing company) was also very beneficial. A highly skilled team, they worked well together and integrated into the Conservation Lab smoothly. Even though Museum Services were experienced primarily in packing fine art (flat art, paintings, sculpture, etc), Conservation staff set the standards and trained the packing team on specific techniques and use of materials, some of which were new to them. The packing staff designed and built the trays and crates. The first artifacts to be packed were the easiest to work with, often stable rigid objects that could be simply tied to the tray in combination with blocking. Once the Conservator was satisfied with the methodology, the packing team moved on to pack the more complicated pieces. All of this was done in the Conservation Lab, under the supervision of the Conservator. By working in this manner, questions and concerns were immediately addressed. When a technique did not work out as planned, a solution was found immediately through teamwork. By using each individual's strengths, the solutions to packing were highly creative and very successful.

Integration of volunteers and interns within the project also worked very well. The Conservation Department was fortunate enough at the time to have amongst its volunteers; a skilled storage mount maker, an artist, and a mechanical engineer. The storage mount maker added his expertise to the packing staff. The artist provided line drawings for the more complicated artifacts, aiding in condition documentation. The engineer designed and constructed special display mounts as requested. Interns filled in where needed, particularly with documenting packing techniques. As a result of the teamwork, the packing system for the outgoing journey meant that not a single artifact shifted in shipping.

Improvements Required

In this project, the amount of work that was accomplished in a short time was amazing. However, there is always room for improvement. While we were confident that the basic concepts and techniques used for packing the loan were sound, there was no time to test the packing systems, nor was there time to verify the packing documentation and make sure that it would be as easy to use as was hoped.

All such projects have a learning curve. Ideas were put into action, and refined, as we became more proficient at what we were doing. However, there was no time to go back and make the systems consistent. For example, during the packing process, the Conservator refined the attachment of the blotter paper strips under the ties. Originally, the ties were pulled through holes on either end of the strip and then tied. The revised design as described above came in the middle of the packing process and staff were unable to go back and fix all of the objects that had been tied into place. A number of paper strips were lost during the unpacking and unavailable for repacking in Spain.

Extra archival material had been included in the crates to be used for the exhibit installation. Unfortunately, there was not enough material provided and some of the actual packing materials were used for the installation. These supplies were not adequately replaced, and some objects were not as well secured on the return journey. Had there been more time allotted to packing, this problem could have been alleviated by physically attaching the materials directly to the trays, making it harder to remove them. This is a solution the Conservation Department has employed for years in the Science Museum of Minnesota's traveling exhibits.

As mentioned above, the Assistant Curator/Collections Manager for Ethnographic Collections returned to Spain at the close of the exhibition, to supervise re-packing the loan. Unfortunately, there was a smaller crew to pack the artifacts, and insufficient time was allowed for packing. The Assistant Curator/Collections Manager did not have time to personally check every tray and every artifact to ensure it was packed correctly. Not everything was packed as carefully as it had been at the Science Museum of Minnesota. As a result, one bandolier bag slipped in transit and arrived bunched at the end of its tray, but fortunately did not suffer any damage.

To avoid this problem, we recommend that the either same number of staff be available at the de-installation as at the install, or that more time be scheduled for de-installation. All of the people working on the install and de-install team were highly qualified and professional. However, there was simply not enough time to check and cross check that the objects were in the proper places and tied securely. In a situation such as this, where the time frame was short it would have been advantageous for the Conservator to be a part of the de-install team. Since the packing system was designed by the Conservator it would have been easier to make corrections to the packing.

While the artifacts had very thorough condition documentation, there were concerns with the packing instructions. One person's concept of clarity and obvious instruction does not always transfer to another. While we attempted to provide clear packing instructions in a visual way, it was not always the case. There was some confusion during the re-packing process at the end of the exhibition. This would have been less of a problem if there had been more time to refine and check the documentation.

Clearer visual packing instructions would have helped the repacking process immensely. Each tray had one photograph of its finished wrapped appearance included in the tray. A second photograph of the unwrapped appearance would have helped orient each artifact. Additional notation on the packing material would also have been beneficial. While a CD with all of the images was also sent, it was not made available to the unpacking and repacking crew. One solution for this is to return to the traditional condition report notebook, containing all images and reports and organized by crate and tray. There is a tendency for misplacing loose paper during the flurry of unpacking and re-packing.

Digital cameras were an indispensable resource for this project. Conservation staff were able to photograph the entire process and all of the artifacts quickly and access the images immediately. However, it's important to schedule enough time to properly save the digital files, to manipulate the images, and to print them. There were several late night hours spent getting all the images printed and associated with the correct artifacts and trays. There was not time to cross check all the images with object number lists and condition reports. As a result, there were a couple of transposed numbers and missing images. Additional time should have been allowed for this, or alternatively an additional person, more experienced with digital photography, should have been assigned the project.

Conclusions

The project was a success, although exhausting. We knew up front that the schedule was extremely abbreviated and that there would be no time for errors or changes in the plan once we started. Despite that, we agreed to the project because of the opportunity to loan 101 premier Native American artifacts from the collection to a unique exhibition in Spain.

If possible with projects like these, sufficient time should be made available to test the consistency of the packing systems, verify the packing documentation and make sure packing instructions are simple and understandable. Time should be allowed to properly save digital files of the specimens, to manipulate the images and to print them. It is also important to be able to cross check all the images with object number lists and condition reports.

If at all possible, the same number of staff should be available at the de-installation as at the install, or more time should be scheduled for de-installation if this cannot be achieved.

The success of the project described here was mostly due to a terrific team of skilled and creative people on both sides of the Atlantic. The plan was pulled together quickly and implemented with confidence. The resulting packing system and thorough documentation proved very successful. With a few minor improvements the job would have gone off without a hitch but was well worth the effort.

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CALLING ON GOD: THE GALLERY OBJECT DATABASE AT THE ROYAL ONTARIO MUSEUM

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Abstract.—The Royal Ontario Museum has embarked on an ambitious Renaissance project aimed at doubling attendance by the year 2007. Twenty-six individual gallery projects are proceeding almost simultaneously, drawing on collections from 20 disciplines, each with its own independent cataloguing system. A comprehensive Gallery Object Database (GOD) was developed in Microsoft Access 2003, containing a record of each of the 25,000 individual specimens or artifacts being considered for use in a gallery. Standards were developed in consultation with the curators and collection managers involved in the various gallery projects. A single database manager has control over creation of new records, which are then managed and updated by about 20 collection managers. The centralized database has eliminated the risk of double booking of objects into more than one gallery. Information such as specific conservation concerns (light, RH), conservation and mount making instructions, registration concerns, and exhibit location codes can be tracked in one place with current specimen location, preparation status, mount status, and gallery label text updateable. GOD information will ultimately be migrated into the main collections databases, complementing the much larger ongoing process of migrating the main collections databases from a variety of platforms into Access 2003

Introduction

In 2002 the Royal Ontario Museum (ROM) embarked on an ambitious Renaissance project (RenROM) aimed at doubling attendance by the year 2007. The project will result in over 300,000 square feet of new and updated galleries and public spaces opening over three phases including a landmark building addition designed by Daniel Libeskind, and major renovation of the heritage buildings (Royal Ontario Museum 2005). For the gallery planning process, following an extensive competition, the ROM contracted Haley Sharpe Design Limited (HSD) in Leicester, England.

It is estimated that some 20,000 specimens and artifacts will ultimately be installed in 26 new and refurbished galleries, which are being designed almost simultaneously. Each gallery has a design team consisting of designers and interpretive planners engaged by HSD and a coordinating curator from the ROM staff, who selects the objects and provides academic content. A contract academic advisor is hired where there is no one on staff with expertise in the particular collection discipline. Some galleries have several curators and a nominal coordinating curator. Other ROM academic and support staff, including collection managers, registrars, preparators, technicians, and conservators are also involved, as well as contract mount builders.

Gallery planning has been object driven. Initially, each ROM gallery team was asked to come up with their "120% list"—a wish list of the best and most significant material in the collections. Specimens and artifacts selected range in size from several metres long (mounted dinosaur skeletons) to less than a centimetre. Many were already on display and had to be moved, sometimes more than

Table 1. Selected multidisciplinary galleries in the RenROM project.

Gallery working name	Discipline collections involved
Age of Dinosaurs	Vertebrate Palaeontology, Invertebrate Palaeontology, Geology, Mineralogy, Entomology, Ornithology, Mammalogy, Botany
Age of Mammals	Vertebrate Palaeontology, Invertebrate Palaeontology, Invertebrate Zoology, Geology, Mineralogy, Ornithology, Mammalogy, Far Eastern, European, Textiles, West Asian, Ethnology
Earth and Early Life	Vertebrate Palaeontology, Invertebrate Palaeontology, Geology, Mineralogy
Earth's Treasures	Geology, Mineralogy, Ethnology, European, New World Archaeology, Egypt, China
Evoloution	All Life Sciences, Vertebrate Palaeontology, Invertebrate Palaeontology
Stair of Wonder	European, Mammalogy, Ornithology, Entomology, Invertebrate Zoology
Canadian Heritage	Canadiana, European, Ethnology, New World Archaeology, Mammalogy

once, as gallery spaces were emptied for demolition and renovation. Unlike the old, mostly discipline specific galleries, the new galleries will be multidisciplinary. This means that any one gallery may have specimens from several different collections, and any collection may be providing specimens for several galleries (Table 1). A tracking method was required that would immediately flag all objects being considered for gallery use, along with their destination gallery and any other relevant information. As most of the ROM collections have been databased, it would seem logical simply to incorporate the gallery information into the existing databases. However, there were several historical roadblocks to this approach.

ROM Collections Databases

ROM specimens and artifacts currently reside in 20 independent discipline collections, with data residing in about 30 databases (Table 2). Most of these (nine humanities with parallel registration databases, and six sciences) were downloaded from the Canadian Heritage Information Network (CHIN) platform in 1993 into Microsoft Access v. 2.0. The remaining databases were developed independently of CHIN on a variety of platforms. Except for certain numeric or date fields, no rules of entry were ever imposed by either CHIN or the ROM. Participating disciplines initially selected fields from an extensive dictionary of fields (see CHIN 2002a, 2002b) but received little guidance in how the fields were intended to be used. This resulted in considerable disparity not only in how data were recorded but also in the selection and content of fields from one database to the next. There is no mechanism for searching all the databases at once or for communicating information between databases. When CHIN devolved the databases to their home institutions in 1993, ROM selected Access 2.0 as a temporary platform until resources should come available to select and implement a permanent solution. Unfortunately, the resources to realize this transfer have not materialized. The Access 2.0 databases are becoming unstable, and the software is no longer supported. Work is underway to develop institutional standards for migrating the existing databases to Access 2003. This process comes too late to benefit the exhibit design process for RenROM.

Table 2. Status of ROM collections databases in 2005.

Natural Science collection databases:

Discipline	Platform	Downloaded from CHIN
Botany	Access 2.0 (flat file) using CHIN fields	No
Entomology	Access 97 (relational)	No
Geochronology	Superbase (relational)	No
Geology	FoxPro (flat file)	No
Invertebrate Zoology	Access 2.0 (relational)	No
Herpetology	Access 2.0 (flat file) using CHIN fields	Yes
Ichthyology	Access 2.0 (flat file) using CHIN fields	Yes
Invertebrate Palaeontology	Access 2.0 (flat file) using CHIN fields	Yes
Invertebrate Zoology	Access 2.0 (relational)	No
Mammalogy	Access 2.0 (flat file) using CHIN fields	Yes
Mineralogy	Superbase (relational)	No
Mycology	Access 2.0 (flat file) using CHIN fields	No
Ornithology	Access 2.0 (flat file) using CHIN fields	Yes
Vertebrate Palaeontology	Access 2.0 (flat file) using CHIN fields	Yes

World Cultures collection databases:

Discipline	Platform	Downloaded from CHIN
Canadiana	Access 2.0 (flat file) using CHIN fields	Yes
Egyptian	Access 2.0 (flat file) using CHIN fields	Yes
Ethnology	Access 2.0 (flat file) using CHIN fields	Yes
European	Access 2.0 (flat file) using CHIN fields	Yes
Far Eastern	Access 2.0 (flat file) using CHIN fields	Yes
Greek and Roman	Access 2.0 (flat file) using CHIN fields	Yes
New World Archaeology	Access 2.0 (flat file) using CHIN fields	Yes
Textiles	Access 2.0 (flat file) using CHIN fields	Yes
West Asian	Access 2.0 (flat file) using CHIN fields	Yes

For each discipline database in World Cultures there is a corresponding Registration database that includes Conservation fields.

Early in the project, HSD developed a set of Object Reference Sheets (ORS) in a Microsoft Excel workbook, one object per sheet, which included a low resolution image of the object and salient information provided by ROM staff, such as dimensions, weights, and special conservation concerns as an aid to design development. There was space to add gallery location codes, storage location, preparation tracking, and other information as the gallery development progressed. The plan was to print multiple hard copies of each sheet to distribute to all stakeholders—designers, curators, conservators, mount makers and installers. This system was cumbersome and there was no easy way to sort entries or to compare lists between gallery projects. More importantly, the ROM had no control over the data. Objects can be selected or rejected right up to installation. A live, ever-changing approach was needed.

At the same time, some of the gallery teams were keeping their own databases, often Excel spreadsheets, of all objects selected for their gallery, regardless of the discipline collection in which they were kept. While some of the fields resembled fields in the collections databases (catalogue number, genus and species), much of the information required for gallery design did not exist in all the current databases (dimensions, conservation concerns, common names, general comments relevant to the storyline).

RENROM Gallery Object Database

The fragile nature of the existing ROM collections databases and the fact that they are not related made it impractical to consider adapting the existing databases for gallery tracking purposes. A tracking system was needed immediately. The decision was made to develop a single comprehensive Gallery Object Database (GOD) in Microsoft Access 2003 that would hold a record of every object or artifact being considered for use in a gallery, along with a reference image. There were several reasons for selecting Microsoft Access 2003 as the platform for the GOD: it is an off-the-shelf product; it is compatible with many other database programs, so existing data in other formats could be readily extracted; most collections staff were already familiar with using an earlier version of Access so there was not a steep learning curve; and finally, Access 2003 was already being considered as an interim platform for the main collection databases. This account is presented from the perspective of the coordinating curator of a gallery and a primary database user (JW), the designer and manager of the database as well as a user (WP), and the coordinator of the Access 2003 migration (JS).

There are presently about 25,000 records in the Gallery Object Database, with 114 fields (listed in Appendix). As each curatorial team made its initial selection of objects for a gallery, data were loaded into the GOD from various sources, including the main collection databases as well as the early team gallery lists in spreadsheet or database format. Subsequent additions have been appended in blocks or sometimes one at a time. Much information has had to be entered manually.

The GOD is a flat file database application with a central database (back end) consisting of a single table for all of the data and several supplementary lookup tables used in the forms, and 30 or more linked databases (front end) for each gallery as well as Conservation, Production, Exhibit Design, Marketing Communications and other stakeholders. The forms for each of the linked databases filter the data so that collection managers and curators assigned to each gallery work only with the records relevant to that gallery. World Cultures artifacts have unique ID numbers (accession numbers) across all departments. Natural History disciplines have independent catalogue numbering systems so the same ID number can be duplicated across collections. Thus the unique identity (Access primary key) of each object is a combination of its catalogue number [ROMID] and its collection number [DisciplineID].

The system will not accept duplicates, so the same object cannot be designed into more than one gallery. Records of objects flagged for deletion from a gallery [DisplayStatus = deleted] are removed from the working form but are kept in the database in case the object is reinstated at a later date for the same or a different gallery. Only the database manager can add or delete records.

Curatorial, Conservation, Design, and Production teams each have unique concerns about the mounting and display of an artifact or specimen and fields are provided for each to document their wishes and concerns. For example, Design may want an artifact to be displayed at a certain angle, the Curatorial team may require a different angle to show a particular detail and Conservation may require

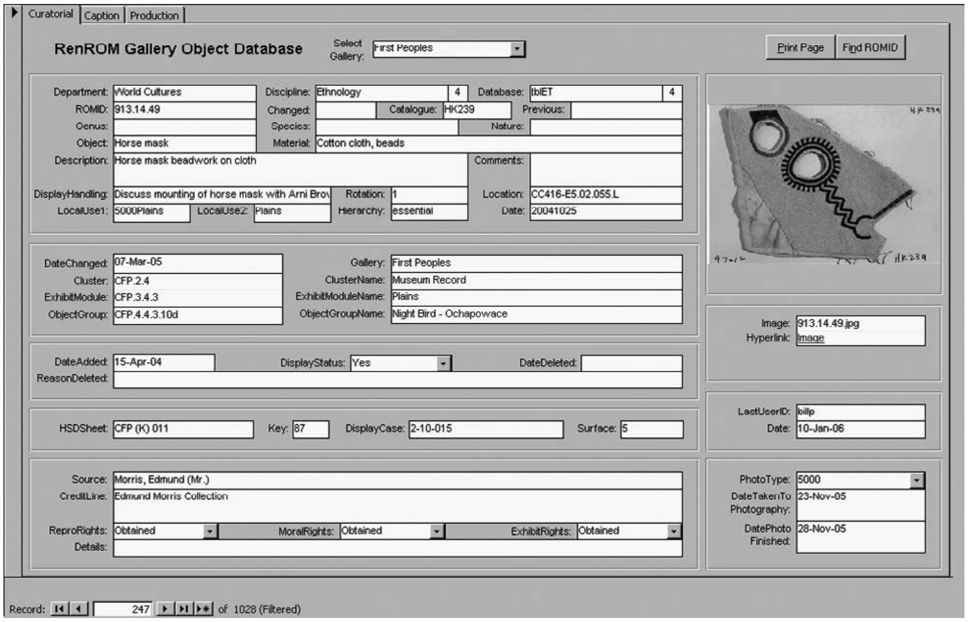

Figure 1. Curatorial screen of the Gallery Object Database main form.

a specific angle for protection and security of the artifact. Before a mount is constructed, Production can analyze the various concerns in the database and, if necessary, a compromise is reached.

Each record has a general image of the object as well as an image of its completed mount, once it is constructed, and the object on its mount. Some of the mounts are quite complex and, since the person who installs the object in a gallery is not necessarily the person who designed the mount, photographs of the mount and the object on its mount are crucial. The images are stored together in a single directory and for speed of delivery across the ROM network have all been resized to a uniform 300 pixels $\times$ 300 pixels, averaging about 25KB. Access programming code is used to display each image in forms and reports. Only the database manager is able to add new images. Where possible the image filename corresponds to the object's ROMID so that a simple update query updates the image field in the database eliminating typing errors. Each record also includes a hyperlink to a full size image of the object, which can be opened in a graphics program to see details and to print.

For each record, the form has grown to three pages containing Curatorial, Caption and Production data. A list of fields is given in the appendix. Figures 1 to 3 show the form for a single artifact in the ''Gallery of Canada: First Peoples.''

Applications, Benefits and Lessons

One benefit to the collections staff was the immediate upgrading of many old computers to handle the demands of Windows 2000 or higher. The GOD is proving its value in many phases of gallery development.

Scheduling.—Objects were initially assessed on their need for conservation

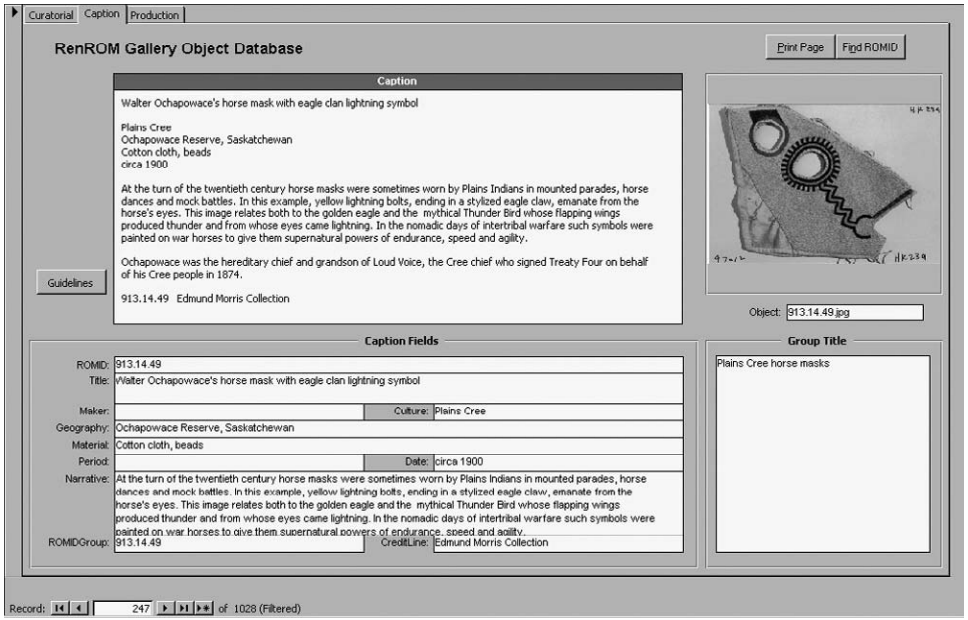

Figure 2. Caption screen of the Gallery Object Database main form. ''Group Title'' refers to text that applies to more than one specimen.

