Articles

SOCIETY FOR THE PRESERVATION OF NATURAL HISTORY COLLECTIONS (SPNHC) 25TH ANNIVERSARY CELEBRATION BANQUET ADDRESS - BIODIVERSITY 2010 AND BEYOND: SCIENCE AND COLLECTIONS SPNHC AND CANADIAN BOTANICAL ASSOCIATION (CBA/ABC) JOINT CONFERENCE, OTTAWA, ONTARIO, CANADA

Richard K. Rabeler

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Twenty-five years. Depending on your perspective, it is either a short or a long period of time. If you are thinking in terms of the age of some of the objects that we curate, it could be quite short. If you have been working as a collection manager at the same institution for about that time, it might seem like a very long time.

For a successful scientific society, 25 years may not be that significant. But, in the context of what the founders of SPNHC started with and the notion that, to some, collection care is not a big deal, it *is* something to celebrate. I think one of the founders captured the essence of why we should be proud of this moment: "I am most proud of what SPNHC has been able to accomplish from the meager beginnings."

While Janet will tell us more about some of the important people and events of our past, I want to take a few minutes to look ahead. What will SPNHC accomplish in the next 25 years? We have grown into an organization that is becoming more widely known for our collections expertise, which can be easily described as "best practices." With the increased emphasis on collection digitization and biodiversity, "best practices" pops up time and time again. Each time I hear it, I say "ah, an opportunity for SPNHC." During my presidency, I have made a conscious effort to make sure that SPNHC is involved where it looks like we might be able to contribute our talents for the betterment of the community. I think we are in an excellent position to make our mark.

In part, this depends on keeping the society vibrant with the energy that has carried forth from the founders and charter members. As more of us approach retirement, we need to attract new members to help carry on the work of SPNHC. As one measure, we started a travel grant program this year; 13 people applied and two were named recipients of the first grants. It gives me great pleasure to announce that, as of this past Monday, this grant now bears the name of one of our founders, Jerry Fitzgerald.

One of our winners noted how much she appreciated how open and friendly we are—that's the attitude that hooked me 16 years ago. SPNHC has accomplished a lot since it was conceived; it survived a sometimes rocky childhood, and now, in many ways, is a mature society.

The best should be yet to come!

NAMING OF THE SPNHC TRAVEL GRANT HONORING JERRY FITZGERALD

Judith Price

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Gerald R. Fitzgerald, collections care professional and past President (1992–1994) of the Society for the Preservation of Natural History Collections (SPNHC) was honored at

the Society's annual meeting in June 2010 in Ottawa, Ontario by the naming of the Fitzgerald Travel Grant.

The Society recognizes Jerry's many contributions to the field of collections care, from his long career at the Canadian Museum of Nature (CMN) where he served as the first Director of Collections, to his pivotal role in the origins of SPNHC. Jerry had a knack for teaching and a deft touch in promoting the professionalism of his colleagues.

Kieran Shepherd of the CMN, in his letter of nomination stated, "This is to honour Jerry Fitzgerald, one of those key individuals that recognized a need for an organization to promote the preservation of natural history collections and acted upon it. Through his devotion to the cause, SPNHC was born. He was, and still is, a steadfast believer in the organization."

"We as members should recognize his contribution to the founding of the society. The naming of the newly created travel grant to honour him is a fitting tribute to his service to the society and the natural history community in general."

Mr. Fitzgerald worked as a student for the Geological Survey of Canada and the National Museum of Natural Sciences (NMNS). In 1970, he joined the palaeontology staff of the NMNS, later renamed the Canadian Museum of Nature and became the first Director of the newly created Collections Division in 1991. During his career, he produced 23 publications, and presented numerous talks and professional training workshops. Dedicated to the highest standard of care for the national collection of natural history objects, he assisted his staff in elevating their own skills to equal the task. He established a Conservation unit under the leadership of Rob Waller, who was honoured at their 2010 meeting by SPNHC with the Carolyn Rose Award for significant contribution to the objectives of the Society. As well as encouraging others, Jerry worked to improve his own skills and was accredited by the Canadian Association of Professional Conservators in 1989 and served as President from 1996 to 2000.

The seed that became SPNHC was planted when Jerry and his colleague Dan Faber organized the first international workshop on care of natural history collections in Ottawa. Says Stephen L. Cumbaa of the CMN, "That was in 1981, and the workshop proved to be an inspired idea. The proceedings of that workshop came out in 1983 as Syllogeus No. 44, a publication of this museum. Jerry was beating the drums for conservation even then; his paper in the volume, 'The wet-epoxy-surface technique of casting with pour-in-place polyurethane foam' was one in a series of 'how-to' papers. Jerry always had ideas of how to do it better."

Catharine Hawks of Falls Church, Virginia points out: "Jerry was instrumental in the founding of SPNHC, in no small part by helping to smooth the way to an amicable joint Canadian–American enterprise at times when factions within the organization were notably fractious. He persistently instilled a sense of 'gentlemanly conduct' that helped to make SPNHC able to attract members from many nations. Without his quiet leadership, I don't think the organization would have survived to reach a 25th anniversary, at least certainly not as a multinational entity. We owe him more than most of our members will ever know."

"Always hardworking on behalf of collections care for the natural sciences, Jerry helped raise awareness in Paleontology about sound conservation practice and the importance of using the same ethics in preparation that are expected from conservators in other fields."

Janet Waddington of the Royal Ontario Museum in Toronto, Ontario recalls, "Jerry has always been passionate about the welfare of collections and about SPNHC, having served in the presidential offices from 1992 to 1996. Two other awards (the Carolyn Rose

Award, for significant contribution, and the Faber Award, for research on collections care) are named after founding members who remained active in the society. As Jerry was instrumental in starting a tradition of meetings on aspects of collections care, it is fitting to give his name to the Fitzgerald Travel Grant to help defray the costs for young professionals to attend the annual meetings of SPNHC.''

NAMING OF THE SPNHC TRAVEL GRANT HONORING JERRY FITZGERALD, RESPONSE

Gerald R. Fitzgerald, Canadian Association of Professional Conservators

Museum Associate, Canadian Museum of Nature; and Director, Collections Services Division, Canadian Museum of Nature (Retired)

I want to thank the Society for honouring me with the Fitzgerald Travel Grant. On hearing the announcement at this year's SPNHC banquet I was overcome with emotion and at a loss for words—a situation in which I seldom find myself. I have always felt that encouraging, training, and sharing knowledge with students and up-and-coming professionals is a responsibility not to be taken lightly, and I have always done my best to help them achieve their potential. For this reason, the naming of the travel grant is very special to me and I feel greatly honoured by the Society. I think it is a mark of the maturity of the Society to have established the grant program. I am encouraged by the participation of so many young professionals at the annual conference and feel that the future of the Society is secure in their capable hands.

PRESENTATION OF THE OF THE CAROLYN B. ROSE AWARD TO ROBERT WALLER

Catharine Hawks, Fellow, International Institute for Conservation, Professional Associate, American Institute for Conservation

Conservator, 2419 Barbour Road, Falls Church, Virginia 22043-3026

In recognition of his outstanding contributions to the fields of conservation and collections management worldwide, with impacts far beyond the field of natural history

I first met Rob Waller when we were speakers in a special session on natural science collections during the 1985 AIC Annual Meeting in Washington, DC. Rob, our fellow speakers (Frank Howie, Mary-Lou Florian), and I were amazed/dismayed at the number people who attended the session. As a student overwhelmed to be on the program with people who were already legendary for their publications about conservation of these collections, I was more than a little nervous. When I confessed this, Rob very kindly convinced me that if anything, he and the other speakers were equally apprehensive. Actually, I think he said, ''Oh my, I'm [expletive deleted] terrified.'' He remains the kindest as well as the most innovative conservator it has been my privilege to meet in the intervening years.

Rob had a distinguished career at the Canadian Museum of Nature, becoming Chief of Conservation in 1996, a position he held until he retired from the museum in 2008. His time at CMN incorporated a visiting research position at the Canadian Conservation Institute.

1996–2008	Chief, Conservation Section, Canadian Museum of Nature
1992–1996	Managing Director, Collection Division, Canadian Museum of Nature
1991–1992	Head, Conservation Section, Canadian Museum of Nature
1987–1988	Visiting Scientist, Canadian Conservation Institute
1975–1991	Conservator, Mineral Sciences Division, Canadian Museum of Nature

For anyone interested in geosciences collections, Rob's papers have been remarkable in creating an understanding of how seemingly immutable materials deteriorate over time. His work on how we assess and maintain fluid-preserved collections has been no less remarkable in fostering knowledge about preservation of these poorly understood resources.

Always a patient, dedicated, and very creative teacher, Rob has freely shared his expertise with interns, students in various collections care programs, staff from numerous museums, and colleagues in conservation and collections management. He has given seminars, workshops, and short courses at universities, museums, and museum organizations, only some of which are listed here.

- University of Kansas Natural History Museum
- Virginia Museum of Natural History
- Illinois State Museum
- Royal British Columbia Museum
- Institute of Archeology, University of London
- Department of Earth Sciences, University of Cambridge
- The George Washington University
- Missouri Botanical Garden
- British Museums Association
- Canadian Museums Association
- American Institute for Conservation
- Leisure and Cultural Service Department, Hong Kong SAR
- National Archives of Canada
- American Museum of Natural History
- Instituut Collectie Nederland
- Queen's University
- The Natural History Museum
- Yale University
- Institute for Preservation of Iraqi Cultural Heritage

His teaching venues have included sites throughout North America, Europe, Asia, the Caribbean, and most recently, Iraqi—as part of the new Institute for the Preservation of Iraqi Cultural Heritage.