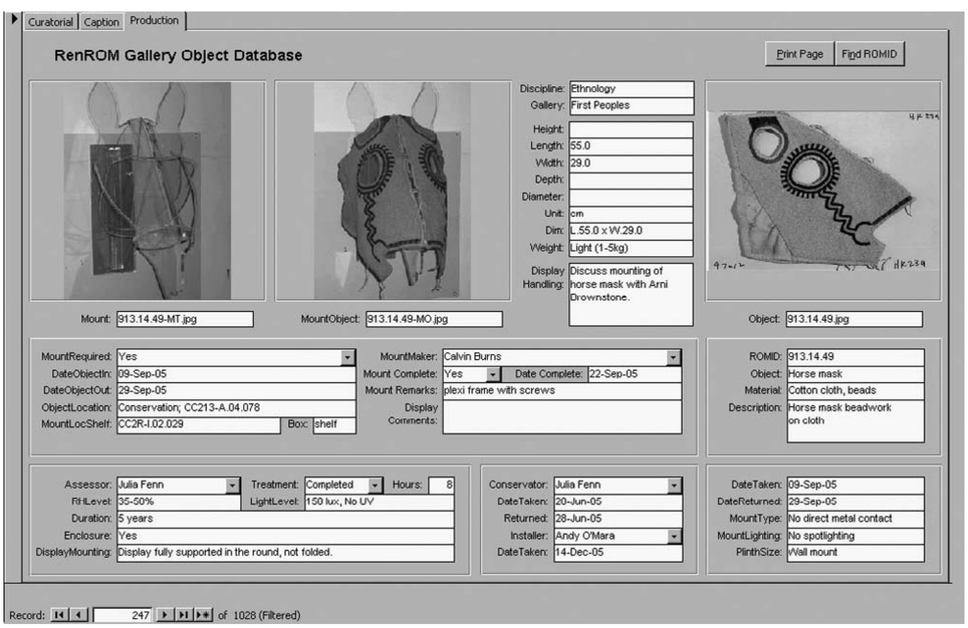

Figure 3. Production screen of the Gallery Object Database main form.

(A)
[Genus] [Species]
[Object], [ObjectNature]
[Geography (locality)**]**
[Period], [Date (age in years)**]**
[Narrative]
[ROMID] [CreditLine]

(B)
[Title]
[Culture]
[Geography]
[Material]
[Date]
[Narrative]
[ROMID] [CreditLine]

Excalibosaurus costini
Ichthyosaur
Lyme Regis, England
Early Jurassic, 180 million years old

Excalibosaurus was named for its long sword-like snout, extracted from the rock like the legendary sword of King Arthur.

47697 Gift of the Louise Hawley Stone Charitable Trust

Walter Ochapowace's horse mask with eagle clan lightning symbol
Plains Cree
Ochapowace Reserve, Saskatchewan
Cotton cloth, beads
circa 1900

At the turn of the twentieth century masks were sometimes worn horse by Plains Indians in mounted parades, horse dances and mock battles. In this example, yellow lightning bolts, ending in a stylized eagle claw, emanate from the horses eyes. This image relates both to the golden eagle and the mythical Thunder Bird whose flapping wings produced thunder and from whose eyes came lightning. In the nomadic days of intertribal warfare such symbols were painted on war horses to give them supernatural powers of endurance, speed and agility.
The owner, Ochapowace, was the hereditary chief and grandson of Loud Voice the Cree chief who signed Treaty Four on behalf of his Cree people in 1874.

913.14.49 Edmund Morris Collection

Figure 4. Fields used to build labels and examples for (A) a natural history specimen and (B) a world cultures artifact.

treatment or a display mount. Regular status reports from the database aid in scheduling priorities.

Design and text writing.—Lists can be generated by display case code for checking against detail drawings and text development. As well as object name, locality, age, donor recognition, and other provenance information, there are fields for descriptive narrative label copy. Copy for individual specimen labels can thus be generated directly from the designated fields in the database, requiring only minor editing and formatting (Fig. 4).

Object and mount status tracking.—Date and current location are tracked when an object is removed from storage for conservation or mount design and construction. This is vital because the object may go back into regular storage, or may be stored elsewhere until installation. The mount may stay with the object, or be stored separately. At the same time that the galleries are being updated, there is a ROM initiative to provide images and data on its website of 5,000 featured objects in the museum's collection. Since most of these objects are planned for exhibit and are therefore in the GOD, a separate section on the Curatorial page is reserved for tracking these objects through the professional studio photography process. At any time an object can be in one of many stages of the gallery process—conservation, production, photography, installation—and the database ensures the current location of object and mount is always available.

Images.—Two versions of the main form are provided, one of which displays the image of an object automatically on entering the record. However, scrolling through the records too quickly can cause the database to crash, as network access to the images cannot keep up with the display. A second form necessitates the user clicking a button to display the image. This would make it possible to use images larger than 300 × 300 pixels. However, limitations of the local area network can result in problems when printing reports with several records containing several large images per page. There is a trade-off between network speed and image size.

Collections database standards.—Basic taxonomic and provenance data were extracted from the main collections databases. In the process, errors, omissions and inconsistencies in the heritage data were noticed and corrected. Thus the standards for the heritage data were improved. While the GOD is considered a temporary database, and will not be maintained after the end of the RenROM project, curators and collections staff are anxious not to lose the information that has been generated about the specimens and artifacts during the process. As the main collection databases are migrated into Access 2003, provision will be made to import this information, enhancing the main databases. Thus, even though the GOD is not permanent, its development complements the standardization process for future migration of heritage data.

Summary

The Gallery Object Database was developed to address an immediate need that could not be met using existing digital resources. It was populated with data from a variety of sources: spreadsheets, databases, text files, email messages, and scribbled notes. Fields were defined in consultation with a diverse group of stakeholders to address curatorial/collection management, text development, and conservation/installation information requirements. Tightly enforced standards and control over record entry have resulted in a versatile database that can be used by all the various groups involved in the gallery development and installation.

A primary goal of the main collections standardization project has been to improve our databases so that they can serve multiple needs across the museum. The Gallery Object Database process has benefited from earlier standards work already underway and has also served to demonstrate additional uses for information that should be considered within the main collections databases, including gallery design and preparation applications and image management.

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Appendix. Field structure of the Gallery Object Database. Asterisk (*) denotes an Access primary key field.

Function	Field	Description	DataType	Size
System	ID	A unique number assigned automatically to each record.	AutoNumber	5
System	User	The logon username of the last individual who changed this record.	Text	255
System	RecordDateofChange	The date on which this record changed.	Date/Time	8
Object-Reference	Department	The department to which this object belongs.	Text	255
Object-Reference	Discipline	The departmental discipline to which this object belongs.	Text	255
Object-Reference	DisciplineID*	The ID for the departmental discipline to which this object belongs	Number	2
Object-Reference	Database	The departmental database where this object resides.	Text	255
Object-Reference	DatabaseID	The ID for the departmental database where this object resides.	Number	2
Object-Reference	ROMID*	The unique ROM identification number assigned to this object.	Text	255
Object-Reference	ROMIDGroup	The ROM identification number assigned to or group of objects.	Text	255
Object-Reference	ROMIDGroupCaptionRecord	A yes flag indicating this record is the caption record in a ROMID group of records.	Text	255
Object-Reference	ROMIDStatus	Administrative field for verifying the ROMID number for this object against the Registration source table.	Text	255
Object-Reference	DateROMIDChanged	The date on which the information changed in the ROMID field.	Date/Time	8
Object-Reference	CatalogueNumber	A catalogue number assigned to this object.	Text	255
Object-Reference	PreviousNumber	A number that had previously been assigned to this object.	Text	255
Object-Reference	Genus	The scientific genus to which this object belongs.	Text	255
Object-Reference	Species	The scientific species to which this object belongs.	Text	255
Object-Reference	ObjectNature	A description of the nature of this object, e.g. study skin, mount, skull.	Text	255
Object-Reference	Object	The name of this object.	Text	255
Object-Reference	Material	The material from which this object is made.	Text	255
Object-Reference	Description	A detailed description of this object.	Memo	65,535
Object-Reference	Location	The current location of this object.	Text	255
Object-Reference	LocationDate	The date on which the location of this object changed.	Text	255
Object-Reference	Comments	Curatorial comments associated with this object.	Text	255
Object-Reference	Hierarchy	Information indicating the prioritizing of objects for display.	Text	255
Object-Reference	Rotation	A numeric indicator of the display rotation of this object.	Text	255
Object-Reference	LocalUse1	Local field to store information of a temporary nature associated with this object.	Memo	65,535
Object-Reference	LocalUse2	Local field to store information of a temporary nature associated with this object.	Memo	65,535
Object-Reference	LocalUse3	Local field to store information of a temporary nature associated with this object.	Memo	65,535
Object-Dimensions	Height	The maximum height of this object.	Text	255

Appendix. Continued.

Function	Field	Description	DataType	Size
Object-Dimensions	Length	The maximum length of this object.	Text	255
Object-Dimensions	Width	The maximum width of this object.	Text	255
Object-Dimensions	Depth	The maximum depth of this object.	Text	255
Object-Dimensions	Diameter	The maximum diameter of this object.	Text	255
Object-Dimensions	Unit	The units used to measure this object, e.g. cm.	Text	255
Object-Dimensions	Dimensions	A concatenation of the maximum measurements of this object or additional measurements.	Text	255
Object-Dimensions	Weight	An approximation of the weight of this object.	Text	255
Object-Status	DateAdded	The date on which this object was added to the database.	Date/Time	8
Object-Status	DisplayStatus	An indicator, Yes or Deleted, whether or not this object will be displayed.	Text	255
Object-Status	DateDeleted	The date on which this object was deleted from the display	Date/Time	8
Object-Status	ReasonDeleted	The reason this object's display status was changed to deleted.	Text	255
Object-Photography	Image	The image filename of this object.	Text	255
Object-Photography	HyperlinkImage	A hyperlink to an image of this object.	Hyperlink	2,048
Object-Photography	MountImage	The image filename of the mount for this object.	Text	255
Object-Photography	MountObjectImage	The image filename of this object on its mount.	Text	255
Object-Photography	PhotoType	The type of photography needed for this object, used primarily for the ROM 5000 project.	Text	255
Object-Photography	DateToPhotography	The date on which this object was taken to photography.	Date/Time	8
Object-Photography	DatePhotographed	The date on which this object was photographed.	Date/Time	8
Object-Caption	NarrativeLevel3	A level 3 narrative associated with a group of objects including this object.	Memo	65,535
Object-Caption	GroupNarrative	A caption narrative associated with a group of objects including this object.	Memo	65,535
Object-Caption	GroupTitle	A caption title associated with a group of objects including this object.	Memo	65,535
Object-Caption	Title	A title associated with this object.	Memo	65,535
Object-Caption	ObjectStatus	The status of this object whether an original, cast, replica, model or reproduction.	Text	255
Object-Caption	Maker	The artist or maker of this object.	Text	255
Object-Caption	Designer	The designer of this object.	Text	255
Object-Caption	Culture	A cultural description of this object.	Text	255
Object-Caption	Geography	A geographical description of this object.	Text	255
Object-Caption	Period	A period description of this object.	Text	255
Object-Caption	Date	A date description of this object.	Text	255
Object-Caption	NarrativeObject	A Level 4 narrative associated with this object.	Memo	65,535

Appendix. Continued.

Function	Field	Description	DataType	Size
Object-Caption	DateCaptionChanged	The date on which information in any of the caption fields was changed.	Date/Time	8
Object-Caption	DateCaptionSent	The date on which the caption was sent to Haley Sharpe for editing.	Date/Time	8
Registration	Source	The acquisition source of this object.	Text	255
Registration	CreditLine	The credit line associated with this object.	Memo	65,535
Registration	ReproductionRights	The reproduction rights of this object.	Text	255
Registration	MoralRights	The moral rights of this object.	Text	255
Registration	ExhibitionRights	The exhibition rights of this object.	Text	255
Registration	CopyrightDetails	Copyright details for this object.	Memo	65,535
Conservation	ConservatorAssessor	The name of the conservator who assessed the conservation requirements of this object.	Text	255
Conservation	TreatmentRequired	An indication as to whether or not conservation treatment is required by this object or is completed.	Text	255
Conservation	AssessedHours	The number of hours assessed to treat this object.	Number	4
Conservation	RHLevel	The relative humidity level required by this object.	Text	255
Conservation	LightLevel	The light level required by this object.	Text	255
Conservation	DurationofDisplay	The duration of display for this object.	Text	255
Conservation	Enclosure	A description of the enclosure in which this object will be displayed.	Text	255
Conservation	Conservator	The name of the conservator who took this object for treatment.	Text	255
Conservation	ConservationTaken	The date on which this object was taken to Conservation.	Date/Time	8
Conservation	ConservationReturned	The date on which this object was returned from Conservation.	Date/Time	8
Gallery Design	Gallery	The gallery where this object will be displayed.	Text	255
Gallery Design	ClusterCode	The gallery cluster code assigned to this object.	Text	255
Gallery Design	ClusterName	The gallery cluster name assigned to this object.	Text	255
Gallery Design	ExhibitModuleCode	The gallery exhibit module code assigned to this object.	Text	255
Gallery Design	ExhibitModuleName	The gallery exhibit module name assigned to this object.	Text	255
Gallery Design	ObjectGroupCode	The gallery object group code assigned to this object.	Text	255
Gallery Design	ObjectGroupName	The gallery object group name assigned to this object.	Text	255
Gallery Design	ObjectNumber	A unique number assigned to this object for ordering and prioritizing within the display.	Text	255
Gallery Design	DateCodeChanged	The date on which a change was made to any of the Haley Sharpe fields.	Date/Time	8
Gallery Design	HSDSheet	The HSD sheet number on which this object appears.	Text	255
Gallery Design	HSDKey	The key number that relates this object to the layout drawing on the HSD sheet.	Number	4

Appendix. Continued.

Function	Field	Description	DataType	Size
Gallery Design	HSDDisplayCase	The HSD case or open display code assigned to this object.	Text	255
Gallery Design	HSDDisplaySurface	The HSD display surface code assigned to this object.	Text	255
Production	DisplayHandling	Curatorial comments on special requirements when handling or displaying this object.	Text	255
Production	DisplayMounting	Conservation comments on the methods required to display or mount this object.	Text	255
Production	MountDisplayComments	Mount makers' comments on object display considerations.	Text	255
Production	MountRemarks	Mount makers' production remarks about this object.	Text	255
Production	MountRequired	An indication as to whether or not a mount is required for this object.	Text	255
Production	MountTaken	The date on which this object was taken to be mounted.	Date/Time	8
Production	MountReturned	The date on which this object was returned from mountmaking.	Date/Time	8
Production	ProductionIn	The date on which a mount maker checked this object in for mount making.	Date/Time	8
Production	ProductionOut	The date on which a mount maker returned this object to the department.	Date/Time	8
Production	ProductionLocation	The storage location of this object during production of the mount.	Text	255
Production	MountMaker	The name of the mount maker assigned to make the mount for this object.	Text	255
Production	MountComplete	An indication as to whether the mount has been completed.	Text	255
Production	MountCompleteDate	The date on which the mount was completed.	Date/Time	8
Production	MountLocationShelf	The storage shelf location of the mount for this object.	Text	255
Production	MountLocationBox	The storage box location of the mount for this object.	Text	255
Production	MountType	The type of mount used to display this object.	Text	255
Production	MountLighting	The type of display case lighting needed to display this object on its mount.	Text	255
Production	PlinthSize	The size of plinth used to display this object.	Text	255
Production	InstallationTaken	The date on which this object was taken for installation into the gallery.	Date/Time	8
Production	Installer	The name of the individual who took this object for installation in the gallery.	Text	255
Production	InstallLocation	The temporary storage location of this object before installation into the gallery.	Text	255
Production	InstallDate	The date this object was installed in the gallery.	Date/Time	8

FROM THE LEDGER TO THE WEB: SETTING 21ST CENTURY DOCUMENTATION STANDARDS FOR THE COLLECTIONS OF THE NORTH CAROLINA STATE MUSEUM OF NATURAL SCIENCES

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Abstract.—The Research and Collections Section of the North Carolina State Museum of Natural Sciences consists of eight units: Mammals, Birds, Reptiles and Amphibians, Fishes, Invertebrates, Paleontology, Invertebrate Paleontology and Geology. Prior to this project, only a few units had preexisting electronic databases. We purchased an MS Access-based framework from the Florida Museum of Natural History, which we modified after developing comprehensive documentation standards for fields common to all units. Documentation standards were created by examining our own ledgers and comparing these with standards used at the National Museum of Natural History, Smithsonian Institution and the Academy of Natural Sciences of Philadelphia. Dictionaries were created to help maintain these data standards. While development is ongoing, seven of the eight units have now gone live with unit specific databases. These relational databases meet the myriad requirements for each unit's collection and will soon be converted into a web-based format searchable by researchers and the general public. In developing databases we recommend that all users be involved, goals are determined beforehand, comprehensive documentation standards are created, the strengths and limitations of available technology should be considered, robust data management strategies should be developed, and training guidelines and procedures established.

INTRODUCTION

The North Carolina State Museum of Natural Sciences (NCSM) was founded in 1879 by the North Carolina General Assembly "to illustrate the agricultural and other resources and the natural history of the State." Today, as it was in 1879, the Museum's mission is to educate the people of North Carolina. During the past century, the focus has shifted from a multipurpose institution displaying agricultural and natural resources to a natural sciences museum concentrating on documenting and preserving the state's biological diversity, promoting environmental awareness, and relating the natural sciences to everyday life.

The Research and Collections Section of the Museum is made up of the following eight units: Mammals, Birds, Reptiles and Amphibians, Fishes, Invertebrates, Paleontology, Invertebrate Paleontology, and Geology. The collections are home to approximately 1,761,000 specimens. More than 95% of the specimens are from North Carolina and the Southeastern and mid-Atlantic United States. Most of the biological collections contain between 90–100% of the species known to occur in North Carolina within the major taxonomic groups targeted for collection. Table 1 shows the method of cataloging that each unit was using prior to this project.

There was an obvious need to standardize the method of cataloging in order to advance the museum by putting its collection information on the web. Therefore, over the last several years, we have undertaken the task of establishing relational databases that meet the myriad requirements for each unit's collection but still allow for the data to be compiled into one master database. The order that each unit was tackled was not determined by the collection size, but by the willingness of the curatorial staff to devote the time needed to customize the

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database for their specific needs. Due to the fact that each unit has a unique database with some structural differences, describing the intricacies of each unit's database would be overwhelming. Therefore, we will address the commonalities between all of the databases but will focus on the specifics of the fishes database because it is the template from which all of the other databases have been created. In this case study we will show how the database was developed, with particular emphasis on how we developed and applied data standards.

Requirements and Standards

Our first step was to define the requirements for this multidimensional, multi-user system and then to develop documentation standards. By involving all of the users in every step of the process, we were almost assured that each unit would have all of its requirements and needs met by the end product. Our requirements were: the database had to be able to adapt to changing software and hardware so as to not be instantly obsolete; the product had to be managed in-house; the database had to allow us to import existing databases and be able to export data into common formats for other researchers; the product had to be simple enough for those that are not computer or database experts to use, but robust enough to streamline the entire collection management process. Finally, we needed to be able to develop a comprehensive disaster mitigation strategy that allowed for simple back-ups and data recovery, which had to be compatible with our existing server back-ups in order to automate permanent data storage.

Once we had established our requirements, we began searching for a solution that would meet our needs. Due to the criteria set for us by the Information Technology Department (IT) of the North Carolina Department of Environment and Natural Resources, under whose jurisdiction our museum falls, we were required to use Microsoft Access as the platform. This restriction limited our search tremendously but one of the staff members had experience with the Florida Museum of Natural History's (FLMNH) Fishes Database. Their database met most of our requirements and was acceptable to the IT people involved. The other option would have been to develop the database in-house, but we had neither a database manager nor developer position at the time. Therefore, the decision was made to purchase the existing database structure from FLMNH. Along with the software, we were provided with a Database Users Manual (Paine 1999) that outlined the various forms, their usage, and gave management suggestions. We were also able to establish a database manager position. The person in this position would be required to modify the purchased product to meet the needs of all eight units and then maintain each of those databases. Since we were purchasing the structure of the fishes database from FLMNH, we decided to begin by modifying this product for use in the Fishes Unit of NCSM. We would then take that product and make the necessary modifications for each of the other seven units in our museum.

One of the most vital prerequisites for the multi-unit system we hoped to develop was the creation of documentation standards for all units. Therefore, we took a significant amount of time in developing standards within and among the units. We felt that it was imperative that we had these documentation standards in place before development of the databases began and especially before entering data. As was stated in the introduction, we began this project with disparate

Table 1. Eight units of the Research and Collections Seciton of NCSM and their method of cataloging prior to this project.

Unit	Method of cataloging
Mammals	Excel
Birds	Dbase
Reptiles and amphibians	Dbase
Fishes	Handwritten ledger
Invertebrates	Dbase—crayfish only
	Handwritten ledger—other
Paleontology	Handwritten ledger
Invertebrate paleontology	Excel
Geology	Handwritten ledger

methods of cataloging among the units (Table 1). A few of the units had produced some form of documentation standards but comprehensive documentation standards had not been developed. We knew that in order to be able to have a collections-based web presence, it would be imperative that we create documentation standards that would limit data entry into certain fields for ease of retrieval. We also knew that certain fields would need to be unconstrained fields so that the cataloger could enter information in more of a freeform manner.