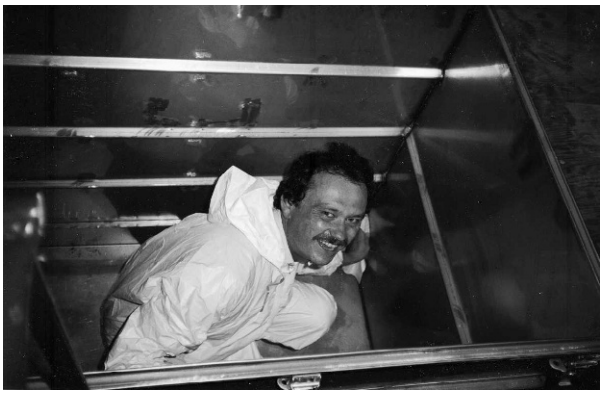
Rob never stops learning. He never shirks from delving into new fields in great depth, if it appears that the transfer of knowledge will further the cause of collections care.

His brilliant foray into quantitative risk assessment is continuing to change how conservators and collections managers worldwide approach the care of all types of heritage property. He has steadily improved the way we address our public trust responsibilities by developing a means to both demonstrate accountability and estimate the preservation potential of our actions.

Others have contributed to these concepts, but only Rob has managed to synthesize their efforts, add *essential* academic rigor to the process, and infuse the whole with insights that stagger lesser minds. I have been told that NATO regards Rob's risk management program as perhaps the most comprehensive ever studied by that organization.

In his copious spare time, Rob has taken part in a number of professional activities with various organizations, serving as:

- Vice-Chair and Chair of the Canadian Association of Professional Conservators;
- Assistant Coordinator, Natural History Working Group, ICOM Committee on Conservation;



- Editor of *Natural History Conservation*;
- Executive Councilor and Vice-President of the Canadian Association for Conservation;
- Member of the Society for Risk Analysis;
- Executive Councilor and Vice-President, Canadian Association for Conservation; and
- Member, Society for Risk Analysis.

And in SPNHC as:

- Member-at-Large;
- Co-Chair, Finance Committee;
- Co-Chair, Conservation Committee; and
- Chair, Conservation Committee–Assessment Subcommittee.

Rob's doctoral dissertation in conservation, C*ultural Property Risk Analysis Model,* Göteborg Studies in Conservation 13, Acta Universitatis Gotheburgensis, is but one of his over 30 publications in risk management and conservation.

Another great service to the field was saving the faculty of the Collections Care Pilot Training program in Los Angeles, when, during a syllabus revision meeting in a hot tub, the faculty discovered they had wine, but no corkscrew. Debate about whether Rob solved the problem with a sandal or a sneaker continues, but the accomplishment was important because many of the participants in that training program were the backbone of SPNHC throughout its formative years.

In fact during an academic discussion of Rob's methodology at a SPNHC meeting in Canada, Carolyn Rose demonstrated the leadership for which she was so well known by calling Rob to ask him to settle the issue. Unfortunately, it was 2:30AM when we called. This may have been the only time in all the years I have known him when Rob could have been described as ''kinda cranky.'' And, we still don't know the answer to the question of how he opened the wine.

However, as we all know, Rob is normally a genial and witty friend and colleague.

Collections not used are useless collections.
I. P. Sofacto
(aka R. R. Waller)

Since his retirement from CMN, Rob has taught in the Queens University conservation program and has established Protect Heritage Corporation, to continue his work with museums around the world.

SPNHC is not the first to honor Rob's achievements. He has been elected a Fellow in the International Institute for Conservation and in ICCROM, and he received:

- International Council of Museums—Canada Award, Best International Project Advancing Museology;
- Canadian Museums Association, Outstanding Achievement Award; and
- Canadian Museums Association, Outstanding Achievement Award for a Conservation Project.

He has helped bring prestige to the field of natural science conservation through his recognized professionalism, his contributions to the literature, which include numerous articles in *Collections Forum,* and his service to national and international organizations.

The Rose Award is the highest honor that SPNHC confers. It recognizes a career of contributions. I think that in Rob's case, this is a mid-career award and we can look forward to benefitting from his active participation for many years to come.

It's difficult to imagine that the interests of SPNHC could have a better representative than Rob.

He consistently brings uncommon intelligence and a strongly innovative mind to the issues that confront our work. We and the heritage collections that unite us, would be much poorer were it not for his talents and his generosity in sharing them

With many thanks those who shared images and recollections of Rob: Carolyn Leckie, John Simmons, Janet Waddington, Tim White, and Stephen Williams.

ACCEPTANCE OF THE CAROLYN B. ROSE AWARD

Robert Waller

President and Senior Risk Analyst, Protect Heritage Corporation and Museum Associate, Canadian Museum of Nature

Thank you so much Cathy—you are too kind, actually I think you are all too kind—but I am glad you are the way you are. I want to right away give a special thanks also to Lisa Elkin who, I have learned, initiated this act of kindness.

When, in March, Rich first tried to contact me about this, I was busy teaching with Jessie Johnson at the Iraqi Institute for Conservation in Erbil, Iraq. It was difficult for us to connect given the time change and my being with a class all day. I had to wait over a week before we could connect in anywhere near the same time zone. During that time I kept wondering what deadline I had missed or task I let slip that would have warranted a call from our President. I was sure I was in trouble for something. You can imagine the delight I felt when Rich not only let me off the hook but actually told me I was to receive the Carolyn L. Rose award.

I felt quite shocked and incredulous at first. I could think of dozens of people I felt were more deserving than myself. I still think that but I also came around to feeling that I should accept blessings, as and when they come. And I do feel blessed by your recognition and so fortunate to have found myself working in a field and a situation where collectively we could accomplish so much for the benefit of humanity in such a short time as 25 years.

I want to take just a minute or two to thank those who have been pivotal in getting me here. Of course, I should begin with my families, starting with my parents and through to my current family with wife, Karen, and children, Tom, Tracey, and Ashlea. Ridge Williams first hired me to work at the Canadian Museum of Nature some 35 years ago and provided me with both freedom and support for developing the new subject of mineral conservation.

Jerry Fitzgerald has been supportive and a good partner in idea development in all his roles of colleague, manager, and friend. Finally, Roger Baird helped me leave the CMN while retaining an association that lets me continue to share the knowledge we generated there. What we developed at CMN was the result of efforts by all of the collection staff, and many of the research staff, and I am grateful to them all. Through my years at the museum I have been fortunate to have worked with a series of wonderful ladies in our Conservation Section culminating with Luci Cipera, Carolyn Leckie, Marcie Kwindt, Laura Smyk, and Garnet Muething. They have all greatly enriched my life.

Colleagues from museums and agencies across North America and around the world have contributed greatly to my work and my life. I will resist the temptation to name names as that would have us here for hours. I trust all these people know who they are and understand I appreciate their contributions. One colleague and friend who was especially important was Carolyn Rose, for whom this award is named. Carolyn, though not much older than me, was the undeniable matron of our field, although matron sounds more than a little too stuffy for such a beautiful and dynamic lady. Carolyn supported and encouraged the development both of our field and of my work from the moment she first encountered us. So much of what we have all accomplished within our organization can still be traced to her influence.

Last, and perhaps most, I am grateful to all of you. None of us accomplishes anything alone. What I have achieved is really no more than documenting what you and others have taught me. I cannot have achieved anything beyond what we collectively have accomplished. It is with all the humility engendered by that understanding that I thank you for this honour you have bestowed on me.

ALCOHOL RECYCLING AT THE SMITHSONIAN INSTITUTION, NATIONAL MUSEUM OF NATURAL HISTORY (NMNH)

William G. Keel,[1] William Moser,[1] Jennifer Giaccai,[2] Andrea Ormos,[3] Jackson Tanner,[4] and Lee A. Weigt[3]

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Abstract.—In an attempt to reduce the volume of hazardous waste generated by specimen processing and curation activities, the Smithsonian Institution, National Museum of Natural History evaluated a solvent/formalin recycler. The purpose of the evaluation was to produce a contaminant-free recycled alcohol product for reuse in specimen curation. Over 40 test samples of used alcohol (isopropanol and ethanol) from various fluid-preserved zoological specimens were tested. The distillation of each 13–17 L used alcohol sample required 5–9 hours to complete, yielding recycled alcohol at 89–95% concentration. A significant odor, probably derived from amines, not specifically identifiable through chromatography or other methods, could be detected in the recycled ethanol. Molecular analysis of a spiked alcohol sample both before and after distillation showed that DNA does not survive the distillation process. Pre- and postdistillation samples were analyzed by gas chromatography–mass spectrometry (GC–MS). The GC–MS results for ethanol routinely identified the presence of ethyl ethers, ethyl esters, and aldehydes, all in very small concentrations. These compounds were present both before and after distillation, with little change in concentration. Arene compounds, including toluene and xylenes, also were routinely identified in the isopropanol solutions both before and after distillation.

Introduction

Chemical recycling regularly occurs in medical histological laboratories and manufacturing plants (Pinizzotto and Baker 2000; Hampton 2007). It is not used widely in natural history museums, but could be a tremendous cost saver by reducing the amount of new alcohol purchased and hazardous waste generated. In general specimen curation and processing activities, the Smithsonian Institution, National Museum of Natural History (NMNH) consumes 11,945 L of ethanol and isopropanol a year at an annual cost of $12,661.64. The NMNH also generates 4,789 L of hazardous waste alcohol a year at an annual total cost of $4,070.65 to process.

The NMNH evaluated a solvent/formalin recycler as part of a study to reduce the volume of new alcohol consumed and hazardous waste generated by specimen processing and curation activities. The recycler was assessed to determine its effectiveness and feasibility for general museum use by producing a cost-effective, contaminant-free, recycled alcohol for reuse in general specimen curation. The recycled alcohol needs to be chemically and molecularly pure enough to be reused without contaminating any specimens that it contacts. The goal was to take any alcohol sample, even those with high levels of contaminants, and provide an end product that was as clear and odorless as a purchased product.

Materials and Methods

Recycler

Fluid samples from collections of the NMNH were gathered to test a commercially available 19-L capacity SLV–99U(L) model fractional distillation Formalin/Solvent

Recycler. Due to the small quantity of formalin-archived collections and resultant waste produced annually by our departments, it was decided to only test the solvent (alcohol) component. The test samples included almost all of the major phyla that comprise the fluid collections at NMNH, covering a wide spectrum of contaminants derived from the fixing/preservation of these taxa as well as the chemicals derived from the reaction of the specimens with the preservative fluid. The unit was programmed with heat settings designed for use with isopropanol and ethanol. One program temperature (85°C) was set up for the recycling of high-concentration fluids (>65% alcohol) with a second program using a higher temperature (90°C) to derive the same results for starting solutions with a concentration of <65% alcohol. These settings provided us with a clear product between 89% and 95% concentration and a waste product that was approximately 30% alcohol. Pre- and postdistillation 2-oz (59.2 ml) samples were taken and the volume and alcohol percentage were recorded. Any special characteristics of the predistillation samples or end product were also recorded, generally to remark on the odors that survived the distillation process.

One alcohol pretreatment test was performed prior to distillation. The alcohol was acidified with concentrated sulfuric acid to a pH of 5 before recycling. To allow complete reaction of any amines in the alcohol with the sulfate ion, forming insoluble salts, the pretreatment sample sat for 24 hours and then was distilled in the recycler.

A number of alcohol posttreatment tests were performed. Large quantities of activated charcoal were poured into containers of recycled ethanol, agitated, and allowed to sit for 12 hours. The product poured off was clouded by precipitate from the charcoal but the odor was noticeably lessened. The fluid then was poured through a funnel lined with coffee filters to remove the charcoal dust and recycled a second time. Additionally, two activated charcoal filtration columns were designed for posttreatment of the recycled alcohol. The columns were constructed from 4 ft (1.2 m) tall, 4 in. (10 cm) diameter PVC pipe with a finely perforated cap, lined with four paper coffee filters, packed tightly with granular activated charcoal, and set up with an unused glass catch. A 19-L carboy of recycled ethanol and isopropanol was then placed over each dedicated charcoal column, respectively, and set to a slow drip. The slow drip allowed the fluid a maximum amount of time in contact with the charcoal and prevented fine charcoal particulate in the catch.

GC–MS Analysis

Alcohol samples were run using an Agilent 6890 gas chromatograph with 5975 quadrupole mass spectrometer and an Agilent 7694E headspace analyzer (GC–MS). A number of sample pretreatments were tried, including adding sodium chloride to the alcohol solutions and extracting with chloroform or diethyl ether; however, no pretreatments showed improved volatilization of any compounds in the GC–MS chromatograms. Aliquots of the alcohols collected both pre- and postdistillation were placed in headspace vials, filling half of the vial. Samples were run on two different GC columns. An Agilent J&W DB-WAX, 30 m × 0.25 mm × 0.50 μm column maximized identification of the reactive aldehydes and amines. However, because the large volumes of ethanol and isopropanol present in the samples coeluted on the DB-WAX column, samples were also run on the Agilent J&W HP-5MS, 30 m × 0.25 mm × 0.50 μm column to provide information on the relative amounts of ethanol and isopropanol in each sample.

Prior to headspace extraction, vials were held at 50°C for 5 minutes. The sample loop was filled for 0.2 minutes at 55°C and the transfer line to the GC was held at 60°C.

Helium carrier gas was used at a constant flow rate of 0.8 ml/min. A split/splitless inlet was used in split mode at a temperature of 70°C with a 20 : 1 split. The column was held at 25°C for 5 minutes, then heated at 10°C/min to 150°C and held for 5 minutes. The transfer line to the MS was at a temperature of 200°C. The mass spectrometer used electronic ionization, with the ion source at 230°C and the quadrupole at 150°C, measuring masses from 20 to 300 m/z (mass-to-change ratio).

The peaks in the chromatogram were deconvoluted and identified using both retention time (RT) and the mass spectrum by the AMDIS software program, the NIST MS Search program and the NIST05 library produced by the National Institute of Standards and Technology, Gaithersburg, Maryland. Quantification of any of the compounds was not attempted—too many unknown variables made this difficult—and analysis of the data only established approximate amounts of the compounds.

Molecular Analysis

Because amplifiable DNA is known to leach into alcohol storage solutions (Shokralla et al. 2010) and would contaminate subsequent nondestructive sampling of preservative if not eliminated, we tested for survival of DNA posttreatment. Positive control fish DNA was extracted from a commercially obtained fresh fillet of yellowfin tuna (*Thunnus albacore*) using a phenol-chloroform protocol on the Autogenprep 965 automated DNA extractor (Autogen, Holliston Massachusetts). The concentration of the DNA extract was 39 ng/µl with a spectrophotometer 260/280 absorbance ratio of 1.78. After adding 1 mg of tuna DNA to the 2.75 gal (10.4 L) of clear 96% ethanol, a 50 ml pretreatment sample was taken. The ethanol recycler ran on the 85°C program and an additional 50 ml posttreatment sample was taken after the run was completed.

Pre- and posttreatment samples were prepared for polymerase chain reactions (PCR) to amplify DNA. To test for starting template quantity variation, 10 µl, 100 µl, 1.5 ml, 3 ml, and 9 ml ethanol was evaporated, eluted in 10 µl molecular-grade water, and 1 µl of this was used as template in the PCR reactions. Then, 1.35 ml ethanol was precipitated with 150 µl, 3 M ice-cold sodium acetate (NaOAc), and 7.5 µl 2 M magnesium chloride ($MgCl_2$). The pellet was eluted in 10 µl molecular grade water, and 1 µl was used as template in the PCR amplification to detect DNA.

The PCR was one cycle of 30 seconds at 95°C, followed by 35 cycles of 30 seconds at 95°C, 30 seconds at 52°C, 45 seconds at 72°C, and a final extension of 300 seconds at 72°C. The procedure was performed on an Applied Biosystem 2720 Thermal Cycler (an exception to this protocol was an annealing temperature of 48°C for the primer pair of dgLCO1490/ dgHCO2198).

The 10 µl reaction volume contained 1 µl template DNA, 1.0 µl 10× PCR Buffer, 0.4 µl 50 mM $MgCl_2$, 0.5 µl 10 mM dNTPs, 0.3 µl 10 mM each of forward and reverse primers, and 0.5 U *Taq* DNA polymerase (reagents: BioLine USA Inc., Taunton, Massachusetts). Negative and positive controls were included with each reaction.

Results and Discussion

Recycler

A total of 35 ethanol and 10 isopropanol samples were run through the recycler. Regardless of initial concentration of alcohol, the recycler yielded recycled alcohol at 89–95% concentration by volume. The distillation time and return volume was proportional to the starting fluid concentration (Figs. 1, 2). The waste product created by the recycler was approximately 30% alcohol, a level considered to be hazardous waste.

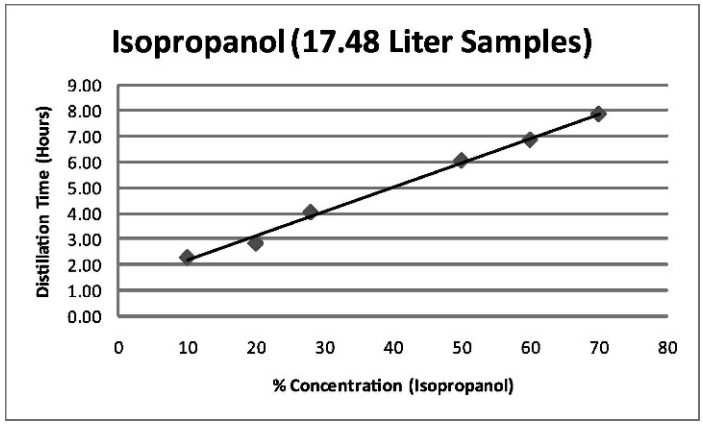

Figure 1. Graph of distillation times and concentration return from isopropanol samples.

The initial samples tested were discolored, clouded with precipitates, and extremely odiferous. The goal was to produce a final product that would be up to archival collections standards. Despite the high levels of dyes, precipitates, and other contaminants, the recycler was able to produce an end product that was as clear as commercially available chemical grade ethanol or isopropanol (Fig. 3). However, the odors in the recycled fluid were equal to the original product or, in some cases, more concentrated. The odors were very strong for the ethanol batches but were perceived to be weaker after distillation of the isopropanol samples. This was not considered significant due to the sharp odor of pure isopropanol and the likelihood that this masked any perception of the odors.

The odors were thought to be amines; a variety of methods were attempted to solve this problem. The recycler was reprogrammed with different temperatures and modes designed to leave the odor-causing compounds behind in the waste product, but none of the new temperature settings were able to achieve this result.

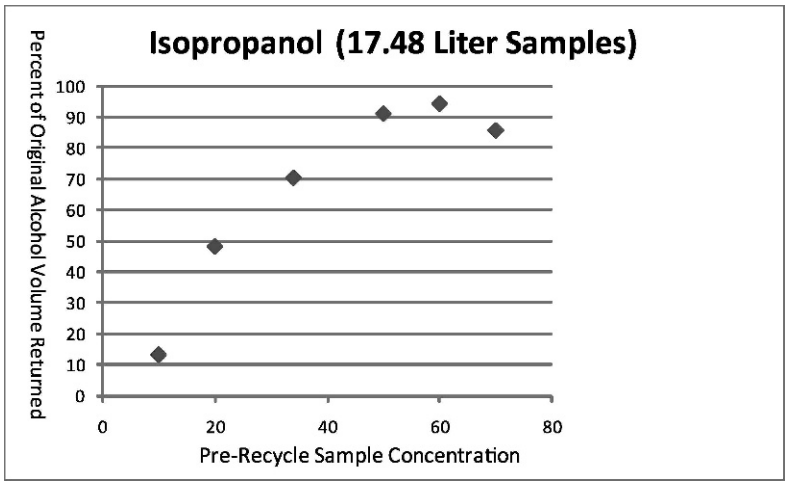

Figure 2. Graph of pre- and postrecycling concentration results for isopropanol.

Figure 3. Comparison of pre- (left) and post- (right) distillation alcohol.

The average pH of the alcohol samples was 7. Lowering the pH to 5 with sulfuric acid could result in the odor-causing amines and other impurities precipitating out of solution. A fine precipitate did result from these tests, but the odors still remained after distillation.