All interested parties from the eight units met and narrowed down the common database fields for all of the units. After this, we developed documentation standards for each of those fields. We developed standards by examining acceptable entries in those common fields within each unit, within their respective databases or ledgers. Then we compared our standards with the standards for the National Museum of Natural History, Smithsonian Institution and the Academy of Natural Sciences of Philadelphia, PA. We had staff that had worked in these institutions and had intimate knowledge of their data basing standards and styles. Each unit then took the documentation standards for the common fields among all of the units and continued developing standards for fields that would be specific to their database. These documentation standards were then developed into manuals that are used for training of personnel. They have become invaluable tools in each of the units. Realizing the amount of effort that would be needed to get the databases linked into one master database and then uploaded to the web, much time was expended in standardization in order to reduce the future workload. We also wanted to take global documentation standards into account and adopt them when possible.

In an effort to maintain the standards developed, we took multiple steps to limit data entry mistakes. These methods included drop-down boxes, data dictionaries, and dividing data entry into temporary and permanent tables. The dictionaries and drop-down boxes are incredibly useful in constraining the data choices and thus limiting data entry error. We also used a system that divides the database into temporary and permanent tables in an effort to catch errors before the data is used for outputs.

Structural Features

While the framework from FLMNH contained many of the features that we required, changes to the user interface and some additions and modifications to the structural features were necessary. The technology and temporary data storage were features already available in the database. The dictionaries and drop-down boxes were features that we added in-house, along with the modification of certain fields within the forms, queries, and tables to match our style of cataloging.

Technology

By using a Microsoft product, we knew it would be well supported, not only by Microsoft, but also by our own IT department. The software package is fairly common and thus we could limit expenditures for support and training and manage it in-house. The software chosen is a relational database split into front-end code files and a back end data file to accommodate multiple users. If we outgrow the current format, we can easily migrate the data to a more advanced package, such as an SQL server for the back end, without having to adjust the front end or completely switch software packages. Also, since we purchased the framework from a museum that had published their data to the web (FLMNH 2005), we have a blueprint to follow in establishing our own web presence.

As mentioned above, this database was split into front end and back end files, allowing for data entry from multiple stations concurrently. The code file consists of all of the forms, queries, reports and code, and is installed on every machine that needs to have access to the database. The data file contains all of the data tables and is installed on the server. The code files are linked to the data file which allows simultaneous data entry with no conflict. This also allows the database administrator to make changes/additions to the master code file while others are working, which can then be updated at a more convenient time. This permits multiple users to perform various functions, with no data disturbance, and greatly improves the speed and performance of the database.

One of the most useful features of MS Access, in our case, is that it is a relational database. Therefore, data can be linked in a one to many relationship, meaning that a single record from one table can be linked to multiple records from another table. This relational data base structure is shown in Figure 1. For instance, as with fish, many different species can be collected at one locality. The locality information is entered once and given a specific field/locality number. This number is then entered with each of the species into the specimen information form (Fig. 2). This eliminates multiple entries of the same data, which greatly reduces data entry time.

Another important feature of a well-managed MS Access database is that it is user friendly. A simple, event driven user interface allows those that are not technologically oriented to navigate effortlessly through the database. Even a novice user can maneuver through all of the functions and produce outputs by using push-button driven menus that provide on screen instructions as well as pop-up windows.

Temporary Data Storage

The initial storage of data in temporary tables is a key feature of the database for maintaining data standards. This data is checked by the curator or collection manager and then appended to the final tables. While the data entry personnel utilize the dictionaries and drop-down boxes, it would be impossible to completely eliminate data entry mistakes. The append process involves examining each record

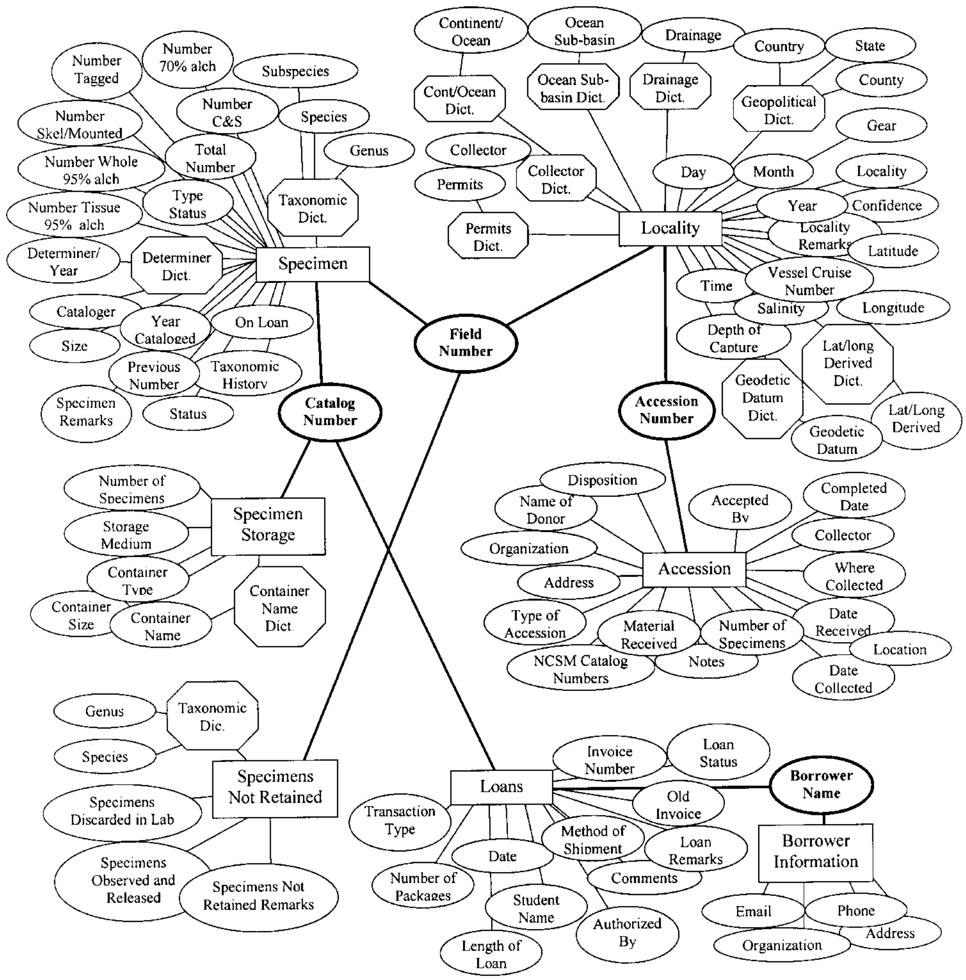

Figure 1. Conceptual view of the relational structure of the NCSM fishes database. Bolded ovals are the linking fields between tables. Dictionaries, depicted as octagons, limit the fields which are joined behind them.

individually. For this process, the curator or collection manager uses forms that are identical to those in Figure 2, but also contain an append button. As the administrator moves through the form, they can examine each field for mistakes and fix anything that violates a data standard. Once the data is validated, it is appended by clicking the append button on the form. This action automatically moves the data from the temporary to the permanent tables. All outputs are created from the data contained in the permanent tables, including things such as labels, reports, loans, exports, and printed archival catalog pages.

Dictionaries and Drop-down Boxes

To assist in maintaining data standards our database uses multiple dictionaries (Fig. 3) and drop-down boxes, which are all expandable. This feature not only minimizes data entry error and maximizes efficiency but it has allowed us to hire

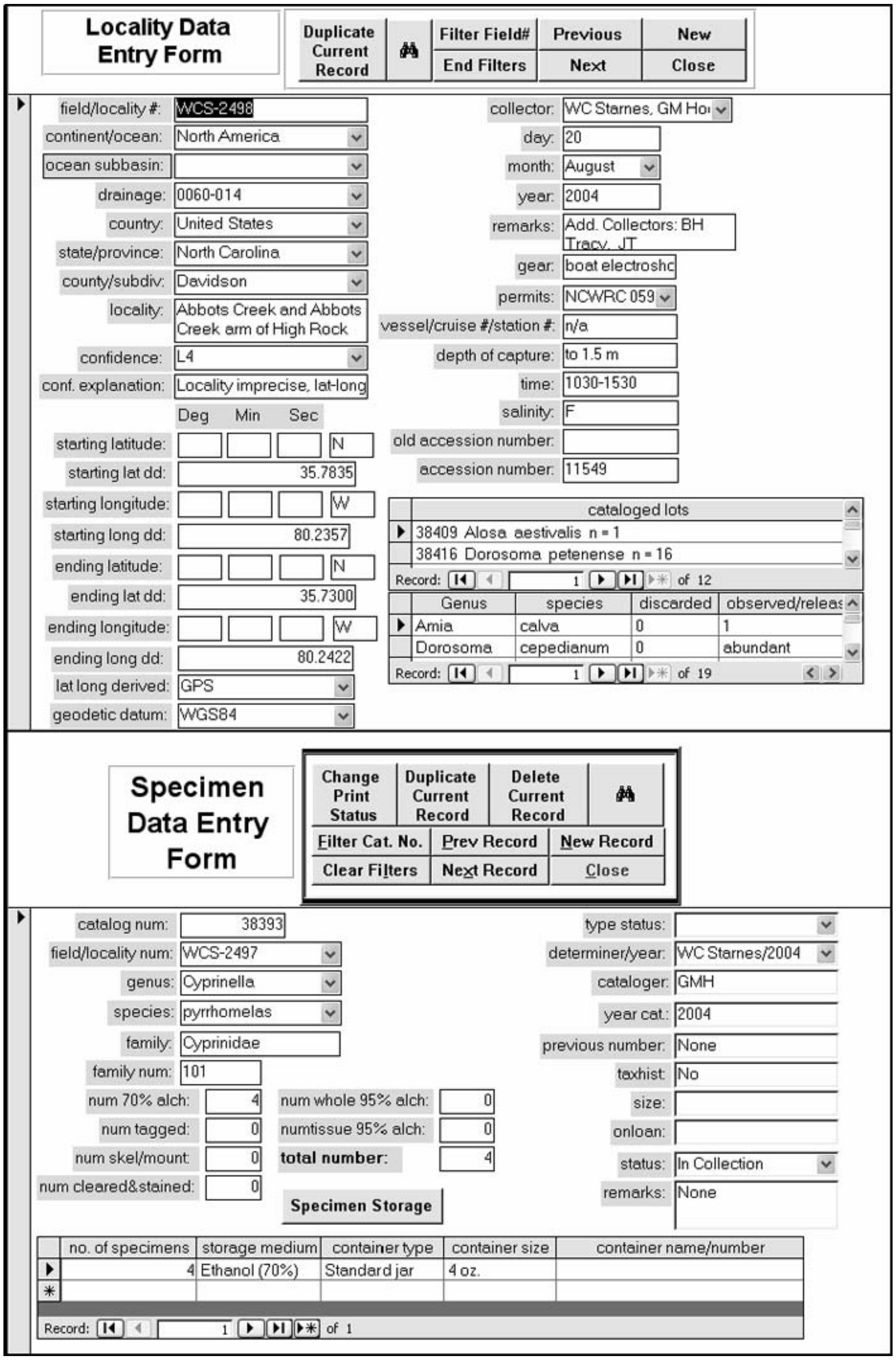

Figure 2. The locality and specimen data entry forms for the NCSM fishes database. The remarks field in both forms is an unconstrained field for any other pertinent information.

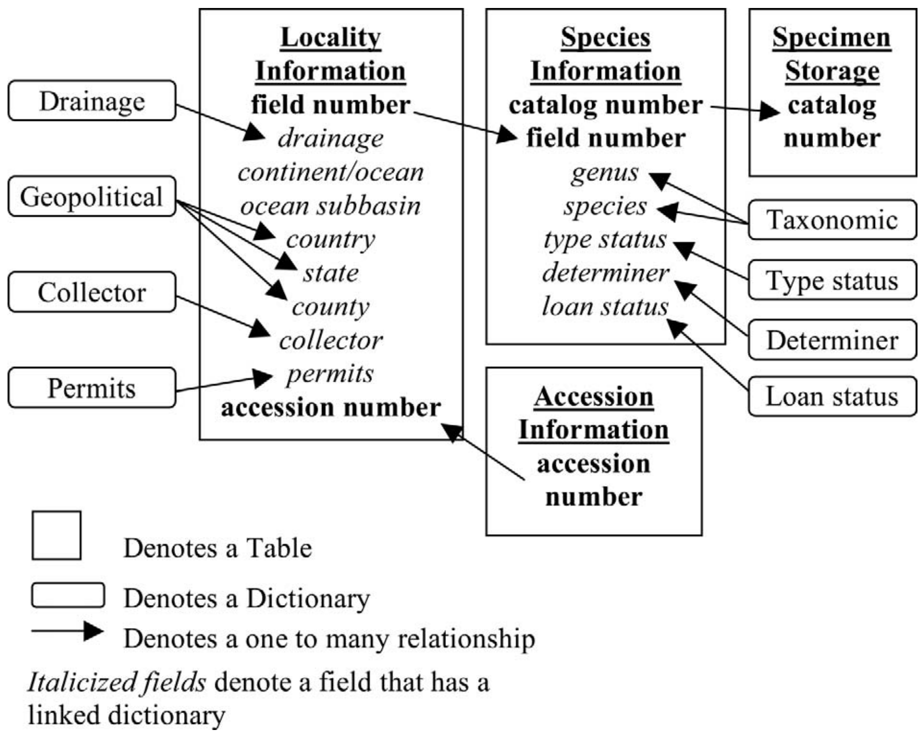

Figure 3. Dictionaries that govern data entry for the NCSM database.

data entry personnel that have computer skills rather than biological expertise. Efficiency is maximized because the fields auto-populate as the user begins to type. Error is minimized because the dictionaries and drop-down boxes are hierarchical. For example, if the genus *Notropis* is entered into the genus field, the only species that are visible in the drop-down list for the species field are those within that genus. The geopolitical dictionary also works in the same manner.

While these dictionaries aid in maintaining data standards, cataloging is a dynamic process, therefore we developed two methods for updating the dictionaries. The first method is administrative; only staff that have administrative privileges in the database are able to add, delete, or edit values in the dictionary. The other method is user updated; this allows data entry personnel to add values as they are cataloging. The user-updated method is used for dictionaries that are only populated from values from the ledger, while administrative updates are used for dictionaries where curatorial expertise or the use of multiple references is needed.

Each unit deals with different groups of specimens, therefore not all the dictionaries are shared among the units. It was the responsibility of each unit to compile the unique dictionaries that they would need for their individual databases. Those dictionaries that are specific to the individual units are taxonomy (limits values for genus, species and subspecies; with the exception of the Geology Unit which does not use a taxonomic dictionary), determiner, permits, and collector. The determiner, collector, and permits dictionaries are user updated. When a new value is entered into the corresponding field, a prompt appears asking the

Table 2. Sources of dictionaries that were not created from existing ledger entries.

Dictionary	Source
Geopolitical	Obtained from the Department of Botany, Carnegie Museum of Natural History, Philadelphia, PA
Drainage	Compiled in-house, using DeLorme Topo USA 4.0, gazetteers, and various atlases
Fish taxonomy	Compiled in-house (Eschmeyer 1998, Nelson et al. 2004, Starnes in press)
Invertebrate taxonomy	Compiled in-house (Hobbs 1989, Huys 2003, Martin and Davis 2001, Turgeon et al. 1998, Williams et al. 1988)
Herpetology taxonomy	Compiled in-house (Crouther 2000)
Paleontology taxonomy	Compiled in-house (Carroll 1998)
Invert paleontology taxonomy	Obtained from the Peabody Museum of Natural History, Yale University, Invertebrate Paleontology Unit
Mammal taxonomy	Obtained from the National Museum of Natural History, Smithsonian Institution, Division of Mammals (NMNH 2005)

user if they want to add this value to the dictionary. They can then proceed or cancel the operation. It is the responsibility of the database administrator to check these values to ensure that they meet the standards established.

Dictionaries that are shared between units include ocean sub-basin, continent/ocean, drainage, geopolitical (limits values for country, state, and county), type status, confidence, lat/long derived, and loan status. These dictionaries are comprehensive, but if a new value has to be added, the database administrator has the authority to update as necessary. By limiting these updates to administrators, it ensures that these dictionaries comply with our own data standards.

Whenever possible, dictionaries were acquired from other institutions that were generous enough to share their data. In the case that existing dictionaries were not available, we used existing data from our own collections, or gathered the information from other sources and compiled it in-house. The sources for many of the dictionaries are given in Table 2.

For aquatic collections, the hierarchical drainage dictionary, which was created in-house, has a drainage number assigned to every drainage in the world. It is not yet completely comprehensive with regard to sub-basins, but most North American and selected basins elsewhere are supplied with sub-basin designations. Beyond these, drainages are fleshed out with sub-basin designations as needed. Each drainage number corresponds to a hierarchical arrangement of basins and can denote the hierarchy down to six levels of sub-basins. For a given collection, data are retrievable at any given level in the internested hierarchy.

For fields with limited values that change infrequently, we used drop-down value lists instead of dictionaries. These drop-down boxes are form specific, therefore very easy to create, but more difficult to keep updated than a dictionary. In order to update them the administrator has to go into the design view of the form and change the value list every time new values are added. Figure 2 shows the two most used data entry forms within the fishes database. All of the fields with arrows have either a dictionary or drop-down box attached; the specimen storage sub-form arrows are displayed when the cursor is in the field. The fields that use drop-down value lists are confidence, geodetic datum, month, storage medium, container type, container size, container name, and status.

Database Features

Another important factor in choosing a single database for all sections was the standardization of outputs. Before the implementation of this product, each section had unique labels, loan procedures, and reports. By converting each unit to this database, it allowed for the production of common outputs. Even though the outputs might display different fields, the format and layout would look similar, giving us a museum-wide standard. All of the outputs currently produced from our database, along with the event driven menus for them, were either completely created in-house, or greatly modified from the original framework.

Labels are one of the main outputs of our database. During the modification stage, we realized that we would need to update the way in which labels were created. Originally they had been handwritten or typed on Resistol paper (36 lb) using permanent, waterproof 172-B ink. The number of suppliers for Resistol paper in the United States has greatly diminished and we could only find the paper in very large sized sheets; therefore production of printed label stock was costly. Handwriting or typing the labels was also very time consuming and inefficient for creating duplicate labels. We needed to be able to mass produce the labels and have a consistent format. Laser printed labels were an option but without applying an acrylic coating (Zala et al. 2005), our labels did not hold up in our ethanol stored collections. Our curators were not in favor of using laser printed labels because studies have not been conducted on the effects of acrylic on specimens and because of past performance of non-coated labels at other institutions. We therefore decided to go with a label printing system that was being used in the Division of Invertebrates of the National Museum of Natural Sciences, Smithsonian Institution and at the Biological Resources Division of the United States Geological Survey, Gainesville, Florida. After consulting with the staff and examining samples from both institutions, we purchased a Datamax I Class Thermal Printer. This stand-alone printer thermally prints the labels on a plastic medium. The printer, plastic medium, and ribbon are readily available (Alpha Systems, Midlothian, Virginia). To further improve the process, we developed a system of label printing within the database (Fig. 4).

The process begins when the user selects the storage medium and container size in the storage sub-form within the Specimen Information Form. The user then moves to the main menu for labels and selects, using the drop-down boxes, a range of catalog numbers that need to be printed and then clicks on the various buttons to view the labels. There are multiple queries that will then run in the background. The first query finds all of the information that will be put onto each label. The next query limits the label size to the container size and only pulls those labels which have a print status of ''no.'' A print preview of the labels appears and this is another point at which the data can be proofed. Once printed, a query runs which asks the user, before closing the print preview screen, if he/she wants to update the print status to ''yes.''