One source of contamination was the recycler itself. Some contaminants were surviving the distillation process, remaining inside the unit, and contaminating each subsequent test. To provide the most accurate posttreatment samples, the unit was cleaned after each sample run by running a batch of 95% pure ethanol through a complete distillation. Even after two cleaning runs of 95% ethanol, the end product still retained the odors imparted by previous contaminated samples.

Activated charcoal commonly is used to remove odors and other contaminants. Several methods were attempted to maximize the effect and the time of contact between the fluids and the charcoal. Simply mixing activated charcoal with recycled alcohol and allowing the mixture to sit for 12 hours produced a good but not perfect result; residual odors remained.

When the activated charcoal was used in the PVC filtration column, it resulted in a clear and odorless alcohol product. Each column worked well for 50 L of fluid before any odor could be noticed. The lifespan of the columns was longer if the charcoal was tightly packed and the flow from the source carboy was kept to a slow drip. Any attempt to speed up the process created preferential flow channels in the charcoal and shortened the contact time between the fluid and the charcoal, which allowed contaminants to remain in the alcohol.

GC–MS Analysis

Known samples.—The samples of pure ethanol and isopropanol each contained a small amount of other alcohols. The isopropanol contains approximately 0.02–0.08% 1-

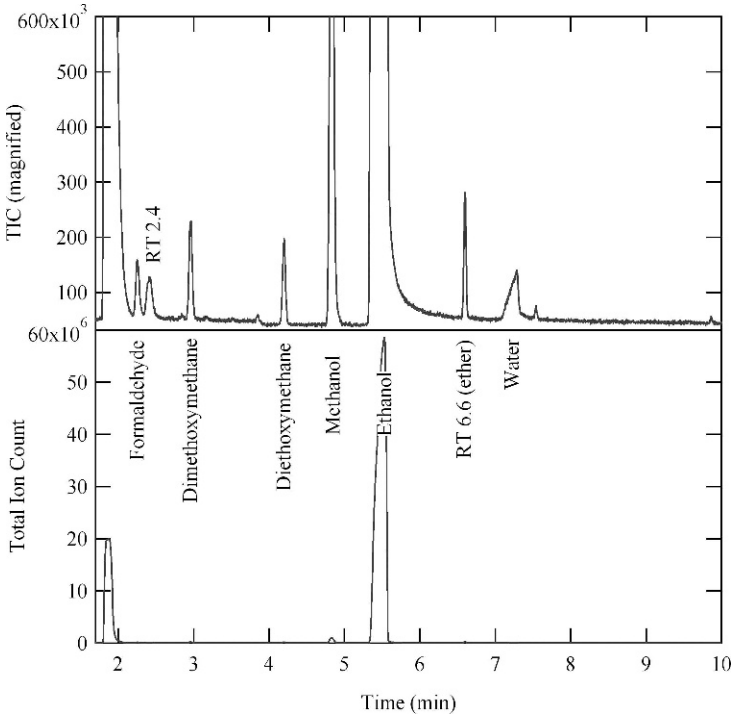

Figure 4. Chromatogram of 1% formaldehyde solution on DB-WAX column.

propanol; the ethanol contains approximately 0.1–0.4% isopropanol and approximately 20–80 ppm of methanol.

When a solution of 10% formalin (3.7% formaldehyde in ethanol and water) was run on the GC–MS, a number of compounds were identified. Formaldehyde and methanol both were present in the chromatogram, along with dimethoxymethane, diethoxymethane, two unknown ethers at retention time (RT) 6.59 and RT 10.84, and an unknown compound at RT 2.4 (Fig. 4).

However, when a more dilute sample of formalin was prepared, the formaldehyde was below the limit of detection for the GC, approximately 0.5%.

Ethanol samples.—Twenty-three ethanol sets (pre- and postdistillation samples) were evaluated with GC–MS.

Five of these sets were pure alcohol run through the distiller to check for contamination of the recycler that might carry across alcohol sets. Of the eighteen storage ethanol sample sets, more than half contained ethyl acetate, acetal, acetone, 1,1-diethoxyethane, methanol, ethyl formate, and diethoxymethane (Table 1). A number of compounds were found more rarely: other ethyl esters, ethyl ethers, and aldehydes (Table 1). Two ethanol samples, ALC0048 (fish source) and ALC0068 (exhibit crab source), showed trimethyl amine, a notoriously fishy smelling amine. All of the contaminants identified in the ethanol samples were present in small amounts. In one of the most contaminated sample sets, ALC0009 and ALC0010, the total of all contaminants identified was 0.39% of the alcohol peak before distillation (approximately 0.20% of the overall starting solution). The total of all contaminants detected by GC

Table 1. Compounds identified in ethanol storage samples: 3/4, 9/10, 13/14, 39/40, 43/44, 47/48, 51/52, 55/56, 59/60, 67/68, 71/72, 73/74, 75–77, 78/79, 80/81, 82/83, 84/85, 86–91. *Identified with HP-5MS column, not used for samples 80–91; † RT = Retention Time.

Name	Compound class	Total sets	Found before and after distillation	Only after distillation	Only before distillation
Acetal (acetaldehyde)	Aldehyde	18	18	—	—
1,1-Diethoxyethane	Ether	17	15	1	1
Acetone	Ketone	16	10	6	—
Ethyl acetate	Ester	15	10	5	—
Ethyl formate	Ester	14	6	4	4
Methanol	Alcohol	13	11	2	—
Diethoxymethane	Ether	12	11	1	—
Isopropanol*	Alcohol	12	12	—	—
Unknown (RT 6.59)†	Ether	8	6	2	—
1,1-Diethoxypropane	Ether	8	4	2	2
Ethyl butanoate	Ester	5	3	1	1
Toluene	Arene	4	3	—	1
2-Butanol	Alcohol	4	—	—	4
Propanal	Aldehyde	4	2	2	—
m-Xylene	Arene	3	3	—	—
1-Propanol	Alcohol	2	1	—	1
2-Butanone	Ketone	2	2	—	—
Ethylbenzene	Arene	2	—	—	2
Methyl 2-methyl-2-propenoate	Ester	2	1	1	—
Ethyl 2-methylbutanoate	Ester	2	2	—	—
Hexanal	Aldehyde	2	1	—	1
Unknown (RT 10.86)†	Ether	2	2	—	—
Trimethyl amine?	Amine	2	—	2	—
p-Xylene	Arene	1	1	—	—
3-Methylbutanal	Aldehyde	1	—	—	1
Ethyl hexanoate	Ester	1	1	—	—
Ethyl 2-methyl-2-propanoate	Ester	1	1	—	—
Unknown (RT 2.4)†	Unknown	1	—	1	—

increased to 0.95% of the alcohol peak after distillation, with the largest individual contaminant, acetal, being 0.36% of the alcohol peak (Figs. 5, 6).

Isopropanol samples.—Six isopropanol storage samples were analyzed. Acetone and 1-propanol are present in all the samples, with 2-butanone, ethanol, toluene, ethylbenzene, xylenes, acetaldehyde, 2-methylpropyl acetate, and methyl 2-methyl-2-propenoate found in half or more of the samples (Table 2).

Pure alcohol samples.—The five pure ethanol samples were very clear. Small amounts of methanol and isopropanol were present in all samples. After the samples were run through the distiller they typically remained quite clear. However, looking specifically for isopropanol and its common aromatic contaminants, xylenes and ethyl benzene, in ALC0038 small amounts of isopropanol (shown by ion 59) and xylenes (shown by ion 106) from the previous run remained in the distiller and contaminated the next batch of ethanol run through the distiller (Fig. 7).

Specially treated alcohol samples.—One batch of ethanol, ALC0075, was acidified with sulfuric acid to a pH of 5, ALC0076, and subsequently distilled, ALC0077. The fish odor was slightly reduced but not eliminated, and GC–MS analysis showed that the

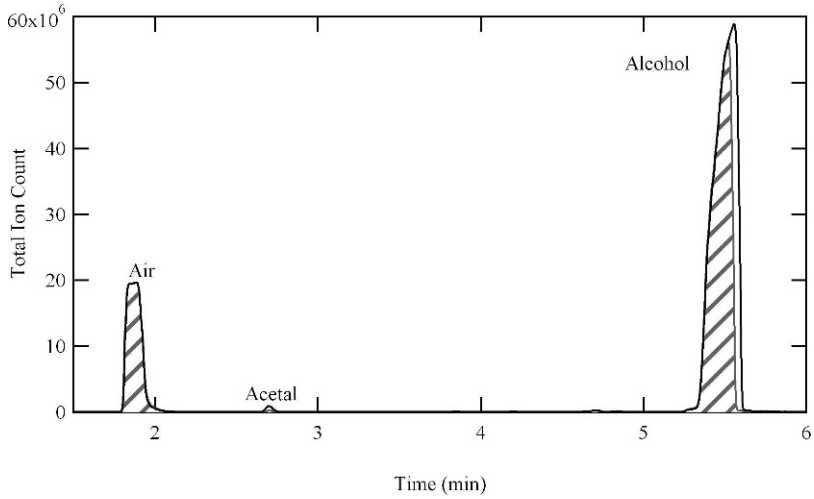

Figure 5. Chromatograms from ALC0009 (shaded) and ALC0010 (black) on DB-WAX column.

majority of compounds identified in the starting solution also remained after acidification and distillation.