Another function of the database is loan management. The database has significantly decreased the time needed for processing loans and standardized the loan process. Multiple loan related functions can be accomplished using the loan

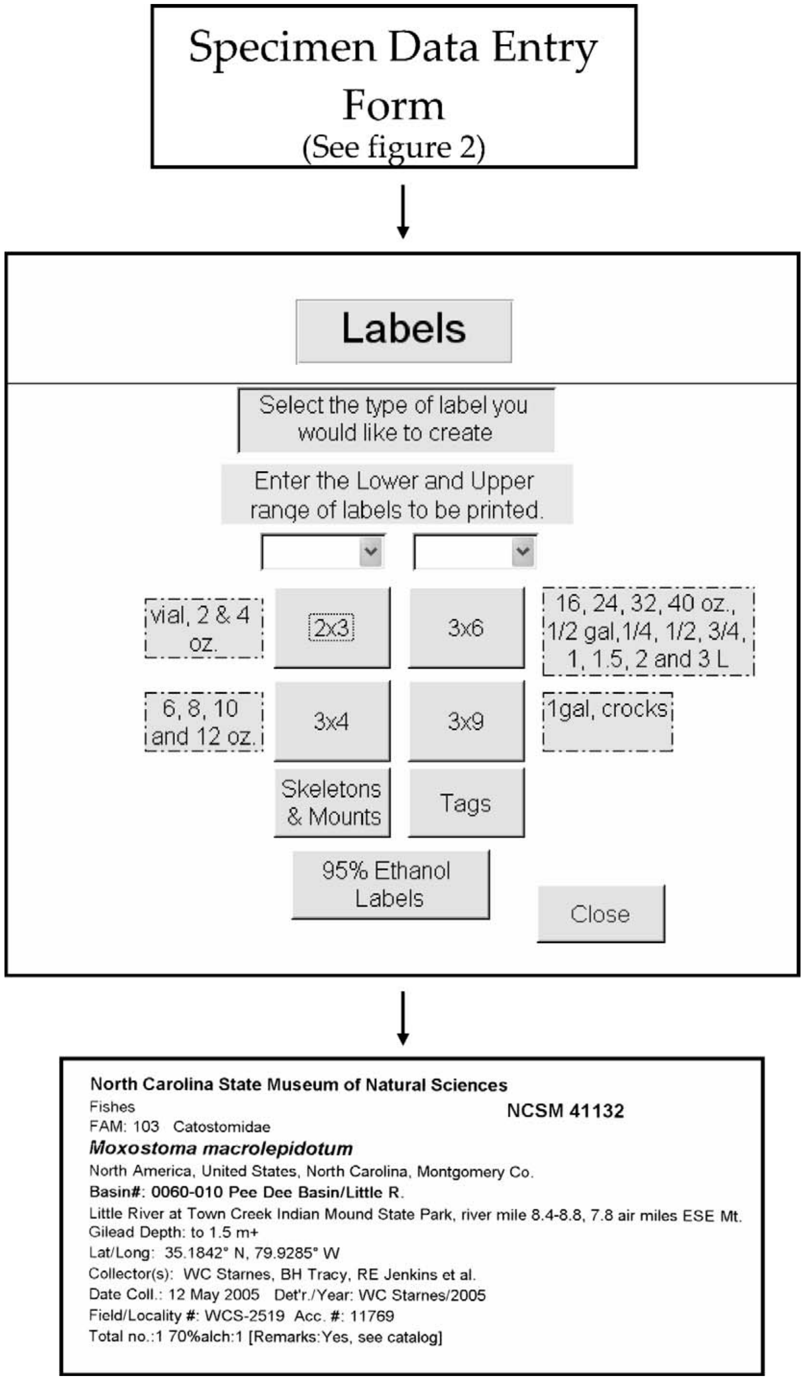

Figure 4. Label creation process for the NCSM fishes database.

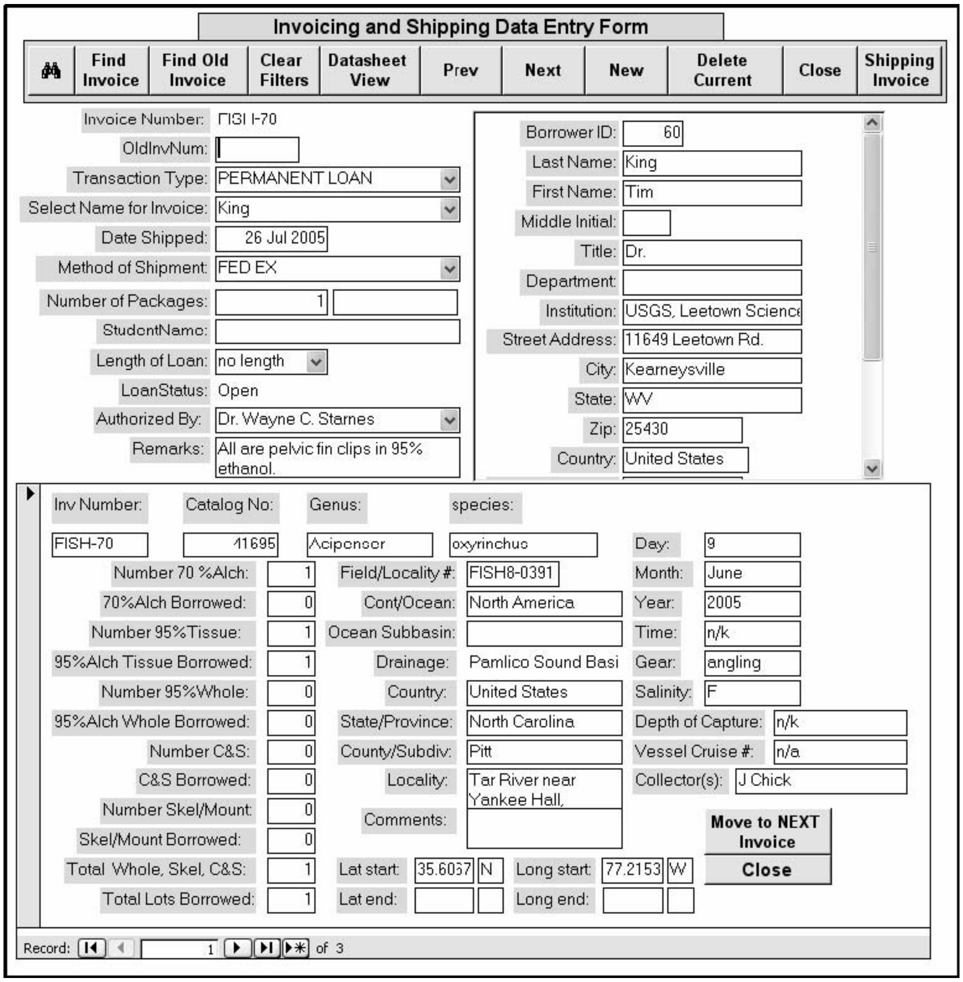

Figure 5. Loan form for the NCSM fishes database.

main menu form. They include adding and editing loans, adding borrowers, creating shipping forms, and various statistics, including loan status for specimens, borrowers, etc. The loan form (Fig. 5) gathers data from four different tables, allowing the user to process a loan with minimal data entry.

Reports are a vital part of any museum database. By having all of our information entered in the database, we can create a large variety of reports using simple queries and push-button driven menus. Figure 6 is a screen shot of one of the pages of our permit reports. Not only can we show all of the species that we collected and cataloged, but we can also show anything that was discarded, as well as what we observed in the field.

Even though we perform frequent back ups and have multiple copies of the database, it is imperative to have a printed archival version of the data. The pages that are created from our database are printed both numerically and taxonomically. They are laser printed on 25% cotton rag and stored in binders in fireproof cabinets. If a record is updated in the database, the archival paper version can be

Summary of Fish Collections Pursuant to NCWRC Fish Collection License 0599 (Yr. 04)

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Wayne.Starnes@ncmail.net

Field/Locality#: **WCS-2498**
Cont./Ocean: North America
Drainage: Pee Dee Basin/Yadkin R.
Country: United States State: North Carolina County: Davidson
Locality: Abbots Creek and Abbots Creek arm of High Rock Reservoir, two areas, from about 375 m below I-85 crossing downstream 2.4
miles to head of reservoir and E bank of reservoir 1.3 miles S of NC 47, average 5.0 air miles S of Lexington
Start: 35.7835° N, 80.2357° W; End: 35.73° N, 80.2422° W (locality imprecise, lat-long approximate)
Geodetic Datum: WGS84 Vessel/Cruise
#/Sta. #: n/a Date Coll.: 20 August 2004 Time: 1030-1530
Collector(s): WC Starnes, GM Hogue, ME Raley et al. Gear: boat electroshockers Depth of Capture: to 1.5 m Salinity: F
Locality Remarks: Add. Collectors: BH Tracy, JT DeBerardinis, RJ Heise; Add. Field #: GMH-2004-05

Specimens Catalogued

NCSM Cat#	Family	Genus	species	Common name	Total Number of specimens
37925	Cyprinidae	*Lythrurus*	*matutinus*	Pinewoods Shiner	1
37926	Cyprinidae	*Nocomis*	*leptocephalus*	Bluehead Chub	5

Specimens Released and/or Not Catalogue

Family	Genus	species	Common name	Number observed/released in the Field	Number discarded in the lab
Amiidae	*Amia*	*calva*	Bowfin	1	0
Clupeidae	*Dorosoma*	*cepedianum*	Gizzard Shad	abundant	0

Figure 6. One page of a permit report from the NCSM fishes database.

updated by simply hand writing the new information, using a permanent ink pen, or reprinted.

Another aspect of the database is that it allows for very simple imports and exports. As was discussed in the introduction section, each unit had different ways of cataloging prior to this project and several of them had existing databases. It was imperative that we were able to take any of the existing databases, i.e., Dbase and MS Excel, and import them into the new database. While there were some challenges that will be discussed later, the ability to easily import large sections of data was vitally important.

In addition to imports, we frequently have to export data to respond to requests from researchers and other institutions. Before this project, that entailed searching and compilation from handwritten ledgers or cumbersome flat data files. Now the exports can be performed simply from within the database and sent in various

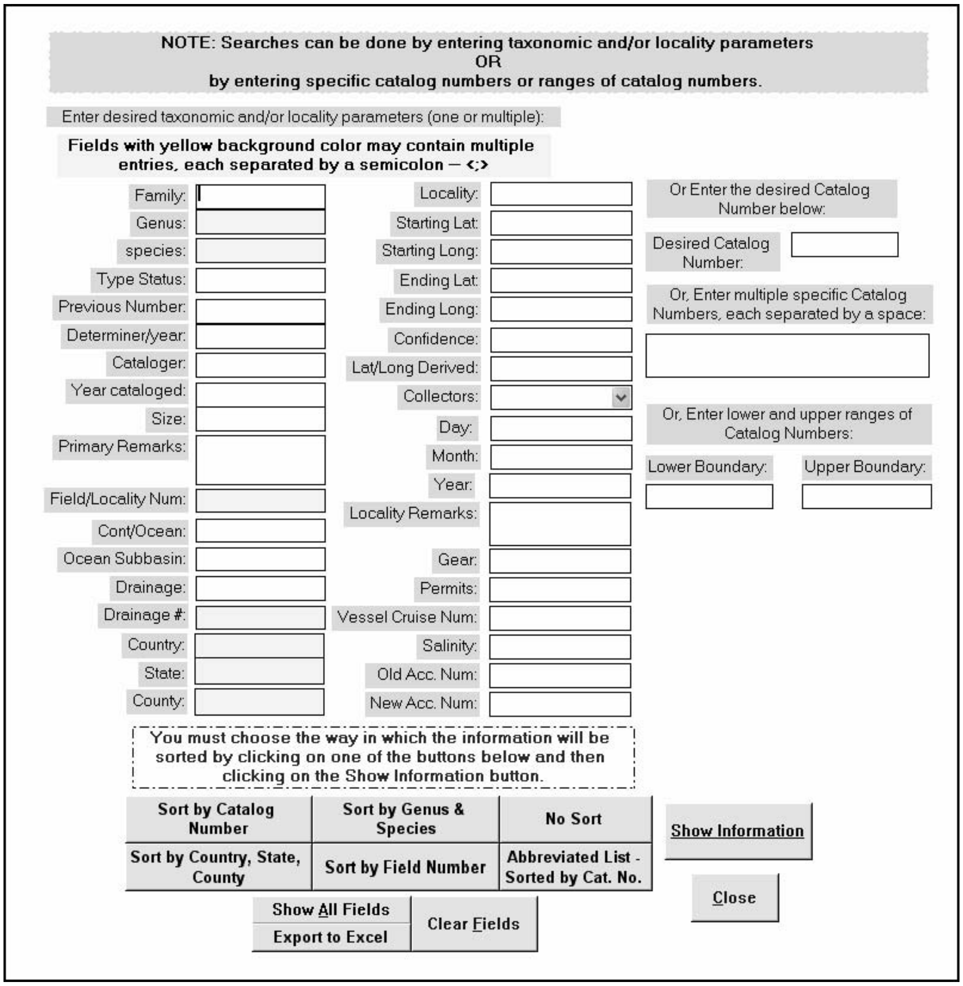

Figure 7. The browse form for the NCSM fishes database.

formats. Also, in an effort to simplify this, if similar data is frequently requested, the export can be automated and performed by pushing a button and entering criteria as prompted. This also allows us to maintain standards in information sharing with other units in the museum.

Figure 7 is the specimen and locality browse form for the fishes database. This browse form varies for each unit. The form allows users to search for data by entering as many or as few criteria as desired. It then runs the query in the background. The user can also specify how the data is displayed and sorted because there are various report formats that can be sorted by a variety of fields; the data can also be exported.

The ability to generate statistics is another very important feature of the database. Since each record has an associated data entry date, daily, weekly or any other timescale statistics can be generated. Most commonly, we generate statistics for specimens, lots, localities entered, and loans processed. This allows administrators to see how much data is being entered and how other researchers are using the collection. This information is accessed using a push-button driven menu.

As mentioned earlier, dictionaries play a very important role in this database. Each of those dictionaries can be updated by using the various update forms that we created. Therefore, there is no need to look at the actual tables to perform updates. Another feature in the database is a global update. This facilitates updating values throughout the database. For example, if a subspecies is elevated to species status, then a global update can be performed so that all records are updated appropriately. In this case, there is also a taxonomic history feature that allows you to track taxonomic changes.

Data Conversion

We were fortunate that MS Access allows for simple data imports and exports because some of the units had data in existing electronic formats (Table 1). There were some challenges performing these imports because of the establishment of new data documentation standards. Old data did not always comply with our new standards and several methods were used to standardize the data.

The simplest method was to do basic update queries. For example, the current standards required the month field to be text with complete words but, in the existing databases, it may have been abbreviated or numeric. In order to remedy this, any values in the month field that matched abbreviations or numeric values were updated to complete words. Global updates were also used to fix other abbreviations such as state, e.g., NC to North Carolina.

Updating fields that were previously unconstrained, such as collector, was much more difficult. In the existing electronic catalogs, collector names could have been entered in any number of different ways, e.g., J.A. Doe, JA. Doe, J. A. Doe, John A Doe, etc. The current standards require that the collector be entered as initials with no punctuation and then last name, e.g., JA Doe. In order to make this data fit with the new documentation standards, we decided to take all the values for the field, in this case collector, and make a list of unique values. We exported the old data into a spreadsheet program, named the column old_collector, and then added a column called new_collector. Then, a member of the unit went through each record and entered the collector name in the new_collector field so that it complied with our new standards. Once this spreadsheet was completed, we used an update query to update every value in the table that matched old_collector, and updated it to new_collector. This not only updated all collector values to fit with the data standards, but also established a dictionary for the collector field.

Another difficulty we faced in data conversion was ensuring that taxonomic dictionaries were comprehensive, and that the taxonomic data within the old data files matched the data in the dictionary. After the old data files were imported into MS Access, we simply linked the taxonomy dictionary and specimen table by genus, species and subspecies. By doing this, any values that did not match could be parsed out, and we could look at those values in the specimen table to determine whether this taxonomic information was missing from the dictionary, or if it was a data entry error.

The Next Step

Although there were numerous pitfalls and variables to be negotiated, we have found the project to be extremely successful. While the initial development involves a huge time commitment, that investment is paid back many times over by the increase in efficiency through the streamlining of many facets of collection management. Currently, seven of the eight units have functional databases. Several are still under development, but are functional for data entry and storage. To date, over 103,000 lots of specimens and 56,000 localities have been entered. Various units are ready to put their database information on the web. Recently, the Fish and Invertebrate units received a grant from the National Science Foundation for databasing and creating a web presence. Our hope is to be able to purchase the software and hardware necessary for our master web based database in the very near future.

Recommendations and Considerations

We would like to make the following recommendations and some points to consider for anyone interested in undertaking database development. These can be divided into the following six components: involving users, determining goals, creating standards, technological considerations, management, and training.

Involve all stakeholders at all stages of development. This is especially important because you will be significantly impacting the management of the collection. Most users will be ready to undertake learning new methods if they have been allowed to provide input in the development. It is also advisable that other sections of your museum/institution are kept informed during database development, as they may have similar needs which could lead to collaboration. Involving all of the stakeholders will also enable you to determine how many users you will have and calculate realistic cost figures.

It is also vital to take time to determine what the overall goals are for the project. What functions should the database perform? What products need to be created? We would highly recommend that the database perform all, or as many as possible, of the data management functions. Outputs such as labels, reports, archival catalog pages, and loans should all be automated.

Develop documentation standards and common fields within and among the various units that will be using the database. It is imperative to establish the relevant fields before data entry begins. Adding fields during development is much easier than retrofitting data after data entry has begun. Data entry standards will decrease the time needed for editing and creating new records.

Once the points above have been decided upon, you can begin considering technology. At this point you have determined the number of users and desired products. Based on these criteria and budgetary factors, you can determine the type of database that best suits your needs. Options include: web based, server based, or stand-alone. Each option has its pros and cons. The next step is to determine whether you want to create your own or try to purchase an existing framework. Whether you develop in-house or contract, you must make sure that the technology is compatible with what your institution currently uses. Work closely with your IT department and consider all of the available options.

In our situation, we chose to use an existing framework, which saved us months or possibly years of development, but caused some issues in trying to customize it to meet the needs of all eight units. We spent a great deal of time developing dictionaries and standards, and customizing the database to the specific needs of the fish unit. While it was a great time saver to have the framework for many of the features, such as loans and browse forms, adding the fields that were required for our museum and then changing all of the queries, tables, and forms to match was time consuming. Another great advantage was to have the technical support available from the original creator. At the time our staff was very new to MS Access and Visual Basic for Access, so there was an extremely steep learning curve, and the assistance was invaluable. It was also a great comfort to be working with a proven commodity. Unfortunately, trying to make one database structure fit for eight unique units was at times like trying to fit a square peg in a round hole. Because each unit deals with completely different specimen types the customization to fit the unique needs was excessively time consuming and in some cases, such as geology, it may have been more appropriate to start from scratch using existing data standards and common fields. Even though it may have taken time to customize, it has proven successful as both an in-house database for us, and on the web for FLMNH.

Data management is a key consideration to determine the type of database that will be used. In our case, having the database managed in-house was crucial as we needed complete ownership of and access to our data. It may not be as important in other cases. If you decide on a web-based system and contract for server space, you must consider where the data will be hosted. The IT infrastructure must be strong enough to meet your requirements, provide access to the data quickly and easily, and be maintainable within your budget. Regardless of who manages the data, you must develop a strong disaster recovery plan. Make frequent backups and store the backups on and off site and create a printed archival version of the data.

Lastly, take time to train the curatorial staff and data entry personnel by developing courses and manuals. Comprehensive, easily updated, course manuals will aid in the training of data entry personnel particularly if there is rapid staff turn over.

Clearly, there are a number of items to be considered before developing a database. Many of these items are going to be very specific to your needs and budget. We would advise that you take the time to map out the process and develop a good plan. Time invested in the planning process will save time in the development phase. However, database development is a dynamic process. No matter how much prior planning happens, some hindsight-driven evolution will occur.

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DOCUMENTATION STANDARDS REVIEW: PROCEDURES FOR DATABASE UPGRADES

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Abstract.—Documentation standards are the actual rules of structure, content and value that allow the design and implementation of a museum's information systems. Clean, useable data is the product of well designed standards and well maintained documentation systems. Since the upgrading of automated documentation systems is inevitable and the process of upgrading will create the need for updating, reorganizing and cleaning of systems and existing data, a set of procedures to facilitate this process would seem desirable. The following is a strategy of three rules and six steps for the review of documentation standards in museum databases. The steps include studying standards documents and choosing several as primary sources; setting data structure and formatting rules; adoption or creation of controlled vocabularies; production of data dictionaries, prompts and online helps; and finally data cleaning. The international museum community needs to work toward using common documentation standards by promoting the use of the same established standards. Improved data dictionary headings are needed for standards and more universal thesauri, particularly for locality information, are needed to avoid duplication in labor and set future standards.

INTRODUCTION

This project developed from a need to manage the aftermath of a database upgrade. After the upgrade and migration of data, there was a need to clean, tidy, straighten, or put in order all parts of the documentation system, both the data and the database structure. The aim of this paper is to present a useful set of procedures for electronic database design and data cleaning following a database upgrade. Three rules and six stages or steps are described. After using some international standards documents as a guide to this work, some suggestions for future international data standards initiatives have become apparent. These are described at the end of the paper.

Museums do not just curate objects. They are also responsible for the information associated with those objects. This information, or documentation, is considered an integral part of the object and is important in its own right. Providing access to this information is a large part of a museum's function. Museums define and strive to follow professional standards of practice in all their endeavors. Information management, as part of collections management is one of these areas of standard practice (Museums Alberta 2001). Although information management includes paper as well as automated systems, the focus of this paper is computer databases.

There are many standards documents and resources available in published form and on the web. Most of these contain descriptions of theoretical minimum or best practices for information management; the procedural standards. Many also contain a list of actual rules of structure, content and value that set out the requirements to put the standards into practice for recording and entering data; the documentation standards (Bower et al. 2001). There is consensus among these standards documents that documentation standards are important for providing consistency and efficiency for cataloguing and searching, and they allow sharing of data (CHIN 2004a). For more details on the role and purpose of documentation standards see the introductory section of the International Guidelines for Museum Object Information: the CIDOC Information Categories (ICOM-CIDOC 1995).

In this paper, three standards sources will be used as examples. The author has used these standards documents extensively as resources in designing and implementing documentation standards and cleaning and reorganization of databases and data.

1. International Council of Museums (ICOM) especially the International Committee for Documentation (CIDOC).
   a) ICOM-CIDOC's Museum Information Standards (Roberts and Will 2002).
   b) ICOM's Guidelines and Standards for Museums (ICOM-CIDOC 2004).
   c) International Guidelines for Museum Object Information: the CIDOC Information Categories (ICOM-CIDOC 1995).
2. The Canadian Heritage Information Network (CHIN 2004a).
   a) Standards section.
   b) Collections Management section including Humanities and Natural Sciences data dictionaries that provide some documentation standards.
3. MDA (previously the Museum Documentation Association) in the UK (MDA 2005).
   a) Standards and Fact Sheet pages.
   b) SPECTRUM, MDA's documentation standard.

These sources recognize three different types of documentation standards: value, format, and structure. Value standards are authority lists and classification schemes or hierarchies, also called vocabulary standards or terminology control. Format standards are the rules for structure and syntax and are also called cataloguing standards or content standards. The third, data structure standards, are the content of the fields and are termed metadata standards by CHIN (2004a). In this paper I will use metadata as defined by Gilliland-Swetland (2000) and used by CHIN (2004a). Gilliland-Swetland defines metadata as ''data about data'' and then describes how this can produce a very broad conception of metadata that can be seen to have many types, functions, attributes and characteristics. A similar definition is used by CHIN ''museum collections management records (whether paper based or automated) would be considered by some to be ''metadata'' about the collection'' (CHIN 2004b:1). Caution is needed here to avoid confusion about the use of the word ''standard.'' It can be used to describe a particular national or international standard or as a general term in for example ''all museum documentation should follow a written set of standards.'' In this paper, the expression ''standard document'' will describe the former and the term ''standard'' will be used to describe a general item or a user/institution defined set of standards for their particular database or information system.

Upgrade Issues

The University of Alberta, Department of Anthropology, Archaeology Program uses the Oracle based MIMSY database by Willoughby Associates. We recently upgraded to a new version of MIMSY and as the upgrade progressed it became clear that there were several issues that would need attention. The first issue is legacy data. Most museum collection documents begin as paper records with minimal format and other standards. These records were often written in natural language with normal grammar and punctuation so converting to indexed computer fields is not always simple. Our data has been on a computer system since the 1980s and has followed standards and had defined data dictionaries since the start. However, each time a database is changed there is often considerable review and cleaning required. In the last few decades, many museums have used a variety of computer databases starting with flat records and evolving through several relational databases. Having previous databases necessitates accommodating legacy data from earlier systems. The second issue is that each upgrade or new system spawns its own new metadata fields (CHIN 2004a, Gilliland-Swetland 2000). Our early systems had thirty or forty fields but our most recent system has several hundred individual fields. The third issue is that the default upgrade version will probably have a general data structure that will not only be different from the earlier version but will have to be tailored to individual user needs. Since there will be changes in structure, format and value, user defined documentation standards will be different from the older database version. This will necessitate rethinking standards, rewriting data dictionaries, and moving and cleaning data.

Information Technology (IT) personnel will claim that data can be ‘‘easily migrated’’ from one system to the next, but this does not take into account all the reorganization that is required to bring everything up to a single set of standards and formatting rules. Berendsohn, et al. (1999) and Morris (2005) both refer to the fact that the IT industry is continually changing so the need to move or update systems will continue. Morris (2005) estimates that a database lifecycle will repeat every 10 years. As upgrading and this periodic review and cleaning is inevitable, the following set of procedures may be helpful.

Three simple rules are applicable to these procedures. The first two of these, Morris (2005) describes as core concepts in information modeling. The first of these, ‘‘atomization,’’ is the idea that more than one concept should never be put in a field. As well as being a problem for individual databases, fields where concepts were combined and need to be split can cause difficulties for distributed systems (Heather Dunn pers. com. 24 February 2005). The second core concept (Morris 2005) is the ‘‘reduction of redundant information.’’ This idea is fundamental to relational databases and involves adding another table instead of repeating data in more than one row. A good example of this is locality data. If you have many specimens that come from Alberta, Canada, you would want to link the locality information to a second table that acts as the Place Authority instead of continually retyping ‘‘Alberta, Canada’’ in your object table. The third rule is ‘‘never overwrite original data’’ even if you are correcting mistakes. Metadata fields, including fields for date and attributor, will need to be added in order to properly document this process. This separation reduces the risk of artificial accuracy, preventing inferences made during cleanup or other research being mistaken for original facts (Morris 2005, Murphey et al. 2004). This partly explains why the number of fields tends to grow each time a system is changed or upgraded.

PROCEDURES

This set of procedures applies to multiple fields, but Field Groups need to be tackled first and then on a field-by-field basis. All work should be done after consulting the existing data in each field. This makes database design after an upgrade different from design when creating a new database. The appendix provides a concise list of these procedures.

1. Study Standards Documents and Choose Several as Primary Sources

There is no single authoritative reference for documentation standards. Each museum needs to choose several that will work for their purposes. The documents listed earlier in this paper, by ICOM-CIDOC, CHIN, and MDA are good examples for general sources. Each of these will have strengths and weaknesses, so it is advisable to consult at least three. Secondly, choose one or more discipline specific documents. Many examples of discipline specific sources are listed on the ICOM, CHIN and MDA web pages. The International Union of Biological Sciences Taxonomic Database Working Group (TDWG) has a good website, and many of their standards resources have a botanical focus (IUBS-TDWG 2004). Another example is Cataloguing Cultural Objects (CCO)—A Guide to Describing Cultural Works and Their Images (VRA 2003). It is a good idea to reflect what others in your institution and area are doing by including a reference on local standards. This can increase consistency locally and can be useful for topics like legal issues. Finally, you will need documents that are specific to individual fields in your database. Examples of this might include geographic references for locality fields or date standards for fields handling dates.

2. Set Data Structure Standards

By considering field groups it is possible to identify the fields needed to adequately document collections. The minimum number of fields possible should be used while still following the three rules. For each field, define the field and its relationships to other fields. Produce a list of related fields including rules for entry. For example, describe the criteria for deciding whether a term should be recorded in Object Name, or a related field like Object Type.

3. Set Value Standards

Review each field to determine if it should have a controlled terminology. If so, determine if it should be a simple authority or hierarchical thesaurus and whether it should be self-maintained or an existing, established terminology resource. A simple, self-maintained authority can often take the form of a field pop-up or pick list. Examples of existing sources include the Getty Art and Architecture Thesaurus (AAT) (Getty Research Institute 2004) or Integrated Taxonomic Information System (ITIS 2004). Consult Harvey and Young (1994) for an extensive list of existing vocabularies and classification schemes. Most standards documents recommend using an existing source, but this can be difficult or impractical for some fields.

4. Set Formatting Rules

CHIN, CIDOC, and SPECTRUM are only moderately helpful for providing formatting rules. Some formatting rules are defined, others can be deduced by looking at examples in their data dictionaries, but often no explanation is given. Formatting rules are fairly straight forward and include whether a field can be written in natural language with normal grammar and punctuation or whether it should be a single term, the number of occurrences, singular or plural form, capitalization rules, punctuation, abbreviations, language and formats for translation if necessary, if a field is required, and how to deal with empty fields (e.g., write ''unknown'' or leave blank). Be very specific in descriptions of all format rules. Use existing formats wherever possible. Examples of available existing formats are date and name formats. For date, the only standards document that lists the International Standard ISO 8601 (Kuhn 2004) as the date standard used, is ICOM-CIDOC (1995). Several others use a standard that looks like ISO 8601, but do not state a source. It is proposed that all museums should be using ISO 8601 for standard date formats if their individual computer systems will support it. Dates will often require additional fields to handle all required information. An ISO 8601 full date formatted field may need to be supplemented with a date text field for date qualifiers (prior to, later than, uncertain), incomplete dates, ranges, or seasons. This will depend partly on the computer system capabilities and is something to be considered at stage 2 (set data structure standards) as well as this step (Berendsohn et al. 1999, CHIN 2004a, ICOM-CIDOC 1995). Like dates, personal and corporate names often need special consideration. Both CHIN's Standards (2004a) and ICOM-CIDOC's Information Categories (ICOM-CIDOC 1995) suggest using the Anglo-American Cataloguing Rules (AACR) for formatting all types of names. This established format gives rules for personal names and corporate bodies as well as geographic names (Gorman 1999). As with a single date format, using a single established format for personal and corporate names across many institutions is considered a worthwhile goal.

5. Produce Data Dictionaries, Data Entry Manuals, Prompts and Online Helps

Once the data dictionary is complete for each field, the other documents can be produced quite easily. CHIN (2004a), ICOM-CIDOC's Information Categories (ICOM-CIDOC 1995), and SPECTRUM (MDA 2005) all contain data dictionaries that can be used as models for design. Anyone who has used CHIN is familiar with the term data dictionary. It is a description of the units of information, usually one for each field in the database. SPECTRUM (MDA 2005) and ICOM-CIDOC (1995) have their descriptions in alphabetical order and call them Information Requirements and Information Groups and Categories, respectively. It is beneficial to have a data dictionary in place from the beginning of the process, but this will need to be amendable as review and cleaning progress. Ensure that all these documents are in place before any new data entry begins.

Seven different fields or categories are suggested for inclusion in data dictionaries. This should include fields for definition and relationships. These are both data structure standards. It should include rules of entry, both format standards and value standards. The value standards in existing data dictionaries are often very general, for example ''maintain a list of standard terms'' (MDA 2005). It would be possible to be more assertive and add to this first statement something like ''enter terms from the Site Authority only'' or ''use terms from the Getty AAT only.'' The data dictionary should include a field for data type. This is a format standard, for example ''alpha-numeric string.'' Including an Examples category can be very useful. Examples should be taken from the museum's own data. A Source or Other Standards category will give a reference of where information for the field was found, or a list of other standards that use this same field.

CHIN (2004a) has a data dictionary category similar to this, and Bisby (1994) has an ‘‘Other Standards’’ used exactly this way. The final data dictionary category should be Logic or Rationale. For every single decision in each field, state the logic or reasons for the standards. The *logic* behind this category is that well thought out decisions should be documented to avoid loss or duplication of labor.

6. Data Cleaning

The simplest way to clean data is to create a list of distinct field values with a case sensitive alphabetic sort. Scanning such a list will reveal spelling and other format errors. A less experienced worker can do this, or in-house IT people can design scripted tools (see Morris 2005 for a description of some of these automated tools). In addition, someone with expert knowledge or someone who is very familiar with the collections will have to look over the lists to spot errors that casual workers or automated tools may miss. In this description, the dichotomy of data cleaning becomes apparent. This division of cleaning types, simple/expert, or IT/curatorial may account for differences in upgrade or review time anticipated by these two groups. When IT personnel say that data can be ‘‘easily migrated’’ they may only be taking into account simple data cleaning. In reality, this review or cleanup process must also include the type of extensive research that can only be done by more knowledgeable staff or by consulting experts. This cleanup could include researching taxonomic records, geographic references, field notes, or other original documents.

When a record with incorrect data is spotted, the entire record should be examined to clarify the error. It may be that data was simply entered in the wrong field, and requires complementary changes. Rule number 3 applies here: never overwrite original data even if you are correcting mistakes. Of course there are drawbacks to following this rule too closely, like increasing the number of fields.

When the data is clean, it can be used to create pop-up or pick lists for those fields that need a simple, self maintained authority list. Data entry to these fields can be set to validate against these lists, or filling from the list can be made mandatory. These are examples of data quality control that can help ensure clean data through the rest of the database lifecycle. Examples of other quality controls can be found in Morris (2005).

This may all seem very mundane, but it has been a help to have a written set of procedures to manage the upgrade and review process. Available attention to the process may be sporadic. For example, casual employees, students, or volunteers who work a few hours a week for a term or two may do most of the actual work in a database. With this type of work force, it is difficult to have any sort of continuity in a project. A set of procedures helps this problem by giving step-by-step guidance that can be left and then picked up again at a later date by another worker.

All aspects of database design are necessary for this review. Work on the data, such as data cleaning, cannot proceed until a review of the documentation standards is complete. It will usually be appropriate to follow these procedures in order, but some field groups may be more complicated than others and then it may be necessary to move between steps repeatedly to perfect the standards. The documentation of geographic locality information is an example of a complicated field group. Structure and formats for proximity, certainty, uncertainty, and other nuances are handled differently by different countries and different vocabulary sources. It will probably be necessary to move between steps 2, 3 and 4 several times before a suitable set of standards can be developed.

The completed documentation standards review and cleaning procedures and their results are not static. They will need to continue to evolve and change to adapt to the needs of the data during the database lifecycle.

Suggestions for Future International Standards Initiatives

End users benefit from the experience and combined knowledge that has gone into producing nationally and internationally accepted standards documents, some of which have been mentioned here. International groups should be encouraged to carry out the work of developing standards that are acceptable to many. Then we (the museum community) need to *use* these standards in order for them to accomplish their goals of providing consistency to further compatibility and interoperability. As an end user, I have some suggestions for these groups that I hope might improve the usefulness of international standards.

The first suggestion is improved data dictionary headings. It would be very useful to see all the headings or categories listed for data dictionaries (procedure number 5 above and Appendix), in *all* standards. The two that are often missed are Source or Other Standards, and Logic. Logic, or reason, for a particular choice of standard would be helpful when choosing between what seem like equal standard choices. For example, if deciding whether to use a singular or plural term for Object Name, each alternative is suggested by different standards documents. If the standard document does not give a reason for choosing one over the other, there is no basis on which to make a choice.

The second suggestion is based on a need to work toward common standards. Many sources agree that a worthwhile goal is consistent documentation within and among databases. A great way to achieve this is simply to use the same standards. The suggestions earlier about using ISO 8601 for dates and AACR for personal and corporate names are two examples. The international groups that look at standards could suggest more of these or propose additions where there are gaps. Standardization in formats for locality information is an example of an area where work is needed. Access to data for museum staff and researchers, and increasingly to a much wider audience, requires sharing of data between computer systems and among institutions. This sharing can be accomplished by interchange tools including interchange standards, data models such as CIDOC's Conceptual Reference Model (Crofts et al. 2004), and crosswalks or mappings (CHIN 2004a). However, compatible, similar, or identical documentation standards could greatly improve the ability to share data (Berendsohn et al. 1999, Bower et al. 2001, CHIN 2004a, Murphey et al. 2004). Documentation standards documents seem hesitant to enforce or set mandatory standards (ICOM-CIDOC 1995, Heather Dunn pers. comm. 24 February 2005). I would tend to disagree with this and would encourage the international museum community to work toward using common documentation standards by promoting the use of the same established standards.

Finally, the museum community should work towards integrated standard vocabularies. In the section on value standards (procedure number 3 above), it was stated that although standards documents encouraged using existing authorities and hierarchies wherever possible, this is often difficult.

For short lists of terms, the limiting factor in using established lists is that very few exist. Short lists would include fields like Specimen Condition, where there are a dozen or so terms like good, bad, greasy, and needs relabeling. So, existing term lists may not be necessary for these short lists, but the museum community could use this as an opportunity to use the same lists across institutions.

With more extensive authority lists like people, organizations, or publications, it is just not possible to use existing lists. For example, the list of people associated with a collection is completely unique to that collection (collectors, borrowers, donors, preparators). One exception to this may be the Site Authority. Lists of archaeological, palaeontological and other sites are quite scarce, and the ones that do exist are usually for limited areas. Archaeology UK (Archaeological Resource Collection 2005) with its ARCHI database is one exception. We need more of this type of resource. In Canada, provincial historic resources branches have internal databases of provincial archaeology resources. We need to get these onto searchable websites. Some may argue that the locations of sites are too sensitive to have available on the world wide web. Another possibility may be the sharing of data within distributed networks as described by Rabeler and Macklin (2005, 2006). This could both reduce duplication of work and limit access to sensitive information. International groups can promote or lead in locating resources and developing new ones where they are needed.

The authorities where it would be most possible and most beneficial to use existing/established lists are hierarchical thesauri. These include place, taxonomic classification, object, and maybe material and technique. The University of Alberta Department of Anthropology MIMSY database has the Getty Art and Architecture Thesaurus built in, so we can use this for object and material classification. This is good, but not without problems. For Object Name, the AAT terms are too general. We use discipline specific terms for our preferred object names, and can only use the AAT terms as alternative terms. But, even this limited use will improve searching by non-specialists when our database is available on the web and it will improve compatibility with other AAT using institutions. So, the museum community needs to do more of this. The two hierarchies where we could most use the help are place and taxonomy. Both of these are huge hierarchies encompassing all the world's plants and animals or all the world's places. We do use various published and web available thesauri for geographical names to help build our place hierarchy, but the actual building is done by cutting and pasting the information. No one published authority is comprehensive. Resources tend to be for certain geographical areas and different countries have different ways of naming places. I am sure I am not the only one doing this cutting and pasting, which seems like a huge duplication of labor. It would be far more efficient if we had more universal thesauri that could be integrated into our own systems, or that we could link to directly. This is starting to happen with taxonomic information. Some institutions have made hierarchies for various taxonomic groups available. An example is the Smithsonian Institution's (1993) Mammal Species of the World, but these are often for limited groups and taxonomic levels. The most comprehensive of these taxonomic hierarchies is probably ITIS (2004). ITIS is a great taxonomy resource created by an international partnership of agencies and taxonomic specialists (CHIN 2004a), but it still needs work. The community of taxonomists and systematists does not always agree on taxonomic hierarchies. Any comprehensive authority would have to build in this variability. Linking to a live document would be an advantageous way to access these large, complicated authorities because updates to information could then be continuous. I would like to think that the museum community is working towards this. This may be the case. Many in the natural science museum community have come to these same realizations about labour duplication and universality, as evidenced by several papers presented at the recent SPNHC 2005 annual meeting and workshops (Rabeler and Macklin 2005, 2006, Rissoné 2005) and discussions at the SPNHC 2005 Documentation and Database Special Interest Group Meeting.

Conclusion

It appears there is a movement in the museum community to address some of the issues presented in this paper including legacy data, upgrades, standards review, common standards, data cleaning, reduction in labor duplication, and universal vocabularies. Data cleaning procedures and other toolkits from international agencies like Global Biodiversity Information Facility (GBIF) will start to become available (Larry Speers pers. comm. 14 June 2005). A newly formed CHIN Working Group on Data Cleanup will be looking for ways to review standards and clean data and may provide an opportunity to test the procedures presented here in several institutions across Canada. Strategies and other resources appropriate for multiple institutions will assist with data compatibility and be useful to agencies that distribute data from multiple repositories. In addition to upgrades, the procedures described here could be used for maintenance and for cleaning before export to a distributor. It appears that these procedures supplement other work currently under way in the international museum community. It is hoped that they can make a small contribution to museum information management.

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Appendix

Procedures for Documentation Standards Review and Data Cleaning

1) Study standards documents and choose several as primary sources
   a) general sources (example ICOM, CHIN, MDA).
   b) one or more discipline specific documents.
   c) local standards (institutional and local geographical area).
   d) documents that are specific to individual fields in the database.
2) Set data structure standards
   a) Looking at field groups, review what fields are needed to adequately document collections. Use the minimum number of fields possible while still following the 3 rules.
   b) For each field, define the field, its relationships to other fields, and a list of related fields with rules for entry decisions.
3) Set value standards. Review each field to determine if it should have a controlled terminology. If so, determine type:
   a) simple authority or hierarchical thesaurus.
   b) self maintained or existing/established terminology resource.
4) Set formatting rules:
   a) written in normal grammar and punctuation, or a single term.
   b) number of occurrences.
   c) singular or plural form.
   d) capitalization, punctuation, abbreviations.
   e) language, and formats for translation if necessary.
   f) required fields, empty fields (i.e., write ''unknown'' or leave blank).
   g) date format—e.g., International Standard ISO 8601.
   h) name format—e.g., Anglo-American Cataloguing Rules.

   Be very specific, use existing formats wherever possible
5) Production of data dictionaries, data entry manuals, prompts and online helps.

   The fields in the data dictionary should include:
   a) Definition (data structure standards).
   b) Relationships (data structure standards).
   c) Rules of entry (format standards and value standards).
   d) Data type (format standards eg ''alpha-numeric string'').
   e) Examples.
   f) Source or other standards.
   g) Logic (for every single decision in each field, state the logic or reasons for the standards).
6) Data Cleaning:
   a) simple cleaning-scanning lists.
   b) expert cleanup.
   c) correct entire record.
   d) never overwrite original data (remember rule number 3).
   e) build pop-up lists.

TOOLS, TECHNIQUES, AND CODE FOR SUPPORTING IMAGE DATABASES OF NATURAL HISTORY COLLECTIONS MATERIALS

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Abstract.—Managing large image collections and serving images of natural history collection materials to the world in a manner that makes them useful to the scientific community presents significant challenges. The open source community has developed powerful software tools for image manipulation that can assist in overcoming these challenges. A consistent file naming convention allows images to be manipulated in an intelligent fashion by simple scripts that link images, database records, and image manipulation software. We discuss the logical steps involved in writing scripts for maintaining image collection metadata, for preparing images for use on the web, and for manipulating images on the fly on the web. We provide five examples of image manipulation from imaging projects at The Academy of Natural Sciences (The All Catfish Project, The Titian Peale Collection, and Visual Resources for Ornithology) using PHP, bash shell scripts, and ImageMagick. These examples illustrate how large batches of images can be checked against a database and manipulated before being uploaded to a web site, how image specific text from a database can be stamped on variably sized files, and how parts of large image files can be made available to low band width users by zooming into images.