Two sets of alcohol, one ethanol (ALC0086-91) and one isopropanol (ALC0092-94) were further purified after distillation by running the distilled alcohol through a packed column of activated charcoal. The charcoal initially was effective at completely reducing the fishy odor. After 50 L of isopropanol were run through the packed charcoal column the column became ineffective and the fishy odor was no longer removed from the isopropanol, ALC0094. When the samples were analyzed with GC–MS the first

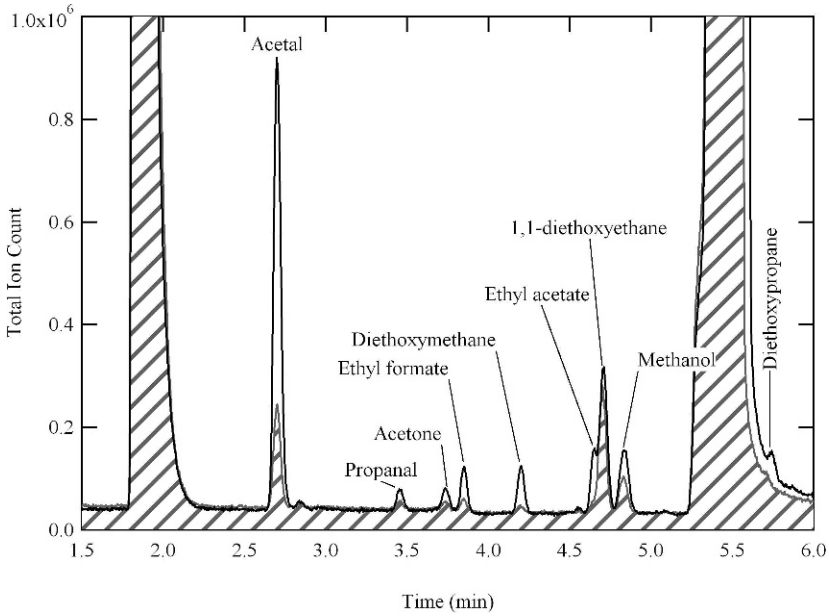

Figure 6. Chromatograms from ALC0009 (shaded) and ALC0010 (black), Figure 5, magnified. Note that many compounds actually increased in the postdistillation sample, ALC0010.

Table 2. Compounds identified in isopropanol storage samples: 17/18, 19/20, 23/24, 27/28, 69/70, 92–94. *Identified with HP-5MS column, not used for samples 92–94.

Name	Compound class	Total sets	Found before and after distillation	Only after distillation	Only before distillation
Acetone	Ketone	6	6	—	—
1-Propanol	Alcohol	6	6	—	—
2-Butanone	Ketone	5	5	—	—
Ethanol*	Alcohol	5	5	—	—
2-Methylpropyl acetate	Ester	4	1	3	—
Acetaldehyde (acetal)	Aldehyde	3	1	2	—
Toluene	Arene	3	1	2	—
m-Xylene	Arene	3	2	1	—
Ethylbenzene	Arene	3	2	1	—
Methyl 2-methyl-2-propenoate	Ester	3	3	—	—
o-Xylene	Arene	3	1	2	—
p-Xylene	Arene	3	1	2	—
Ethyl acetate	Ester	2	1	1	—
Benzene*	Arene	2	2	—	—
Ethyl formate	Ester	1	1	—	—
2-Methyl-1-propanol	Alcohol	1	1	—	—
2-Methyl-3-pentanone	Ketone	1	1	—	—
Diisopropyl ether (isopropyl isopropane)	Ether	1	1	—	—
Formaldehyde	Aldehyde	1	—	—	1
4-Methyl-2-pentanone	Ketone	1	1	—	—
n-Pentanol	Alcohol	1	1	—	—

isopropanol run through the column (ALC0092) still showed the presence of acetone and methanol, although the isopropanol looked and smelled cleaned. GC–MS analysis of ALC0094 showed a larger amount of acetone and methanol than was present in the first sample passed through the charcoal column.

Molecular Analysis

Molecular analysis of a spiked alcohol sample, both pre- and postdistillation, showed that no detectable DNA survived the distillation process and no DNA from the spiked DNA sample was detectable by amplification (Fig. 8).

Conclusions

Alcohol recycling, on principle, is a valid method to reduce the amount of purchased alcohol and the waste product generated. The unit, however, failed to produce a recycled product that met collections archival standards for reuse in multiple disciplines without having potential cross contamination or inherent contaminants from the used fluid source. The cost effectiveness for a museum becomes irrelevant if the end product is unusable for general specimen curation. The Smithsonian rarely produces a large scale, single source recycling event. A proposed use of the recycled fluid is in soaking out formalin in recently fixed specimens as they transfer to the standard preservation fluids of 50% isopropanol and 70% ethanol. This still leaves the disposal cost for that volume of fluid after the process for each batch of specimens, because the waste produced is at a concentration level that is still considered to be hazardous waste.

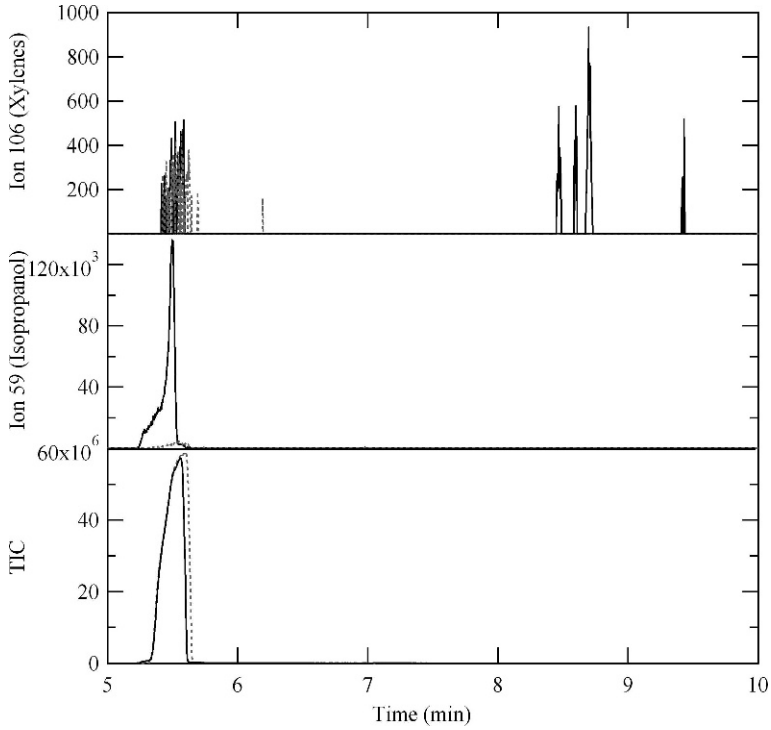

Figure 7. Chromatogram (TIC) and extracted ion chromatograms for isopropanol (59) and xylenes (106) for clear ethanol samples ALC0037 (dashed) and ALC0038 (solid). Note that both isopropanol and the xylenes only are present after distillation, ALC0038.

Alcohol recycling is effective in producing a visually clear fluid that is free of contamination from DNA. However, GC–MS shows the samples still retain a number of chemical contaminants, including cross-contamination between batches of alcohol. This might be acceptable if the sample being recycled is being reused in the original container and is not derived from multiple sources of used alcohol. If the material to be recycled is from multiple sources and multiple phyla, then the final product will be a cumulative solution of all of those chemicals. Introducing this product back into a specimen jar might be detrimental to those specimens.

The unit tested did not provide an odor-free product. An odor-free product was only achieved by constructing a custom filtration column of activated charcoal, which was costly and doubled the total distillation time. Although the odor was reduced, some chemical contaminants remained in the alcohol after charcoal filtration. After a maximum of 50 L, the charcoal in the column would need to be replaced, a significant expense in cost and time with the only result being that the final product does not have a residual smell.

As museum research moves from being libraries of morphologically variant specimens to being repositories of material for DNA, proteomic, or other types of biochemical analysis, formalin and other sample cross-contamination is of paramount importance. Formalin is not completely removed by any of the processes explored in this article. Just as cross-contamination is possible between batches of isopropanol and ethanol, cross-contamination by formalin from batch to batch also could be possible.

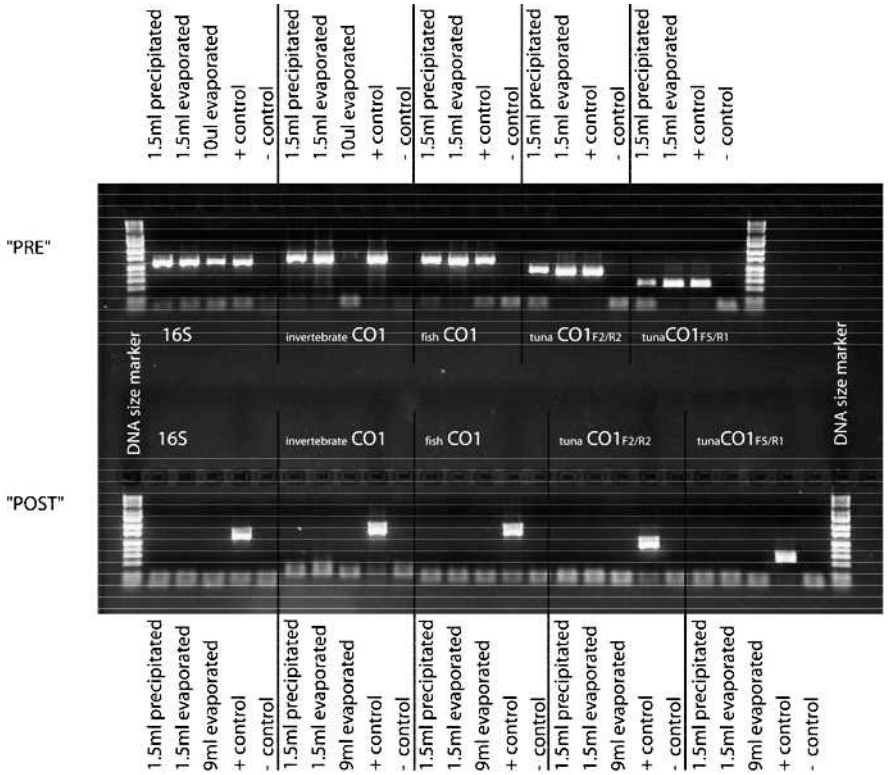

Figure 8. Comparison of PCR amplification of pre- and posttreatment samples with positive controls, negative controls, and DNA size marker. The different template quantity variations and loci with primer sets used are shown.

Storage in alcohol over many years results in reaction between the specimens and the alcohol that produces contaminants with a similar enough volatility to the alcohol that temperature distillation, even combined with charcoal filtration, was unable to produce a satisfactory recycled alcohol end product. Testing of the solvent/formalin recycler has shown that the final product cannot be considered for use in specimen preservation because it does not satisfy many of the requirements in producing a pure chemical-grade product. The solutions produced and the concentration of contaminants is highly variable. Pure ethanol and isopropanol could not be produced, even when the starting solution was fresh from an unused drum of 95% ethanol or 99% isopropanol. Because the final product is unreliable for general curation and the cost of the unit to process the fluid is so high, it is not feasible to purchase a solvent recycler for use in museum collections. The only reliable source of alcohol is still the chemical distributor.

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PORTABLE X-RAY FLUORESCENCE FOR THE EXAMINATION OF TAXIDERMY SPECIMENS AT THE HORNIMAN MUSEUM—EXPLORING THE POSSIBILITIES

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Abstract.—The Horniman Museum in South East London holds natural history collections which include specimens that date from the 19th century to the present day. Since 2008, as a part of a future redevelopment plan for the Natural History gallery, the Collections Conservation and Care section has been investigating the taxidermy specimens using portable X-ray fluorescence (XRF). The aim of the investigation was to detect potentially harmful pesticide residues such as arsenic and mercury in the specimens. As expected, during the process it became clear that a large proportion of the collection contained potentially harmful contaminants and that understanding and interpreting the results and spectra was a much slower and more arduous task than taking the readings.

It also was observed that 1) the technique can help to identify other features of the mount-making process, and 2) the technique is susceptible to interference from other heavy metals such as lead.

INTRODUCTION

The Horniman Museum was founded by Frederick J. Horniman, of the Horniman tea family, in the late 19th century. Originally, the collection was displayed in the family home at Surrey House, Forest Hill, London. This was demolished to make way for the existing Horniman Museum, which was completed and opened to the public in 1901. Consequently, many of the taxidermy specimens in the collection date back to the period when the specimens were housed at Surrey House. Subsequent acquisitions, particularly several large collections acquired throughout the 20th century, also were mainly composed of older specimens collected in the 19th century.

Planning for a major redevelopment of the gallery has been in progress for the past few years (Fig. 1). A full conservation assessment of the collections was needed to establish the overall condition of the collections and to prioritise the conservation work and time required. As a part of the conservation assessment, and in preparation for an anticipated removal of specimens from the showcases, an audit was required to detect the range of chemicals used as preservatives that had been applied to specimens over time, particularly the taxidermy specimens thought to have been treated with arsenic and mercury. Ethylene oxide, methyl bromide, para-dichlorobenzene (1,4-dichlorobenzene), and dichlorvos (2.2-dichlorovinyl dimethyl phosphate (DDVP) also were known to be used previously for pest control. Although these are not addressed in this paper, from our knowledge of the history of their use at the Horniman, they are taken into consideration for health and safety protocols.

The Collections Conservation and Care section has been investigating the taxidermy specimens using a portable hand-held energy-dispersive XRF analyzer. This equipment originally was developed for industrial and commercial purposes, but is employed in museums for its noninvasiveness, speed, and ease of use.

The main aim of the audit was to detect potentially harmful pesticide residues such as arsenic and mercury. In the process, it became apparent that these contaminants were

Figure 1. General view, Natural History Gallery, Horniman Museum 2010.

present in the majority of the specimens, and that interpreting the data and spectra presented some interesting results and challenges.

As the survey progressed, the results indicated that the analytical technique could help in identifying the presence and composition of other features of the specimens such as fillers, armature materials, and paint pigments. There also was evidence that associated materials, such as the composition of bases or backboards, potentially could interfere with results if within the range of the analyzer and that within one single object there could be a significant variation in results, depending on sample location. The results also indicated that the technique was susceptible to interference from other heavy metals such as lead (see Case Study 2).

Methodology

Prior to this study, taxidermy specimens were tested for the presence of arsenic using a standard swab test (Odegaard et al. 2000). This test can indicate relative levels of arsenic by showing a pale yellow to deep brown color on the test papers (Marte et al. 2006). However, although not discounting its continued use at the Horniman, it is a time-consuming process that creates chemical waste which requires toxic disposal. Hand-held XRF analyzers already have been used extensively for identifying pesticides within anthropology collections (Glinsman 2005; Odegaard et al. 2006; Bond 2007; Podsiki 2009; Üstün 2009) and were determined to be a quick, flexible method of examining specimens that are otherwise difficult to access, particularly those on display. At the Horniman Museum, an average of 60 mounted taxidermy specimens could be assessed in a day with the XRF analyzer, as opposed to 10–15 by the standard swab test.

Initially, the hand-held XRF analyzer was rented for 2 weeks in October 2008 and then made available for a further 2 weeks during May 2009. On both occasions we utilized hand-held technology from Innov-X Systems™. The units supplied had two modes of functionality for our analytical interest: ''Analytical'' mode, working under fundamental parameter calculation, was employed for high density materials such as metal objects; and ''Soil'' mode, for low density material such as taxidermy specimens calibrated using Compton normalisation. The Innov-X range of analyzers are tube-based systems and therefore isotope free, with silver (Ag) or tungsten (W) anode. The Alpha instrument uses a SiPIN diode detector, the tube functions at a maximum of 40 kV with a penetration of 20–30 microns in dense material and a few millimetres in less dense material with a 30-second exposure time (Innov-X Systems product data sheet 2009; J. Van Run, technical advisor, pers. comm. 2009; A. Clarke, technical advisor, pers. comm. 2008, 2009, 2010).

In October 2009 a second model, the Innov-X Omega Xpress™ was provided by Innov-X Systems. This analyzer also works at 40 kV maximum, but has a silicon drift detector, which provides an improved signal-to-background ratio, and a better resolution. The count rate is ten-fold and the testing time is greatly reduced. An additional feature is an internal vacuum to allow the detection of lighter elements such as aluminium, calcium, and silicon, which are invisible to the Alpha series, using SiPIN technology in air (Innov-X Systems product data sheet 2009; Van Run, pers. comm. 2009; Clarke, pers. comm. 2008, 2009, 2010).

Both the Alpha and Omega analyzers can identify up to 25 elements, depending on the application, and up to 20,000 test results with spectra can be stored. The software forces standardisation at start up using a 316 stainless steel cover; it recognizes the molybdenum (Mo) and iron (Fe) lines to do an internal self-check. Other assayed standards already held by the Collections Conservation and Care section (Bacon 2003) were used to check the reliability of the equipment with metals.

Full in-house risk assessments were written for the use of the apparatus as well as fulfilling statutory UK radiation regulation requirements with Innov-X. This was particularly important because the equipment was used in gallery spaces whilst the museum was open to the public. The area was secured by barriers, with warning signs deployed and facilities provided to accommodate the two operators and the equipment (Fig. 2). Operators were in full protective clothing, including laboratory coat, plastic apron, nitrile gloves, and disposable dust mask to conform to EN149:2001 FFP3 (European Norm 149:2001 Filter Face Piece 3). The XRF analyzer was programmed in advance with the required automatic exposure time and the list of elements to be included in the identification. The operator held the analyzer so that the nozzle was positioned to be in contact with the specimen. The X-ray beam was directed away from the operator and onto the specimen. The equipment weighed approximately 1.6 kg (3 pounds 4 ounces). This was relatively easy to manipulate, but tiring after some time. A rotation of operators was introduced in order to make full use of the limited rental period. A broad range of taxidermy specimens in the gallery were examined by XRF, but only data results from the mounted bird specimens are reported in this paper. The same points were examined on each specimen, usually the head, back, breast, under tail, and legs.

The data obtained in soil mode can be accessed in two formats: as a list of semi-quantitative elements in a calculated ''results data list,'' identified by both types of analyzer in parts per million; and as a spectrum. Calculated data obtained in analytical mode is identified in percent, and as a spectrum. In both modes the calculated results data list is visible on the screen of the HP iPaq pocket PC inserted into the top of the analyzer

Figure 2. Working with the X-ray fluorescence (XRF) analyzer in the gallery.

and can be viewed instantly. Downloading the calculated results data list from the iPaq was quick and easy. However, initially, downloading the spectra was complicated and very time consuming. Each spectrum was downloaded separately as a CSV (comma-separated values) file, which was then converted into an MS-Excel graph. After discussion, Innov-X supplied software which allowed the download of all the analyses and the related spectra in a much shorter time frame. The latter software offered a much more user-friendly interface and allowed for annotations, overlays, zooming in and out of graphs, identification and annotation of peaks, and generally better manipulation of the data and individual spectra. It is important to ensure, therefore, that full discussion is held with the equipment supplier as to what information the institution expects to be able to access.

Interpreting the Results

Problems with interpreting the results of materials with a lower density obtained in soil mode on anthropology and taxidermy collections relative to denser materials such as metals or glass, have been discussed in other papers (Marte et al. 2006; Bond 2007; Üstün 2009; Podsiki 2009). It should be stressed at the outset that the equipment was developed as a screening tool primarily for the scrap metal trade and is an ideal tool for this purpose. For museums, if a ''yes'' or ''no'' answer is required as to whether arsenic is present, it can provide a similarly quick result. Its further capabilities and potential, however, justified fuller exploration.