Introduction

Museums around the world are creating digital images of natural history collection objects. Large collections of images of collection objects are accumulating and are being made publicly available. Managing large image collections and serving images of collection materials to the world in a manner that makes them useful to the scientific community presents significant challenges. One challenge involves correctly linking the images with information about those images and the collection objects they depict. Another challenge is balancing the tradeoffs among image size, quality, storage space, capture time, processing time, bandwidth, and utility. In this paper we discuss an approach and a software toolkit that can assist with these and other challenges posed by large digital image collections. The central concept in this approach is using software that is capable of both manipulating image files and communicating with a relational database, linking images with database records through consistent image filenames.

Publicly available images of collections objects have many uses and benefits, for the collection objects themselves, for the institutions holding those objects, and for the scientific community. In many cases, virtual loans of collections objects through distribution of digital images are able to answer researchers' questions about those objects, and thus reduce the wear and tear and risk of loss of specimens sent on loan (Huxley 1994, Luneva et al. 2000, Monk and Baker 2001, contra Anderson 1996). Images can form a record of the conservation state of a collections object at a point in time, allow assessment of changes over time, and serve as records in case of loss (Collins 1995, Grimé and Plowman 1987, Huxley

1994, Moore 2001). Images of collection objects can be an important collaboration tool for groups of researchers in systematics and taxonomy. Images of collections objects can also form the backbone of powerful communication tools such as online keys that help distribute the knowledge base of natural history museum and systematic biology communities to a larger audience.

The All Catfish Species Inventory (Leslie 2003, Lundberg 2003) provides a good example of digital images serving as virtual loans through a collaboration tool. The All Catfish Species Inventory is a global collaboration among about 300 researchers in catfish taxonomy and systematics, which seeks to find and describe all living species of catfish by 2009. One component of the project is an online image database. Researchers are encouraged to submit images of types and other taxonomically important specimens to the database. The All Catfish project has also been providing funding for museums to image their catfish types and to submit those images to the project database. This database currently provides images of hundreds of type specimens of catfish. These images can serve as virtual loans for the catfish taxonomy community, reducing the need for hundreds of researchers to visit museums around the world, and mitigating the nightmare of every catfish type specimen being requested on loan multiple times by multiple people around the world in the next few years.

Natural history museum collections contain a great many things that can be depicted in digital images including photographs, transparencies, visualized data, specimens, and other collection objects. A digital image of a collection object also has substantial information that needs to be associated with it. Some of this information pertains to the digital image itself (who was the photographer, who owns the copyright, what rights pertain to the image). Other information pertains to the object depicted in the image (identification, institution, catalog number). Information about the digital image itself is metadata that falls within the domain of the concepts described in the Dublin Core (Dublin Core Metadata Initiative 1995, ISO 15836:2003, Johnston et al. 2002). Information about a collection object depicted in the image, in the natural history museum community, is generally metadata (or data, depending on your perspective) that falls within the realm of the concepts described in the Darwin Core (Blum and Wieczorek 2004, Schwartz 2003), or the wider scope of the concepts in the ABCD Schema (Berendsohn et al. 1999). For a broader discussion of these concepts, standards, and formats for handling these data see the Taxonomic Database Working Group's (TDWG) recently formed image interest group for discussion of taxonomic image standards (Morris 2005). Much of the various image data and metadata is likely to be stored in various forms in internal collections databases and databases related to the imaging project, with some of the image metadata also likely to be stored in a profile within the original image file itself. One of the central problems in managing a large image collection is correctly relating images and any embedded metadata with other information about the imaged objects. The approaches we advocate here will work so long as the filename of an image is stored in the database in a table that relates it to the record for the imaged collection object, or so long as the filename of the image can be constructed from information in the database. If an image file retains the name given to it by a digital camera (e.g., DSC_4562.TIF), that file name needs to be stored in a database table where it can be related to other information. If an image file is given a name that reflects the collection object depicted in it (e.g., ansp_malac_4669.TIF), then that name can be constructed on the fly by software that queries the database for the fields that are used to construct the name (e.g., for acronym, collection, and catalog number). So long as the image file is correctly named to match the database records, it will be possible to associate an image file with metadata stored in the database.

Digital images come in a bewildering variety of formats. Relevant discussions of archival (master) images (see for example Anonymous 2001, Fleischauer 1998, Monk and Baker 2001, Puglia et al. 2004) tend to specify widely used image file formats with no or lossless compression and image properties that provide for substantial image color depth and pixel density. All this makes for large files. Large files make for increased image capture time, increased image-processing time, and, when large images are served over the Internet, increased bandwidth consumption. Non-rational social factors also influence the balance of tradeoffs and choices. For example, the JPEG2000 file format (ISO/IEC 15444–1:2004) allows clients to grab a subset of the information in a large image file from a web server to obtain an overview of the image, and then request additional subsets to zoom into parts of the image at higher resolution. This would seem a very logical tool to use to assist with bandwidth / download time / image resolution issues related to serving large image files to the world over the Internet, except that years after its development the patent encumbered JPEG2000 format is still largely unsupported by web browser software. Typical choices of image file formats and sizes for archival images (usually large uncompressed TIFF files) and images to serve over the web (often lower resolution JPEG or PNG files) can produce significant handling time costs. We will discuss some approaches and tools that can reduce some handling costs by automating processing and can increase flexibility by ready interconversion between file formats and on the fly manipulation of images by a web server.

The open source software community that has developed over the last few decades uses an approach to software similar to that used by academia for knowledge over the last 400 years. The open source software community involves many people who contribute code to a common base of knowledge and tools. Much open source software, like ideas in academia, builds upon existing work. As a consequence, open source software packages tend to play well together. This attribute of working well together lets users pick and choose software packages to assemble a toolkit of code that can then be applied to solve a particular problem. Thinking in toolkits is a very powerful approach to solving problems with software. Thinking in toolkits lets us link image processing code with relational database management code in order to manipulate images in large numbers in an intelligent fashion with the transformation of individual images informed by metadata stored in a database. For example, a single automated pass could take a large set of images of collections objects, add a border at the bottom of each image, stamp the catalog number of the collection object into this border, and write the catalog number into the image headers.

In this paper we discuss several examples of how we have applied code that links image files, database records, and open source tools for image manipulation at The Academy of Natural Sciences for the management and web dissemination of collection object images. Other people have developed many other web image sites using similar technology including SID: Specimen Image Database (Smith et al. 2004) and MorphBank (Buffington et al. 2003). Our goal in this paper is to take you step by step through a set of examples to illustrate how the very simple idea of linking images, database records, and image manipulation software with code can be used to efficiently produce sophisticated web products. The examples we give primarily use the scripting language PHP as the glue between the images, databases, and image manipulation software, but many other languages can be used in exactly the same role. We have included code in the examples to clearly illustrate exactly how you can easily write software that links your images and data with sophisticated open source database, image manipulation and web serving toolkits. The code shown in the examples herein is also available at the All Catfish Species Inventory (2005) site (Morris and Macklin 2005) under a Creative Commons with Attribution License (Lessig et al. 2005).

Tools

There are several sorts of things you may wish to do with images on a large imaging project, such as manipulating images to prepare files for serving up on the web, compiling and checking image metadata, and manipulating images on the fly while serving them up on a web server. These tasks may be greatly assisted by code that is able to interact with both the image files and with a database containing information about the images and the collection objects the images are depicting. We will divide these tasks into two categories: first, preprocessing images to prepare them (and their metadata) for use on the web, and second, manipulation of images on the fly in response to requests made over the internet to a web server.

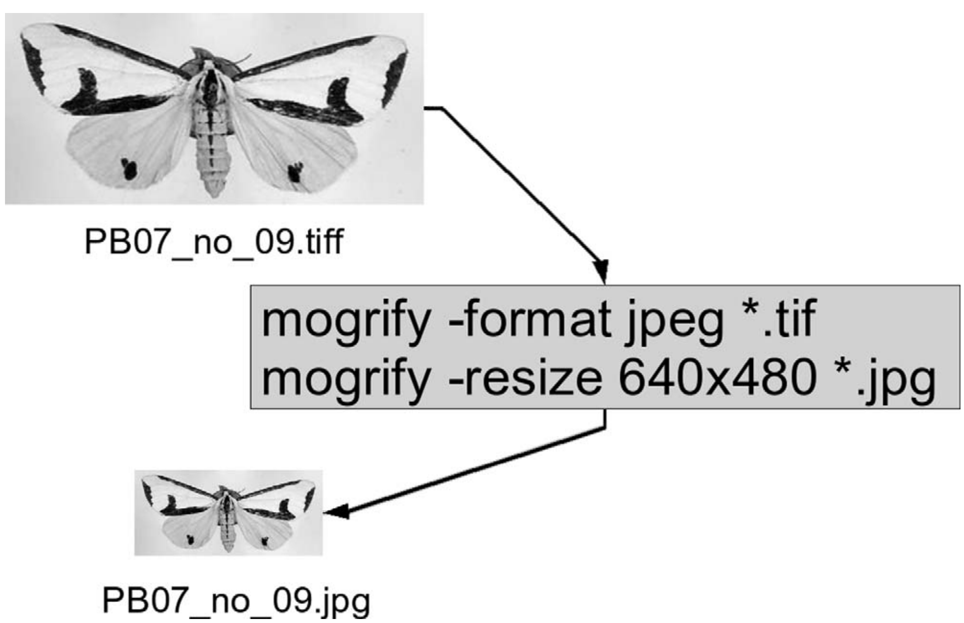

Figure 1. Manipulating a single image file or a set of images with a batch image manipulation tool (two ImageMagick commands).

```
#!/bin/bash
mogrify -format jpeg *.tif
mogrify -size 640x480 -resize 640x480 -comment \
   "Copyright 2004 The Academy of Natural Sciences, All Rights Reserved" \
   +profile "*" *.jpeg
mkdir converted
cp *.jpeg ./converted
rename .jpeg .jpg ./converted/*.jpeg
mogrify -size 320x240 -resize 320x240 -unsharp 0.9 *.jpeg
cp *.jpeg ./converted
rename .jpeg .mid.jpg ./converted/*.jpeg
mogrify -size 100x100 -resize 100x100 -unsharp 0.9 *.jpeg
cp *.jpeg ./converted
rename .jpeg .thumb.jpg ./converted/*.jpeg
rm *.jpeg
```

Figure 2. Example: A shell script containing ImageMagick and bash shell commands to create a set of three different sized .jpeg files from a set of .tif files.

Preprocessing Image Files

Many software packages, both proprietary and open source, are capable of altering images both one at a time and in large batches. If you just want to alter one image, the graphical user interface image manipulation packages Photoshop or the GIMP (Kimball et al. 2004) are quite capable of applying whatever transformations you desire to that image. However, manipulating one image at a time from a graphical user interface is time consuming and does not scale well. If you need to manipulate thousands of images, most operations (such as converting file types and resizing images) are best done as batch operations applied to many images at once. Photoshop and other image manipulation software packages are also quite capable of manipulating large batches of images at once. One open source package for image manipulation is ImageMagick (ImageMagick Studio LLC 2005). ImageMagick can, from the command line, convert, resize, filter, and annotate image files. For example, the ImageMagick command `mogrify -format jpeg *.tif` will create a jpeg file for each TIFF file in the current directory. We will start our discussion of image manipulation with ImageMagick as, unlike the graphical user interface tools, it can easily be invoked from other programming languages. Easy invocation from another piece of software allows code that communicates with a database or on a webserver to also manipulate images through ImageMagick commands. While ImageMagick from the command line is one tool out of many for manipulating individual images, it easily integrates with other software and is thus a good foundation for our discussion of software that links image manipulation and database access.

ImageMagick operates as a typical unix command line tool. It consists of commands (identify, convert, mogrify, etc.) each of which take a set of switches, which tell the command what operations to perform, and parameters, which tell the command what files to perform the operations on. The command `mogrify -format jpeg *.tif` consists of a switch (-format jpeg) and a file specification (*.tif) that together tell mogrify to create a jpeg image for every file in the current directory that has a name ending with. tif. One command can be followed by another as in Figure 1, or a series of switches can be applied in one command (`mogrify -format jpeg -resize 640x480 -size 640x480 *.tif`). The two commands in Figure 1, `mogrify -format jpeg *.tif` and `mogrify -resize 640x480 *.jpg` simply create a set of jpeg files from the TIFF files present in a directory

```
<?php
//
// general_image_checker.php
//
// base script for checking existence of image files against a database
// stores keyvalue, filename, height and width of filenames found based on
// assembly of name from db fields.
// Uses mysql, customize for target database.

// configuration parameters
$target_db = "";
$target_server = "";
$username = "";
$password = "";
// you may wish to get the password from the command line interface instead of
// hardcoding it here
$name_component_count = 2;
// parameters in filelist should start with primary key, then filename components
// in order as used in build_filename
$filelist_sql = "select nameid, common_name as c1, vcode as c2 from vireo_temp ";

$filefound_sql = "insert into filelist (c_nameid, filename, height, width, found)
values ";
// set filenotfound to "" if no action taken on files that aren't found
$filenotfound_sql = "insert into filelist (c_nameid, filename, height, width, found)
values ";
// $filenotfound = "";

function build_filename($row) {
  // function to build a filename out of parameters in $filelist_sql query
  // example here uses $row[1] and $row[2], omitting $row[0]
  // customize this function to build the filename from information in your database
  // function takes $row as an array, $row = mysql_fetch_row()
  $result = "";

  // get the parts of the filename from $row
  $c1 = $row[1];
  $c1 = str_replace(" ","_",$c1);
  $vcode = $row[2];
  $vcode = str_replace("/","-",$vcode);

  // now put the parts together into an image filename
  $result = $c1 . $vcode . ".jpeg";
  return result;
}

// script code, you probably don't need to modify anything below here
// ******************************************************************
```

Figure 3. Example 2: A PHP script that checks a database for filenames, checks a directory for image files with matching names, and stores information about those files in a MySQL database.

and rescale the jpegs to a maximum dimension of 640 pixels by 480 pixels. While manipulating batches of images is a starting point, it is not a good model for manipulating images in a large imaging project where many image files, image metadata, and collections data all need to be linked together.

It is straightforward to work out a series of manipulations to perform on sets of images, and to place commands to carry out those manipulations in a shell script (a batch file in DOS parlance). Once the desired transformation has been worked out, it can be applied to any arbitrary number of image files. A script file containing these commands can be repeatedly used to perform the same set of operations on new image files as they accumulate over time.

```
// establish connection to database
$connection = mysql_connect($target_server,$username,$password);
mysql_select_db($target_db);

// get file list from the database with $filelist_sql query
$filelist_result = mysql_query($filelist_sql);
$filecount = mysql_num_rows($filelist_result);

// step through file list
for ($x=0; $x<$filecount; $x++) {
  // build filename
  $row = mysql_fetch_row($filelist_result);
  $nameid = $row[0];
  // check if file exists
  $filename = build_filename($row);
  if (file_exists($filename)) {
     // file was found, so determine its height and width
     $height = 0;
     $width  = 0;
     $image = $imagecreatefromjpeg ($filename);
     $height = ImageSY($image);
     $width = ImageSX($image);
     imagedestroy($image);
     // store the image height, width, and name
     $sql = $filefound_sql . "('$nameid','$filename','$height','$width','true')";
     $retval = mysql_query($sql);
  } else {
     // file not found
     if ($filenotfound_sql != "") {
        $filenotfound_sql = $filenotfound_sql .
"('$nameid','$filename',0,0,'false')";
        $retval = mysql_query($filenotfound_sql);
     }
  } // end of if file_exists
} // end of loop through file list
//
echo "Done.";
?>
```

Figure 3. Continued.

Example 1.—Figure 2 is a shell script used in the Titian Peale Butterfly and Moth Collection projects (Gelhaus et al. 2004) to generate sets of image files for use on the web out of large master TIFF files. In the Peale Project, individual high resolution TIFF images were taken of each specimen in each of Titian Peale's entomology boxes (of his own design, which have glass fronts and backs). Copies of these images were processed by hand in Photoshop to remove each specimen onto a uniform background. Processed image files would thus accumulate in batches as each box was processed. The script in Example 1 was run to generate a set of scaled images for the web from each processed image in a batch. Mogrify alters images, mkdir creates a directory, cp copies files, rename renames files, and rm removes files. This script creates a subdirectory called converted and fills it with three jpeg files for each .tif file in the current directory (one large, one medium, and one thumbnail). Each jpeg has a copyright statement inserted into its profile and has an appropriate sharpening performed upon it.

Any of a number of image processing tools would have been quite capable of carrying out this task. ImageMagick and a bash shell script were simply logical tools for the environment one of us [PJM] was working in (a workstation running Linux connecting to a Novell Netware file server).

ImageMagick commands (and native image handling functions) can be incorporated into program code in a scripting language such as perl or PHP. Here is where things get interesting. Scripting languages and other sorts of languages such as Java, can both connect to a database and manipulate images on the filesystem of a computer. Information from a database can be added to images and information about images can be incorporated into a database. For example, the catalog number of a specimen can be looked up and automatically stamped into an image of that specimen, or the height, width, profiles, and filenames of images can be stored in a database. Image manipulation can be very flexible. You may wish to stamp copyright information directly on top of an image, or you may wish to add pixels to the bottom of an image and write a catalog number onto those added pixels without overwriting any of the existing image file. Many possibilities exist and are easily carried out by writing code that interacts with both images and information related to those images in a database. Indeed, very simple scripts can provide powerful tools to speed up and efficiently manage workflow in large imaging projects. You can, in essence, transfer image metadata between a database, the image profile, and the image itself.

If you are embedding a robust digital watermark in images, you should check to see whether the specific transforms you are carrying out will degrade the watermark or not. Robust watermarks (Smith and Comiskey 1996) are designed to survive some transformations, but not all, so if you are embedding watermarks in your images you may need to tune your transformations. ‘‘Most watermarking algorithms are resistant to selected and application-specific attacks. Therefore, even friendly attacks in the form of usual file and data modifications can easily destroy the watermark or falsify it’’ (Seitz and Jahnke 2005:2).

Example 2.—Figure 3 is a boilerplate script that has been used as a template in several projects at The Academy of Natural Sciences. The script builds an image filename from information stored in a database, checks the file system to see if such a file exists, stores the filename, with the option of flagging files that were expected but not found, and can determine and store the heights and widths of images for easy creation of <img> tags in html generated from database queries (as in web pages produced by scripts that interact with a database). While this code example and those that follow are written in PHP, there are a great many other languages that are capable of performing the same tasks. This script can quickly compare tens of thousands of database records with thousands of image files and generate a table containing a list of all the files that exist. It can also list files that were expected but do not exist, or files that exist but do not have database matches. This is useful for quality control checks and helps to maintain data standards. The key to this script is a consistent file naming convention that allows image file name to be linked with database records. For example, Visual Resources for Ornithology—VIREO (Wechsler et al. 2005) uses a filename that includes both the database code given to a particular bird photograph (the vcode) and the common name of the bird in the photograph. Both of these pieces of information exist in the database, and it is easy for a script to scan a directory for files matching an expected pattern (vcode_common_name.jpg). VIREO’s file naming convention provides for an interesting complication. To manage the tens of thousands of image files that VIREO is generating, the VIREO staff decided to name each image with a combination of the unchanging unique identifier for the photograph (the vcode) and with a possibly labile human readable piece of information, the common name of the bird in the photograph. Birds in the images can be re-identified, so the common name part of the filenames can move out of sync with the database. Because the database and the filename both contain a fixed unique identifier (the vcode), it is straightforward to scan a directory for files that have exact matches with the vcode_common_name combination or for files that just match on vcode. The VIREO image processing code includes a pass that looks for these mismatched files and renames them to match the current common name. So long as an image file contains a unique identifier that can be matched with a unique identifier for a collection object (or another record) in a database, this process of scanning a directory for image files and linking them to database records will work. Such scripted matching of image files to a database simply takes careful planning of file naming conventions at the beginning of an imaging project. Alternatively, an arbitrary image file name can be recorded in the database and linked to the relevant collection object identifier. This takes careful recording of the arbitrary image file name. As with all collection data, quality control is an issue, and typographic errors in file names will present problems.

In an imaging project the code in Example 1 can be used to generate a set of images to serve up on the web from a set of master images; then the code in Example 2 can be run to check that all database records do have images, and to store image metadata (height, width, mime type, filename, found or not found, etc.) in a database. This process has been used to build web image databases for the ANSP rotifer collection, the Titian Peale butterfly and moth collection, and VIREO (Fig. 4). The table of image files found can be used to quickly identify image files that are expected to exist but haven't been found (incorrectly named files or objects that were passed over in imaging step). A comparison of expected and found filenames is a useful quality control step, but will only catch a subset of possible errors.

For many imaging projects, preprocessing of images is all that is required, as the images themselves are served up as static objects linked from dynamic web pages. With a database query inside the code that is generating a dynamic web page it is possible to retrieve the name of a desired image file, its height, its width, and generate an <img> tag on the fly to display the image on a web page along with related data and metadata retrieved from the database. The image can be embedded into a dynamically generated pdf document, or whatever document your code is generating on the fly. For example, an image tag from VIREO <img src = "get_image.php?target = c40–1–104" border = "0" height = "200" width = "135" alt = "Eastern Screech-Owl"> has target, height, width, and alt elements populated dynamically from a database query. Because the image is preprocessed, its height and width are in the database, and because we have it linked to other information, we know that the common name of the bird depicted in this image is the Eastern Screech-Owl. Preprocessing images with code and using code to store information about images in a database can save considerable

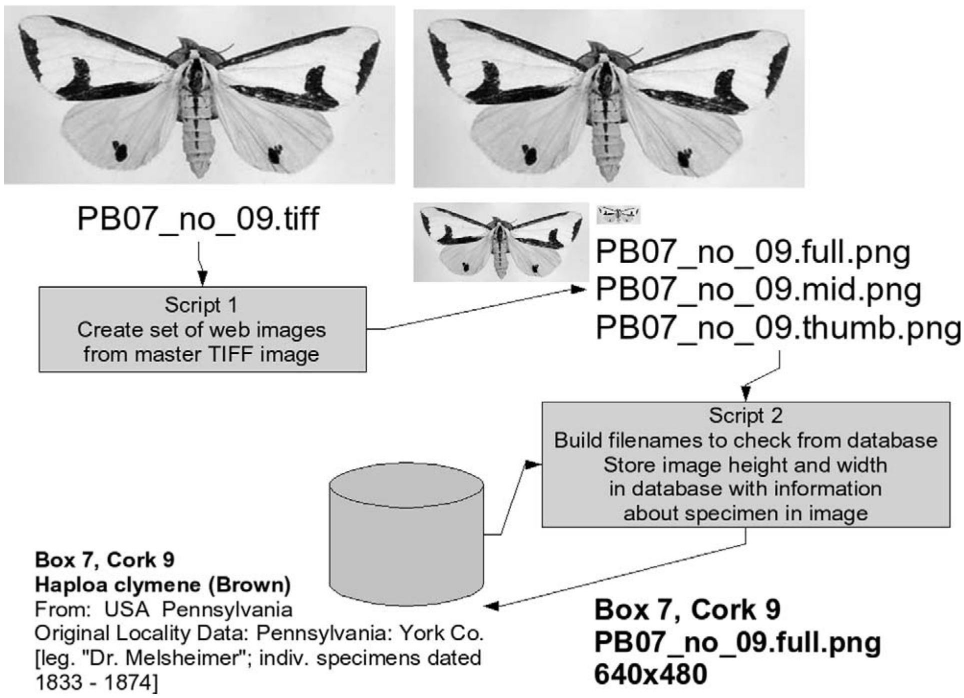

Figure 4. Two scripts using the actions carried out by Examples 1 and 2 to process images to prepare them for serving on the web.

amounts of time and effort and assist in quality control in a project that is producing a website full of images.

Manipulating Images on the Fly for the Web

Dynamic web pages are a standard way of presenting searchable collection data on the web. Such dynamic web pages can easily incorporate images, as noted above, by generating an html image tag that points to an image of a specimen. In Figure 5 an image tag points at an image file. In Figure 6 the image tag points to a script capable of retrieving data from a database and returning an image file; thus sophisticated on the fly image manipulation becomes possible. A program written in a web scripting language (such as PHP or ASP) can generate web pages on the fly incorporating both images stored on the filesystem of the webserver and information about those images stored in a database. In the example above, the script specimen.php queries a database for information about a specimen and generates a web page that includes an image tag that points to the script getimage.php. The script getimage.php acts as if it were an image file, but dynamically looks up and can manipulate the image it is returning. This is the technique used in Examples 3 and 5 to manipulate images on the fly based on requests from users and information stored in a database.

The key is a script that looks at a database, finds an image, manipulates that

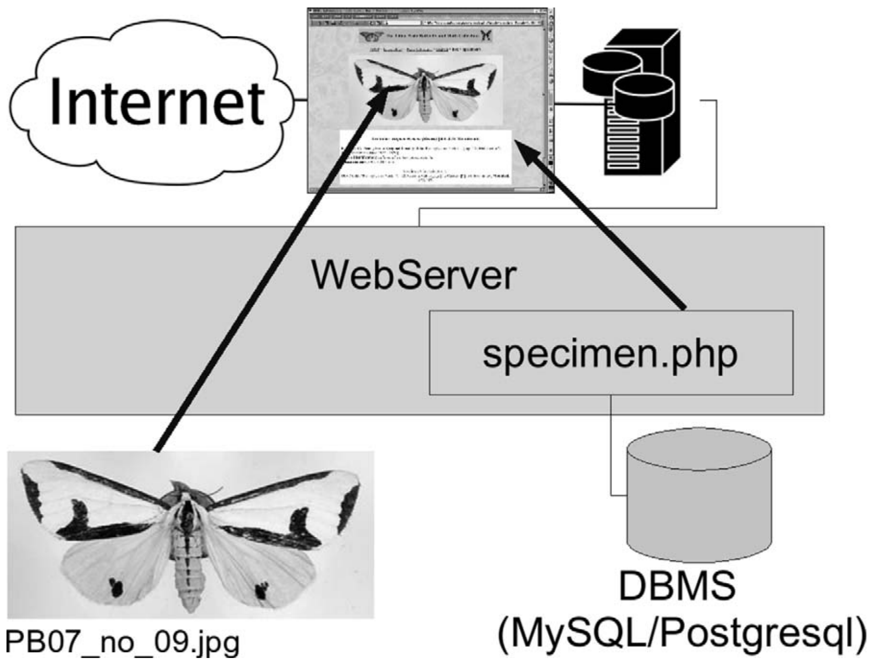

Figure 5. A dynamic web page (specimen.php) displaying a static image using metadata about that image retrieved from a database to construct the image tag.

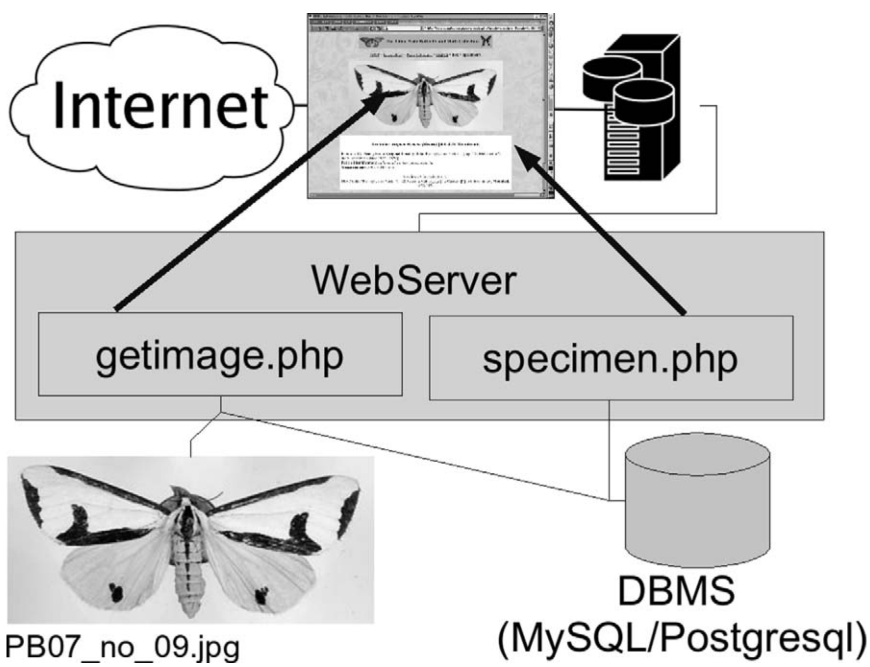

Figure 6. A program written in a web scripting language (such as PHP or ASP) to generate web pages on the fly incorporating both images stored on the filesystem of the webserver and information about those images stored in a database.

```
<?php
// get_zoom.php
// displays a cropped portion of an image with a scale bar added
// invoke in image tag as
// <img src="get_zoom.php?target=999&x=99&y=99&size=350" height=350 width=350>

// include library that contains wrapper around database connection
include("botany_connect_lib.php");
// include library for temporary file handling
include("temp_file_lib.php");

// get and sanitize parameters from user
$target = substr(preg_replace("[^0-9]","",$_GET["target"]),0,50);
$size = substr(preg_replace("[^0-9]","",$_GET["size"]),0,10);
$x = substr(preg_replace("[^0-9]","",$_GET["x"]),0,10);
$y = substr(preg_replace("[^0-9]","",$_GET["y"]),0,10);

// get information about image file to crop
$connection = botany_connect();
if (!$connection) {
   // unable to connect to database
   handle_error("DB_CONNECT_FAILED");
   die;
}
$sql = "select basex_pixels, basex_cm, filename, mime_type " _
        "from image where imageid = '$targetid'";
$result = mysql_query($sql,$connection);
$numrows = mysql_num_rows($result);
if ($numrows!=1) {
   // value passed in $target doesn't match a single primary key row in image table.
   handle_error("BAD_ID");
   die;
}
$row = mysql_fetch_object($result);
$basex_pixels = $row->basex_pixels; // width of original in pixels
$basex_cm = $row->basex_cm; // width of original in cm
$mime_type = $row->mime_type; // correct mime type for image to use in content header
$filename = $row->filename; // name of image file
$path = "/var/www/placeforimages/";
$filename = $path.$filename;
$tempfile = generate_temp_file($filename);
// crop the selected area out of the source file and drop it into the temp file
$convert = "convert -crop $sizex$size+$x+$y $filename $tempfile";
system($convert);

// calculate cm per pixel for cropped part of image
$cm_pix = $basex_cm/$basex_pixels;

// header to send before image to indicate content type for browsers
```

Figure 7. Example 3: A PHP file for a web server that returns a cropped portion of a larger image, with scale bars added into the smaller cropped image.

image, and returns the modified image. Lines containing commands such as $convert = "convert -background White $tempfile -size 25x25 xc:White -append $tempfile "; and system($convert); generate an ImageMagick command and execute that command to alter an image file. Other image manipulation functions are native to PHP (and use the GD image manipulation library).

Another advantage of using a script to return an image rather than having an image tag directly point to an image is that images can be stored off of the publicly accessible parts of a web server and public access to those images can be restricted.

```
$header = "Content-type: $mime_type";
// expand the size of the temporary image file to create spaces for scale bars
// do with imagemagick convert for color depth
$convert =
        "convert -background White $tempfile -size 25x25 xc:White -append $tempfile
";
system($convert);
$convert =
        "convert -background White $tempfile -size 25x25 xc:White +append $tempfile
";
system($convert);

// load image file
$image = imagecreatefromjpeg($tempfile);
// determine image size
$x = imagesx($image);
$y = imagesy($image);
$back_color=imagecolorclosest($image,0,0,0);
$box_color=imagecolorclosest($image,100,100,255);

// write scale bar into bottom of image
imagefilledrectangle($image,10,$y-10,$x-35,$y-8,$box_color);
imagefilledrectangle($image,$x-12,10,$x-10,$y-35,$box_color);
$length = $x - 45;
$scale = round(($length * $cm_pix)*100)/100;
imagestring($image, 5, round((($x-25)/2)-20), $y-25, "$scale cm", $back_color);
imagestringup($image, 5, $x-26, round((($y-25)/2)+25), "$scale cm", $back_color);

// return header to browser
header($header);

// return image to browser
imagejpeg($image);

// clean up
imagedestroy($image);
// remove temp file
deallocate_temp_file($tempfile);

?>
```

Figure 7. Continued.

Example 3.—The code in Example 3 (Fig. 7) is a modification of a prototype of a web image serving application written for the ANSP Botany Department (PH). The code takes a cropped portion of an image, draws a scale bar on the side of the image, and returns the modified cropped portion of the image. Image filenames, sizes, and scales are all retrieved from the database, and the cropped image is produced on the fly from a full size image. This script would work with others to allow users to click on a portion of a low-resolution copy of an image of a herbarium sheet and see the part of the image they clicked on at full resolution with scale bars added (All Catfish Species Inventory 2005, Morris and Macklin 2005).

The key to getting a dynamic web script that returns an image file instead of an image (Fig. 6) to work is to send an HTTP header containing a content type of image before sending any other output from the code back to the requesting client. This header can then be followed by the modified image. This is accomplished in PHP with the header(); and imagepng() commands as shown in the code snippet below.

```
//$dname = "C.R. Sams II & J.F. Stoick";
//$dname, the copyright owner's name is extracted from the database with a query
$copyright = "$copy $dname/VIREO";
if ($stampjustcopyright) {
   $thumbcopy = $copy;
} else {
   $thumbcopy = $copyright;
}
$size = $fontheightinthumbnail;
$rotation = 0;  // horizontal
$startoffset = $size+2;
// test text size against image
$endpoints =  imageTTFText
        ($thumb,$size,$rotation,2,$startoffset,$white,$fontfilename,$thumbcopy);
// set scaling and rotation of text
if ($endpoints[2]>($thumbwidth-2)) {
   // text ran off image
   if ($height>$width) {
      // text is longer than top of portrait image
      $rotation = 270;
      // vertical, read from top to bottom of image,
      // bottom of text on left side of text
      $rotated++;
      if ($endpoints[2]>$thumbheight-2) {
         // text is longer than height of image
         // need to scale font down
         $fits = false;
         $rotatedscaled++;
         $rotated--;
         while ($fits==false) {
            $size = $size - 1;
            $endpoints = imageTTFText
            ($thumb,$size,$rotation,2,$startoffset,$white,$fontfile,$thumbcopy);
            if ($endpoints[3]<=$thumbheight-2) {
               $fits=true;
            }
         }
      }
```

Figure 8. Example 4: PHP code snippet from the VIREO web image preparation code. This code snippet writes the copyright statement for an image into the image, rotating and scaling the text to fit the image if needed.

```
// obtain and sanitize any user input
. . ..
// query the database to get information about the image file to show
. . ..
// before sending anything else back to the user, send the mime type
$header_text = ``Content-type: image/png'';
header($header_text);
// load and manipulate the image based on information in the query
$image = imagecreatefrompng(``$file_to_show'');
. . ..
// send the image to the user
imagepng($temp_image) ;
// clean up
@image_destroy($image);
```

Examples

Having described the core idea of using a toolkit of code that can both manipulate images and communicate with a database we will now present examples of

```
} else {
   // text is longer than top of landscape image, need to scale down.
   $scaled++;
   $fits = false;
   while ($fits==false) {
      $size = $size -1;
      $endpoints = imageTTFText
         ($thumb,$size,$rotation,2,$startoffset,$white,$fontfile,$thumbcopy);
      if ($endpoints[2]<=($thumbwidth-2)) {
         $fits=true;
         }
      }
   }
}
$starttext = $size+2;
if ($rotation==270) {
   $starttext = 2;
}
if ($rotation==0) {
   $command =
      'mogrify -quality 100 -fill white
       -font '.$fontfile.' -pointsize '.$size.'
       -draw '."'".'text 2,'.$starttext.'
            "'.$copyright.'"'."'".' '.$thumbname;
} else {
   $xtext = "-2";
   $command =
      'mogrify -quality 100 -fill white
       -font '.$fontfile.' -pointsize '.$size.'
       -draw '."'".'rotate 90 text 2,'.$xtext.'
            "'.$copyright.'"'."'".' '.$thumbname;
}
system($command);
```

Figure 8. Continued.

this concept in use both in preprocessing images for the web and in serving up dynamic images as implemented at The Academy of Natural Sciences in the VIREO Ornithological Slide Collection (Wechsler et al. 2005) and the All Catfish Project Species Inventory (2005). In VIREO during a preprocessing step, a copyright statement derived from a database query is stamped into each image. In the All Catfish project, a server side image crop is used to allow low bandwidth users to view portions of large high-resolution images.

Adding a Copyright Statement to Each Image

Example 4.—For the VIREO web image database, images of photographic slides of birds held by VIREO are served up on the web as both thumbnails and as approximately 640×480 pixel images. In excess of 13,000 images from VIREO's holdings of more than 100,000 images are currently available on the web. Images from different sources have different copyright statements. The VIREO staff wished to have the copyright statement for each image stamped directly on each web image. Because there are both thumbnails and larger images, this requires intelligent stamping of a copyright statement onto each image, as text that is legible on a thumbnail takes up too much space on a larger image. This could be done by hand by opening each image in Photoshop, looking up the copyright holder in the VIREO database, and pasting that photographer's name as text on to the image. With tens of thousands of images this would be a very time consuming task to repeat for each large web image and each thumbnail. The PHP code in Example 4 (Fig. 8) is part of a script that opens an image file, checks the

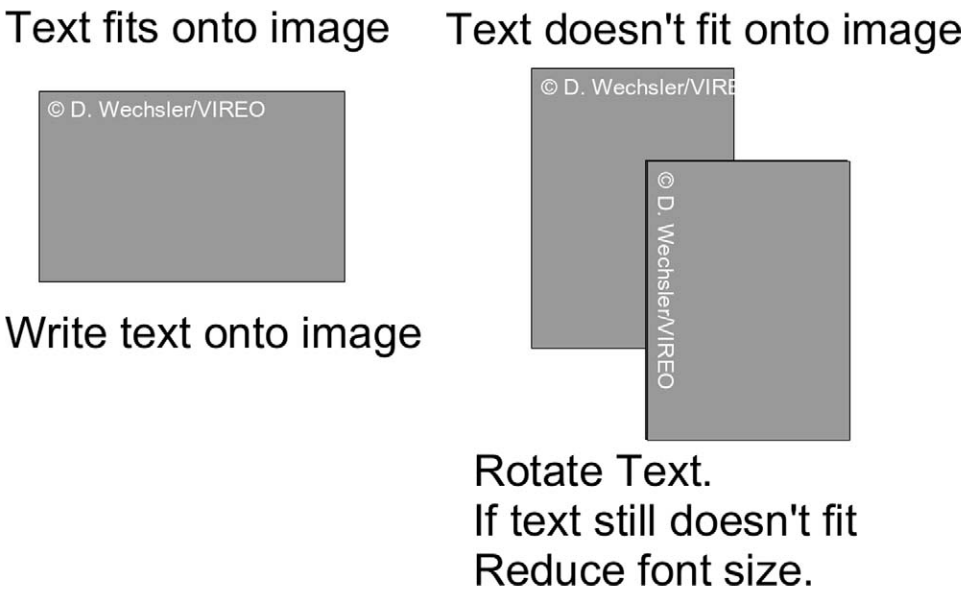

Figure 9. Copyright statements, containing the photographer's name vary in length, applied to images of different sizes and aspect ratio (see Fig. 8).

database for the copyright statement that should be stamped onto the image, checks to see if the text fits onto the image at an appropriate font size for the image size (a smaller font is needed for thumbnails than for large images). If the copyright text fits on the image it is written onto the image, if not, the code rotates and scales the font as needed to get the text to fit onto the image before writing it. The problem arising from different length copyright strings and from portrait and landscape aspect ratio images is illustrated in Figure 9.

Allowing Low Bandwidth Users to View High Resolution Images

Because many of the participating taxonomists in the All Catfish Project do not have access to wide bandwidth connections, it was desirable to find a way for those users to see portions of high resolution images in the database at full resolution. Users with high bandwidth connections can readily see and download the original multiple megabyte files; users with low bandwidth connections need an alternate means of viewing images. Example 5 (Fig. 10) is a portion of the code that retrieves images for users and on request alters those images, in this case by generating a thumbnail image with a blue box drawn into it marking the area displayed in a separate high resolution crop. Using PHP code and a database query allows retrieve the entire image, a thumbnail, a cropped portion of an image, or an image with information written onto it. This flexibility is being used as the basis of a tool to let the users of the system construct illustrated taxon-character matrices. With this tool, a taxonomist can highlight a portion of an existing image to illustrate the presence of a particular character state in a taxon. By manipulating an image file on the fly using information provided by the user and retrieved from a database we can produce an addressable, annotated, image zoom function for the web by simply using a toolkit of code.

```
// retrieve image metadata from database using target image id provided
$sql = "select file_name_assigned, mime_type from image where oid =
'$target'";
$result = pg_exec($connection,$sql);
if (pg_numrows($result)>0) {
   $row = pg_fetch_array($result,0);
   $filename = trim($row[0]);
   $mime_type = trim($row[1]);
}
....
$uploaded_file = upload_directory()."$filename";
// create a php image object from the target file
if ($mime_type==$UP_PNG) {
    $header = "Content-type: image/png";
    $image = imagecreatefrompng("$uploaded_file");
}
// [similar blocks populate $header and $image for different image types]
....
// send http response header, this must be the first output from this file
header($header);
 // return the image with any desired modifications
 if($mode == "box") {
    // draw a box on the image
    if(imagesx( $image ) > $scalingthreshold ) {
       // need to scale down the image and return a thumbnail copy
       $actual_x = imagesx( $image );
       $actual_y = imagesy( $image );
       $new_x = $actual_x / $scalingfactor;
       $new_y = $actual_y / $scalingfactor;
       $temp_image = imagecreate( $new_x, $new_y );
       imagecopyresized(
           $temp_image, $image, 0, 0, 0, 0, $new_x, $new_y, $actual_x, $actual_y );
    } else {
       // image is small, return the whole image
       $temp_image = imagecreate( imagesx( $image ), imagesy( $image ) );
       imagecopy(
           $temp_image, $image, 0, 0, 0, 0, imagesx( $image ), imagesy( $image ) );
    }
    $box_color = imagecolorallocate( $temp_image, 84, 81, 255 );
    imagerectangle( $temp_image, $x, $y, $x2, $y2, $box_color );

    // send the image to the user
    if($mime_type == $UP_PNG) {
       imagepng( $temp_image );
    }
 }
 // clean up, deallocate resources
 @image_destroy($image);
 @image_destroy($temp_image);
?>
```

Figure 10. Example 5: Code snippets from the PHP script used in the All Catfish Project to return images and modified images.