At the Horniman Museum, conservation staff collaborated closely with Innov-X representatives to work on the final outcome of the spectra and quantitative analysis. The

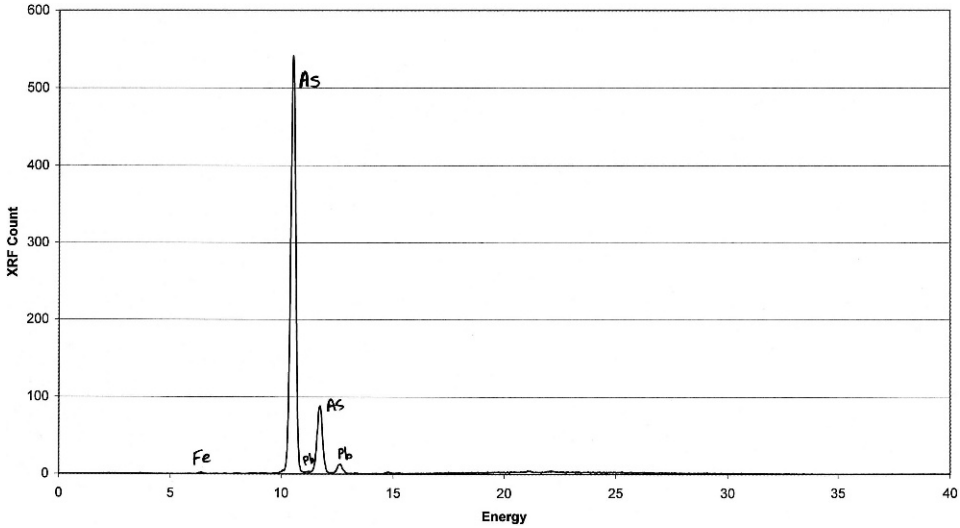

Figure 3. Arsenic spectrum for Grey Junglefowl (*Gallus sonneratii*) NH.Z.214.

work that was carried out on the collections is stored as hard copy and on an Access database so that it will be accessible for years into the future. It therefore is very important that it is in an understandable and readable format to be used as an ongoing permanent record for reference by museum staff in the future. For current use, a printed copy is retained in the conservation laboratory in binders, identified by showcase or storage location.

Identifying valid readings when there are overlapping peaks on the spectra is an important factor, particularly, for example, in the case of arsenic and lead peaks. It is essential, therefore that the correct peak is identified. In Figure 3, arsenic can be identified very clearly by its two peaks in the spectrum. However, arsenic and lead have similar energy levels and therefore their peaks overlap. The analyzer can, in effect, give a false reading. In such instances, the results data always must be compared against the relevant spectrum to assess whether or not the calculation of the analyzer is correct.

The analyses from a Domestic Fowl (*Gallus gallus domesticus*) NH.Z.208 showed arsenic levels of 23,578 ppm, mercury at 17,693 ppm, and lead at 11,918 ppm. In England, the recommended exposure level (REL) for arsenic over an 8-hour period is 0.02 mg/cm^3. Even allowing for errors converting ppm by volume to mg/cm^3, the results still exceed the REL. For example, using the formula: Ymg/m^3 = (xppm)(molecular weight)/24.45 at 1 atmosphere and 25°C. Applying this formula to the arsenic result: Y = 23,578 × 74/24.45 = 71,360. When 71,360 mg/m^3 is converted to mg/cm^3, the resulting value is 0.071, which exceeds the REL.

However, the REL refers to an airborne particle, not one which is on, or in, a more-or-less solid object and is less likely to be inhaled or otherwise ingested; this illustrates the importance of using comparable units for health and safety analyses.

This, in turn, raises another issue: the XRF analyzer cannot identify whether the arsenic occurs on the surface or the interior of the specimen. Arsenic treatments generally were applied to the inside of the skin during the mounting process; however, over time, arsenic might have migrated to the surface. Many of the Horniman Museum mounted

specimens have shrunk over the years; therefore, loose seams and splits in the skin are potential sites of arsenic escape. One advantage of the swab test is that a sample usually is taken from the surface of the object, so it can be inferred that arsenic is present externally. Surface arsenic swab tests were taken from a Grey Junglefowl (*Gallus sonneratii*) NH.Z.21, and in this instance the results compared relatively favourably in concentration terms to the XRF results from the same areas of the body.

A complicating factor is the path and penetration of the X-ray beam. It spreads as a V-shaped beam, and with low density materials such as a mounted bird, there are fewer counts per second; therefore the error is higher. Denser materials, such as metals, return much more reliable readings. One way to reduce error is to increase test duration to 120 or 180 seconds, rather than 30 seconds. However, this means supporting the equipment on a tripod, which makes accessing display specimens particularly difficult; over a period of time this can be very tiring if it is hand-held in awkward and strenuous positions. The rental of the Innov-X Omega Xpress analyser, which has a shorter test duration compared to the Alpha series analyzer (15 seconds vs. 30 seconds), mitigated this issue to some extent, and also allowed for light element detection (see Case Study 5).

Particularly with the birds on display, it became apparent that the analyser was picking up metals contained in the paints used in display cases and on museum bases attached to the specimens due to the penetration of the X-ray beam. These included barium, zinc, lead, and titanium, all of which were all used in paints during the 19th and 20th centuries. The software provided allows for overlays of one reading (the background) over another (the object plus background) so that these elements can be identified and excluded.

Pesticide Treatments

To relate the results to past pesticide treatments, communication was made with present day taxidermists and curators of taxidermy (the following are pers. comm. 2009 except as noted; M. Adams, Senior Curator, Bird Group, Dept. Zool., The Natural History Museum, Tring, UK; J. Dickinson, Taxidermist, Lancashire Museums Service, UK; D. Frampton, Private Taxidermist, England; M. Harman, Curator and Taxidermist, Powell Cotton Museum, UK, 2008, 2009; S. Trodd, Taxidermist (retired), South East Museums Service, England; H. Van Grouw, Curator and Taxidermist, Bird Group, Dept. Zool., The Natural History Museum, Tring, UK). Many arsenic and mercury treatments were identified in Montagu Browne's invaluable book *Practical Taxidermy* (Browne 1884, 1922) and in *Artistic and Scientific Taxidermy and Modelling* (Browne 1896). Montagu Browne (1845–1928) was curator at Leicester Museum in England. The preparations he cites, in relation to the age of the specimens in the Horniman Museum collections, have given an indication of what might have been applied to the skins. Other formulations are found in books about renowned taxidermists such as Rowland Ward, Edward Gerrard and Sons, and the Hutchings of Aberystwyth (Morris 2003, 2004; Morris and Freeman 2007). Other issues relating to poisons on specimens held in museums, particularly in the United States, have been raised by Odegaard et al. (2005) in *Old Poisons, New Problems*.

Arsenic

Arsenical soaps have been used for treating skins for taxidermy since the 18th century when Jean-Baptiste Bécoeur (1718–1777) developed a mixture which was in common use until the early 20th century (Browne 1922). Other taxidermists developed their own

arsenical soap preparations, but with little variation in the proportions of the ingredients to distinguish them.

Although control of the purchase of arsenic in England has been in place since the Arsenic Act of 1851 and the Pharmacy Act of 1868, these would not have greatly affected taxidermists who could buy it for business purposes, and Browne refers to preparators having boxes of dry arsenic which was sprinkled onto the skins by hand (Browne 1884). The use of arsenic in taxidermy preparations has been known to occur until the 1980s at least in the USA, the Netherlands, and the United Kingdom (Knapp 2000; Adams, pers. comm. 2009; Van Grouw, pers. comm. 2009).

The preparations cite common additions of potassium carbonate in soaps and aluminium sulfate in powders, as well as calcium in the form of lime or chalk. Potassium (K), aluminium (Al), and calcium (Ca) were difficult to detect with the Alpha series analyzer. XRF analyzers are not sensitive to certain elements when the emissions have such low characteristic energy levels that the signal output is low; therefore, it was difficult to use these coingredients (K, Al, and Ca) as markers for the use of such mixtures. On a number of specimens the tests were later repeated with the Innov-X Omega Xpress where they could be identified (see Case Study 5).

Arsenic and Mercury

Browne gives only one preparation that incorporates both arsenic and mercury, No.6 Gardner's Preservative:

6 ounces arsenic
3 ounces corrosive sublimate (mercury [II] chloride)
2 ounces yellow soap
1 ounce camphor
½ pint spirits of wine (aqueous solution of ethanol)

He also gives the warning "The preparation referred to, … should be labelled 'Dangerous! Not to be used!'"

Browne (1845–1928) cites two preparations using mercury (II) chloride as a wash for brushing over the whole of the outside of the specimen after it had been mounted. Charles Waterton (1782–1865), a keen ornithologist and taxidermist in the 19th century also used corrosive sublimate (mercury [II] chloride) as a wash on specimens (Browne 1884).

Another possibility for the presence of mercury is the anecdote that "dishes" of mercury (II) chloride were placed in show cases or boxes to act as a pest deterrent (Trodd, pers. comm. 2009). Goldberg also cites that mercuric chloride (corrosive sublimate or mercury [II] chloride) was used at the Smithsonian Institution, usually as a weak solution in alcohol, or as a scattering of crystalline mercuric chloride (mercury [II] chloride) in the corners of drawers (Goldberg 1996).

Case Studies

Case Study 1, Specimens with Arsenic and Mercury

An analysis from a specimen of an African Cuckoo (now Senegal Coucal; *Centropus senegalensis*) NH.Z.983 (Fig. 4) demonstrates the problem of arsenic and mercury having similar energy levels that has already been mentioned. The results data list showed both elements as being present.

The Innov-X team advised that any element can be considered suspect when figures are around three times the variance of the element detected or less. Due to the nature of the

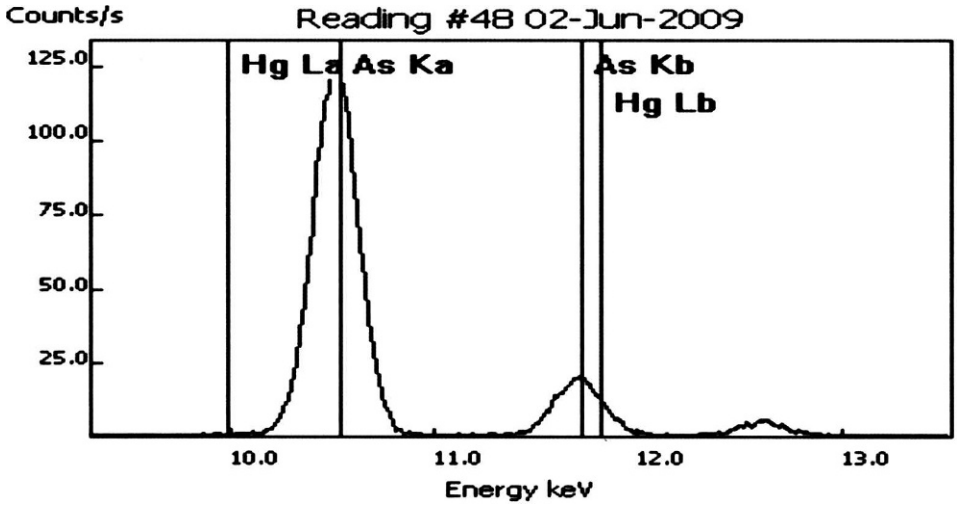

Figure 4. Mercury and arsenic peaks from African Cuckoo (now Senegal Coucal, *Centropus senegalensis*) NH.Z.983.

specimens where the X-ray beam is deflected through a lower density mass, the analyzer can be ''confused'' and calculates mercury as being present when in reality it is not there. This can clearly be seen on the spectrum where there are no double peaks for mercury. This stresses the importance of not relying on the calculated ''semiquantitative'' results data list as shown and downloaded from the iPaq. The spectrum must be examined to clarify the results to avoid any confusion; each element must be represented by two peaks.