This application for zooming into images has a much larger context. A similar problem exists for the manipulation of raster map data, something that is usually solved by tiling images (McCormack 1996, Wittenbrink and Somani 1993). Given the small user community of the All Catfish Project and the relatively small images involved we can rely on very simple server side cropping and image processing. However, this method will not scale well to larger sizes (e.g. 50+MB images) or heavier loads. To scale to larger images sizes or heavier loads it would be necessary to use more efficient methods such as the tiling used by GIS applications such as mapserver (Lime and Burk 2004, see also Kropla 2005, Baumann 2003), or XASTIR (Xastir Group 2005). This application is also relevant to TDWG's developing discussion of standards for web interchange of biological specimen images and data (see Morris 2005).

Summary

Imaging projects in natural history museums can involve large numbers of images and complex metadata related to both the images and the collection objects imaged. We have described how images, database records, and image manipulation tools can be connected with simple programs to assist in the processing of images for the web, assist in the management of image metadata and quality control, and be used to manipulate images on the fly on a web server. The key to this manipulation of images is the ability to relate image files with database records containing data and metadata. We have linked images with their metadata through file names that use a consistent convention such that image file names can be constructed from information in a database. An alternate approach is to give images arbitrary file names and store these in a database. In either case, preplanning and developing a consistent image naming scheme is essential in a large imaging project.

Once information about images can be linked to the image files, images can be manipulated by code in an individual and intelligent manner. We have described examples where simple scripts use open source database and image manipulation tools to link images and data about specimens in those images. This has allowed us to capture image metadata into databases, manipulate the images individually based upon related database records (such as stamping image specific copyright information into the images), and to retrieve and manipulate images related to particular database records in a web database. Using this approach, very simple code can produce very sophisticated web image database applications through linking powerful open source database, image manipulation, and web serving software tools. Linking in other open source tools (such as statistical, mathematical, GIS packages, or data exchange tools) offers even more possibilities for the use of images of biological collection objects beyond simple web serving of images and their metadata.

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HERBARIUM NETWORKS IN THE UNITED STATES: TOWARDS CREATING A TOOLKIT TO ADVANCE SPECIMEN DATA CAPTURE

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Abstract.—From a workshop on herbarium networks held in September 2004 at Michigan State University, a bold challenge arose: to capture the data of all specimens in United States herbaria by 2020. The Toolkit Committee was formed to focus on standards, which would be required at all stages of the data capture process. The committee's first priority is providing a set of standardized tools for capturing herbarium specimen data and associated information. Initial efforts involved a schema that provides the flexibility necessary to represent our unique specimen data. This paper reviews currently available information on herbarium information standards. Of great concern is the daunting number of specimens that remain to have their data captured (approximately 90 million), with the limited resources currently available in our community. Developing on-line tools, including authority files, which promote sharing data directly between herbaria and/or the use of distributed networks holds great promise to speed data capture, reduce duplicative effort, and aid in quality control. The Toolkit Committee intends to evaluate the components necessary for providing our toolkit, promote initiatives that contribute to its refinement, and communicate them to the user community.

Introduction

The impetus for this paper arose from a discussion session at the Botany2004 meetings at Snowbird, Utah (Reznicek and Rabeler 2004) and from the National Science Foundation-sponsored Herbarium Networks Workshop held on September 20–21, 2004 at Michigan State University. At that workshop, 25 participants, from both large and small herbaria, met to discuss the possibilities of what could be done to stimulate communication and networking among herbaria. One goal that arose from that workshop may act to focus our attention: *to make all botanical specimen information in United States collections available online by 2020.*

What is the United States herbarium community facing in attempting to reach the 2020 goal? Of an estimated 95,000,000 specimens in U.S. herbaria, about five percent may have been databased over the last approximately 30 years (R. Beaman pers. comm.); this leaves about 90 million to complete in 15 years. Assuming that each specimen will be processed and that databasing and georeferencing each of the 90,000,000 specimens may take 10 minutes per specimen (some certainly will), it would take 900,000,000 minutes, 15,000,000 hours, or 2,142,857 days to complete the job. This translates to one person working for 9,524 years (assuming 225 work days per year) or 635 people working full time for 15 years. If you assume $30,000 US per year for one worker, $285,720,000 would be required to pay for data entry, excluding any costs for computers, etc. If you happen to represent a major defense contractor, $285M may just be a drop in the bucket; for a natural history museum, a university museum, or even the collective herbarium community it is a big number. This is likely a ''worst-case'' number—it is our intent to show that efficiencies could be developed that could significantly reduce the total monetary and labor costs.

Databasing collections has become an integral activity in many, but by no means all, herbaria. The level of databasing activity varies widely and is often done on a project basis, often tied to available funding. Data standards are still being developed; some that have been around for many years still have not been generally adopted. Many herbaria do adopt standards—their own—which may, or more often may not, be compatible with those of other major herbaria.

Just because a collection is databased does not mean it is available online. In a May 2005 survey of the Global Biodiversity Information Facility web site (GBIF 2005), 14 of the 32 US data providers serving data to GBIF were herbaria. Of the 3.3 million botanical specimens available at that time, 60% were from a single source: the Missouri Botanical Garden. Of the 10 largest US herbaria (ranking per data from P. Holmgren, pers. comm.), three were serving to GBIF. Enlarging this analogy to include the 50 largest US herbaria, 32 were serving data to the World Wide Web (their content varying from static lists to searchable databases) but only six directly to GBIF. On the flip side of this, there were some very small collections (e.g., University of Tennessee-Chattanooga fungus collection) providing data to GBIF that otherwise would likely be difficult to obtain.

We often point to 'diversity' in our work with collections. In the case of herbarium collection databases, it is certainly alive and well. We know of at least 29 different programs for databasing collections (C. Lapham pers. comm.); we have heard there may be as many as 124, but have not yet seen a compiled list of such. Many herbaria 'roll their own' database using programs such as Access or FileMaker Pro; relatively few use commercial offerings. In an effort to show the community 'who is doing what with what', Prather and Krings (2005) have compiled an online database of herbaria data basing efforts. As of early June 2005, 95 herbaria were represented; most are from the United States but some international collections are also included.

Diversity seems to be the rule in data systems in use at the largest U.S. herbaria. If you consider the 10 largest herbaria (including approximately 32 million specimens, about 1/3 of the 95 million noted earlier) you find the following programs in use: KE EMu (3), Access (1), Specify and Access (1), SQL with Access as a front end interface (1). Tropicos (1), SMASCH (1), FilemakerPro/Biotica (1), and a custom Oracle database (1). When we surveyed the 50 largest US herbaria, we noted that 15 different programs were in use, with Access and Specify being the most common. What this '15 different programs' does not take into account is the variation present among different users of the same program. For example, users of Specify may be using similar, but not identical structures, but cannot directly communicate with each other with the most recent version of the program (Specify 4.6).

The Toolkit Committee was one of four committees formed at the Michigan State University workshop: Community Network Development, Content, Toolkit and Vision. The committee includes 15 members, is convened by Aaron Liston of Oregon State University, and was issued the following charges: to consider the informatics infrastructure needed to fulfill the Mission and to identify the technology needed to support the infrastructure, including both hardware and software.

This paper focuses on:

1) Reviewing the currently available web resources and other information that could assist us in developing a set of community standards, including a standardized mechanism for exchanging data between collections and improving/expanding/creating community-wide authority files;
2) Discussing sharing data entry across the community and increasing data capture/processing rates with an emphasis on maximizing efficiency and minimizing costs; and
3) The projected deliverables of the Toolkit Committee.

Review of Currently Available Resources Useful in Developing a Set of Community Standards

Although initiated before the Toolkit Committee was formed, the use of the Herbaria Listserv (2005) was encouraged as a means of communication and it now serves some 490 subscribers and is also mirrored into Mexico and Central America (A. Liston pers. comm.).

The Australian botanical community got an early start on the concept of using a database to organize and store specimen-based data in their herbaria. It was quickly recognized that the ability to exchange accession-based records between herbaria would be advantageous, instead of duplicating effort. In order to achieve this exchange, a set of standards was required to facilitate the proper matching of information to the appropriate fields in those databases. This set of standards named the Herbarium Information Standards and Protocols for Interchange of Data (HISPID) was agreed upon for this task (Croft 1989). The HISPID standard contained about 160 common fields or elements that were necessary to exchange all relevant information about the specimen being accessioned. This standard has continued to evolve over the past several years to its present version HISPID4 (2005).

A more generalized standard for exchanging core information on biological collections, the Darwin Core, was next created based on the simple resource-discovery metadata standard, the Dublin Core Metadata Initiative (1995). These standards use a core (small) number of elements to facilitate search and retrieval of information between databases. More detailed information known about a collection record can also be exchanged through using standard extensions. The Darwin Core (2005) is currently in its second version and has a core set of 44 elements with several collection-specific extensions. The Toolkit Committee is currently working on a plant-based, curatorial extension. The Darwin Core elements and extensions have been adopted by several biological informatics initiatives including the Ocean Biogeographic Information System (OBIS), the Mammal Networked Information System (MaNIS), HerpNet, FishNet II, and the Ornithological Networked Information System (OrNIS).

A near philosophical opposite, the Access to Biological Collection Data (ABCD Schema 2005) standard has no need for extensions as it has over 700 data elements. This all-inclusive standard has been adopted primarily in Europe to query collection-based resources under programs such as the European Network for Biodiversity Information (ENBI) and Synthesis of Systematic Resources (SYNTHESYS). In order to maintain consistency between standards, the ABCD Schema, now in its second version, maps elements directly with HISPID and the Darwin Core.

The distribution of information between databases has evolved with changing network technology. The HISPID elements were simply exchanged by delimited text that was delivered by e-mail to the other institution (Conn 1998). Human intervention was then required to input the appropriate data into the corresponding fields in the 'receiving' database. The Darwin Core and ABCD standards have, to this point, been primarily used to facilitate request-response querying across distributed networks. Both standards require a set of transport protocols that use the 'mark-up' language XML to define the structure and rules for the data elements. These XML documents are then referred to as schema. The Darwin Core schema uses Distributed Generic Information Retrieval (DiGIR) software that is a managed, open-source project (DiGIR 2005). The ABCD schema is distributed through Biological Collection Access Service for Europe, software that is a collaborative venture involving many European partners (BioCASE 2005).

Having standard elements ensures that the user can request data from several databases and receive a response that allows them to compare 'apples with apples.' However, within a single element an 'apple' may vary in flavor and quality. The naive user must assume that the information provided is accurate, as he/she typically has no knowledge of the information sources. Thus, it is very important that within an element the data is normalized (the flavor) and clean (the quality). A common way to control both the normality and quality of data in an element is through the use of authority files. In the context of this paper we can separate the kinds of authority files into two categories: non-herbarium specific and herbarium specific.

An obvious example of the 'non' category is geography. Several sources maintain lists of countries, states/provinces, cities, parks etc. (e.g., GII 2000, USGS 2001). Also, the International Organization for Standardization provides both the standards for geographic data and authoritative lists when appropriate (ISO 2005). These authoritative lists can be integrated into a database and used as 'pick-lists' to enforce consistency, thus avoiding spelling mistakes and formatting errors (e.g., USA, U.S.A., US, United States, The United States). However, in biological collections data we are often confronted with geographic conundrums in deciphering old labels that have geographic descriptions based either on names no longer in use or names that represent an entity whose borders have fluctuated dramatically over time. This is one example of the challenge we face in attempting to distribute high quality data to our users.

Several examples can be cited of authority files that are specific to herbaria. Perhaps the most obvious are taxonomic lists, several of which are searchable online, for example, International Plant Names Index (IPNI 2005), Integrated Taxonomic Information System (2005), and Missouri Botanical Garden's VAST (VAScular Tropicos) nomenclatural database and associated authority files (VAST 2005). These lists can be very useful in preventing data input errors, which run especially high for non-familiar 'Latinized' scientific names. Of course, in having more than one list of known taxonomic names (none of which are complete) to choose from there is no single standard. However, there is certainly value in being able to cross reference lists to identify possible errors. Another example, parallel to the taxonomic lists, is collector databases. These databases store the names of botanical plant collectors and/or authors and other useful information such as date of birth and death, taxonomic specialty, and geographic regions where collections were made. Two important examples are the Harvard University Herbaria Plant Author Database (2005) and Brummitt and Powell (1992) *Authors of Plant Names,* which is used to standardize as much as possible, the short forms of author names in the International Plant Names Index (IPNI 2005) database. A final example, unique to the botanical community, is Index Herbariorum (Holmgren & Holmgren 1998 onwards), which manages a list of acronyms used to represent all known herbaria as well as information about their holdings and staff. It is important to remember that all of the above authority files are dynamic and thus static copies of these files used in other databases must be regularly updated.

As mentioned above, several other biological collection disciplines are collaboratively working on standardizing and distributing their collection data. The herbarium community has the advantage of being able to evaluate these projects and share in the wisdom that they produce. The history of the collection of botanical specimens is not without idiosyncrasies and these may turn out to be advantageous, as will be highlighted in the next section.

Sharing Data Entry Across The Community And Increasing Data Capture Rates

One way in which sharing data entry across the community may be most easily visualized involves dealing with the question of data entry from 'duplicate' specimens. Virtually all herbaria contain considerable duplication, often in the form of specimens obtained via exchange where duplicates were sent to enrich collections.

Another botanical phenomenon is the exsiccata, a series of duplicate specimens 'published' (sometimes literally) and distributed as reference collections, often with 100 sets of each specimen. While this used to be a popular practice in vascular collections, especially in Europe, some cryptogamic exsiccatae are still being distributed. Why should each owner of such a collection database and georeference it?

In May and June 2005, we attempted to gather data on the percentage of duplicate specimens present in US herbaria. After sending a query to the Herbaria listserv, we later contacted 12 herbaria directly, four large (1 million+ specimens), four medium-sized (250,000 to 999,999 specimens), and four smaller (less than 250,000 specimens), asking collections personnel to sample several species in their vascular plant collection and record the number of specimens that originated at their herbarium vs. those acquired from elsewhere (via exchange, gift, etc.) and segregating their tallies by in-state vs. the rest of the United States and also a selection of international holdings. Eleven of the twelve herbaria responded, giving results which illustrated an interesting pattern (see Table 1). While 13% (a range of 0–23%) of specimens collected from the state where the herbarium was located were duplicates, about two thirds of both the out-of-state (69%, range 53–82%) and international collections (67%, range of 44–97%) were duplicates. This suggests that the community should move toward prioritized data basing: each herbarium should concentrate on data basing master/primary sets and distribute this data to the community. Since the field notes may include additional information that was not included on the specimen label as distributed, the field notes

Table 1. Results of a survey of 11 herbaria. The number of specimens originating from that herbarium (primary), those acquired from other herbaria (duplicates), the total number of specimens sampled, and the percentage of duplicate specimens is given for each collection sampled. Data from Oregon State University was baded on sampling the entire database of that collection rather than a small sample (> 500 specimens).

	In-state				Out of state				International			
Institution	Primary	Duplicates	Total #	% Duplicates	Primary	Duplicates	Total #	% Duplicates	Primary	Duplicates	Total #	% Duplicates
BKL	197	21	218	10%	38	111	149	74%				
CHSC	311	18	329	5%	20	43	63	68%	1	7	8	88%
DOV	94	0	94	0%	37	88	125	70%				
MICH	109	28	137	20%	54	130	184	71%	37	94	131	72%
MO	152	21	173	12%	146	322	468	69%	254	639	893	72%
MOR	52	11	63	17%	42	56	98	57%				
MSC	126	26	152	17%	50	71	121	59%	13	38	51	75%
PH	97	13	110	12%	49	55	104	53%				
TEX/LL	270	79	349	23%	31	145	176	82%	99	103	202	51%
UNA	126	22	148	15%	9	26	35	74%	39	31	70	44%
SUM of 10 institutions	1,534	239	1,773	13%	476	1,047	1,523	69%	443	912	1,355	67%
OSC	95,362	5,165	100,527	5%	522	1,239	1,761	70%	1	33	34	97%
Ranges:	x = 11		0–23%		x = 11		53–82%		x = 7		44–97%	

Institutions surveyed (abbreviations follow Holmgren & Holmgren 1998 onwards): Brooklyn Botanical Garden (BKL), California State University, Chico (CHSC), Delaware State University (DOV), The University of Michigan (MICH), Missouri Botanical Garden (MO), The Morton Arboretum (MOR), Michigan State University (MSC), Oregon State University (OSC), Academy of Natural Sciences, Philadelphia (PH), the combined herbaria of the University of Texas and the Texas Research Foundation (TEX/LL), and University of Alabama (UNA).

become an important resource which the owning herbarium can share with the rest of the community.

One classic example of the duplicate specimen phenomena is witnessed in a specimen of *Ephedra viridis* collected by Delzie Demaree in 1957 (*Demaree 38875*). Distributed as an unnumbered specimen in the Seventh Distribution of North American Plants by the Southern Appalachian Botanical Club (SABC), the notes accompanying at least the specimen at the University of Michigan Herbarium indicate that "the wind was blowing too strong to make specimens in the field. I boxed up enough for 87 sheets. I simply pruned the shrub a little." That quotation suggests there are 86 other specimens of this collection. Why should there be 87 separate attempts to georeference it, especially when the county name is misspelled on the SABC label accompanying the specimen.

Georeferencing duplicate specimens in addition to standard data capture represents another potentially large time-wasting scenario. In most cases it is logical for the institution that holds the primary set of a given collection to do the georeferencing. The primary institution is likely to have access to associated materials that could aid in determining the precision of the reference, such as field notes, and archives. Further, if the collections are from the local area, then other collectors at the institution may have a greater ability to decipher the locality data, based on their knowledge. Several on-line tools have emerged recently to aid the precision and speed of georeferencing. The Georeferencing Calculator (Wieczorek 2001) was designed to provide a judgment of error for a given locality description. The GeoLocate (2005) project provides a software package to aid in georeferencing from a string of locality data. The BioGeomancer (2005) on-line tool is particularly powerful as it can geoparse a locality string and then, through consultation with the appropriate gazetteers, provide a georeference. All of these georeferencing tools can be run in batch modes to improve workflow efficiency. It must be remembered though, that automated georeferencing is only as good as the gazetteer information available, which outside of North America and Australia is more limited.

Another equally important need in the herbarium community is finding ways to improve the rate at which specimen data is captured in order to meet the 2020 goal. A promising set of tools currently being developed will use high-resolution digital images of herbarium sheets and recognition software to automatically capture specimen data. The recognition component will use Optical Character Recognition (OCR) on type and printed characters, Natural Handwriting Recognition (NHR) on script, and Natural Language Processing (NLP) to recognize words and parse the resulting text string. This project is named by a clever recursive acronym HERBIS, which stands for HERBIS is the Erudite Recorded Botanical Information Synthesizer (HERBIS 2005).

Projected Deliverables Of The Toolkit Committee

The toolkit that we foresee will include herbaria specific information on: 1) reviews of data capture software; 2) standardized elements and a suggested protocol for data entry; 3) a compilation of authority files and other data dictionaries; 4) resources for georeferencing; and 5) links to other networking efforts.

We see the toolkit serving as a community resource to make it easier for community members to learn about and use the resources that are becoming available.

An on-line collaborative environment using wiki technology which allows for any member to edit content of the pages (Leuf and Cunningham 2002) was launched in the spring of 2005 as a tool to assist the committee in organizing content for eventual community release. A more comprehensive Herbaria Collaborative site (Liston and Prather 2005) was announced in September 2005 to the herbarium community and most of the initial content is from the Toolkit Committee.

Summary

If we are to accomplish the goal of making all botanical specimen information in U.S. collections available online by 2020, we need to 1) develop a set of community standards, including a standardized mechanism for exchanging data between collections and improving/expanding/creating community-wide authority files; 2) share data entry across the community, especially concentrating on reducing or ideally eliminating multiple data entry and sharing what we call the georeferencing 'burden;' and 3) increase data capture/processing rates with an emphasis on maximizing efficiency and minimizing costs.

The herbarium community has a vested interest in providing their data contained on the specimens that they curate to researchers and the general public. These data can be used to highlight the existence and importance of botanical collections, and many herbaria have begun capture projects. The existence of considerable amounts of duplication in our herbaria requires a change in focus from concentrating on justifying the importance of 'our own' collection to prioritizing cooperation through data interchange. We need a network that can be used to exchange record sets between herbaria to reduce or eliminate redundant capture and to facilitate georeferencing. However optimistic, we believe that developing a standard schema and a bidirectional, distributed system to maximize our ability to locate and share information about duplicates, and enhance quality control of our data, is within our grasp.

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Museum Collection Resources Display Available for Loan

The Resources Subcommittee of the Conservation Committee (SPNHC) maintains two displays of supplies and materials used by many museums for the storage and preservation of natural history collections. Examples of items included in the displays are: materials used in the construction of storage containers and specimen supports; equipment for monitoring storage environments (e.g., humidity, temperature, air quality, insects); and a variety of containers for the storage of collections and documentation. Some of the products are discipline-specific (e.g., pH-neutral glassine for interleaving between herbarium sheets) but most can be used in multidisciplinary collections (e.g., Ethafoam™ for lining shelves and drawers; Tyvek™ tape for box and tray construction). The displays are available for loan to interested parties for meetings, conferences, and other museum-related activities. Shipping costs to and from the requested venues are the responsibility of the borrower. There is no loan fee but SPNHC invites borrowers to make a voluntary contribution to cover the costs of routine maintenance. For additional information, or to borrow a display, contact:

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