Case Study 2, Arsenic, Mercury, and Lead

The previously mentioned specimen of Domestic Fowl (*Gallus gallus domesticus*) NH.Z.208 exhibited high readings for arsenic, mercury, and lead. Figure 5 illustrates elemental peaks with multiple signatures, which demonstrate that all three elements are present (e.g., the lead L-alpha line could be misinterpreted as arsenic K-alpha, but the second line for lead L-beta confirms its presence).

Lead has been identified in most of the specimens examined and it is possible that lead arsenate was used on occasion as a pesticide on some Horniman specimens (see Discussion and Future Protocols). The use of lead arsenate is not mentioned by Browne, and contemporary taxidermists also are unaware of its large-scale use in the United Kingdom; arsenical soaps were most favored by taxidermists during the 18th through to the 20th century. Future work is needed to correlate the XRF results with the date and provenance of taxidermy in the collection.

Case Study 3, Mercury

Figure 6 illustrates male and female Eurasian Blackbirds (*Turdus merula*) in a diorama (NH83.3/83) made by the naturalist and taxidermist Edward Hart (1847–1928). It is known from his notebooks that they were collected and mounted in 1863, but he makes no mention of the preservative he used. In this example only the male tested positive for mercury and no arsenic was detected in either specimen.

When citing the preparation for mercury wash, Browne (1884) mentioned that feathers, legs, toes, and beaks were brushed. Initial interpretation of the XRF data indicates that

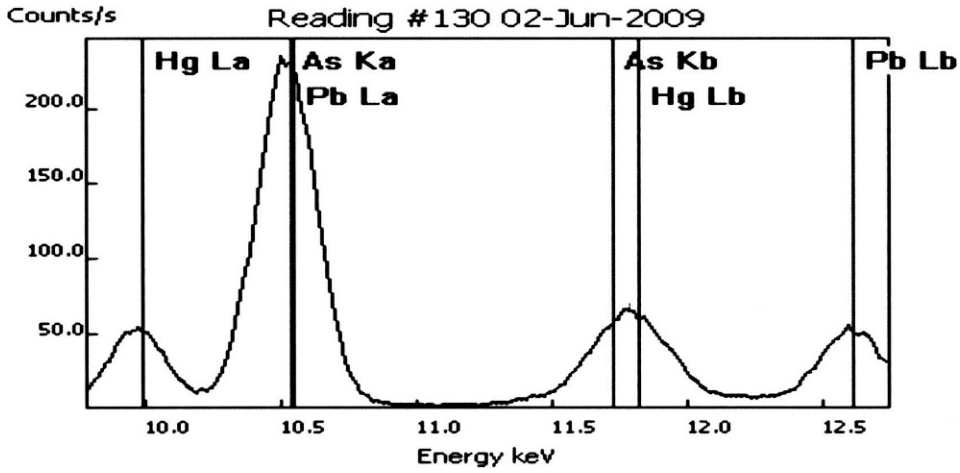

Figure 5. Arsenic, lead, and mercury peaks from in a Domestic Fowl (*Gallus gallus domesticus*) NH.Z.208.

Figure 6. Eurasian blackbird (*Terdus merula*) diorama by Edward Hart. NH.83.3/83.

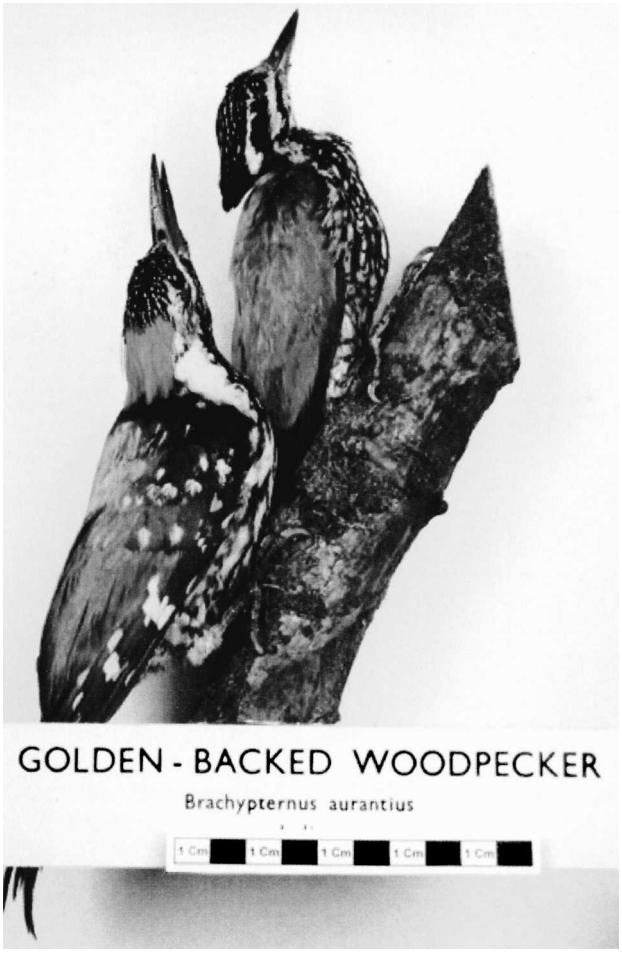

Figure 7. Pair of Golden Backed Woodpeckers reidentified as Black-rumped Flameback (*Dinopium benghalense*) NH.Z.971a and b.

with some Horniman specimens, mercury only is detected at the feet and legs. In these instances the legs have been painted red, which could indicate a mercury-based pigment such as cinnabar (vermilion or mercury [II] sulfide).

Case Study 4, Identifying the Composition of Mounted Groups and Hot Spots

Many of the birds on display in show cases are in pairs or family groups. The difference in arsenic and mercury levels within pairs of birds can confirm whether specimens were put together especially for display. For example, a pair of Golden Backed Woodpeckers (reidentified as Black-Rumped Flameback, *Dinopium benghalense*; NH.Z.971a and b) (Fig. 7) had different levels of arsenic in the two specimens; the male had virtually no detectable arsenic (34 ppm), and the female had much higher levels (8,845 ppm).

The results of the survey showed a disparity in the level of contaminants in different parts of the body of bird specimens; for instance, the head consistently gave high readings. Higher readings in the head areas might be a result of the XRF technology as already mentioned where denser materials return more reliable readings (van Run, pers.

comm. 2009). However, it was commonplace to apply more preservative to the head of a bird to remove moisture and dry it thoroughly. It also was more difficult to remove all remnants of the brain and the muscle tissue from the skull (Harman, pers. comm. 2009; van Grouw, pers. comm. 2009).

Case Study 5, Identifying Armatures and Body Forms

The method of mounting also can affect readings, in particular the density of the chosen filling material, such as wood wool, papiér mâché, or a clay body form.

It was decided to look at whether the XRF analyzer could pick up metal armatures (Fig. 8 X-radiograph pair Scarlet Ibis [*Eudocimus ruber*] NH.Z.289 and 290) when, during the condition audit of the collection, one particular specimen was found to have a protruding copper alloy wire that was actively corroding. This highlighted other conservation issues such as potential deterioration problems inside the specimen due to unstable mounting materials. The XRF detected iron, which was mainly used as wiring inside specimens, and the presence of zinc found in many of the specimen analyses could indicate galvanized wire. It is and has been common practice to use galvanized iron wire in taxidermy (Harman, pers. comm. 2009; D. Smith, Senior Preparator, Museum Victoria, Victoria, Australia, pers. comm. 2009).

Mounting preparations such as wood wool, papiér mâché or clay body forms were identified more readily using the Innov-X Omega Xpress. It has the capability to detect lighter elements such as calcium, silica, and aluminium. X-radiography sometimes can indicate whether there is a body form such as clay within the specimen, or can indicate the presence of chalk, lime, or aluminium sulfate used in taxidermy preparations.

Discussion and Future Protocols

The XRF analyzer, designed as a screening tool for denser materials, particularly metals, is a useful tool for identifying arsenic and mercury in taxidermy collections. Due to the low density of taxidermy specimens it is not possible to accurately quantify the amounts of arsenic and mercury present. The results only can indicate relative levels and care needs to be taken to examine the spectrum to confirm which elements are present. The analyzer has been valuable in assessing the heavy metal-based pesticides present and in using the XRF data to identify contaminated specimens.

High apparent lead values have a possible distorting influence on the detection of other elements; however, spectral reports can confirm the presence of lead. Lead was found in most of the specimens, even those not containing arsenic, which might eliminate lead arsenate as a possible pesticide in some specimens. The source of lead was considered to be present as a solder connecting internal armatures, a consideration which has not been borne out by X-radiography. Another possibility is that it might be a result of environmental pollution, because many of the Horniman Museum specimens have been in London for over 100 years and could have absorbed it into the feathers. Recently, Cross and Odegaard also have raised the issue of naturally occurring levels of contaminants which might have been ingested by birds (Cross and Odegaard 2009). It is evident that more work needs to be carried out to establish the origin of the lead, and future investigations will examine this issue.

From a conservation and curatorial point of view, the relative proportions of elements detected can help determine the exhibit history. A further future project is to track the history of pesticide preservation techniques used on the Horniman Museum collections

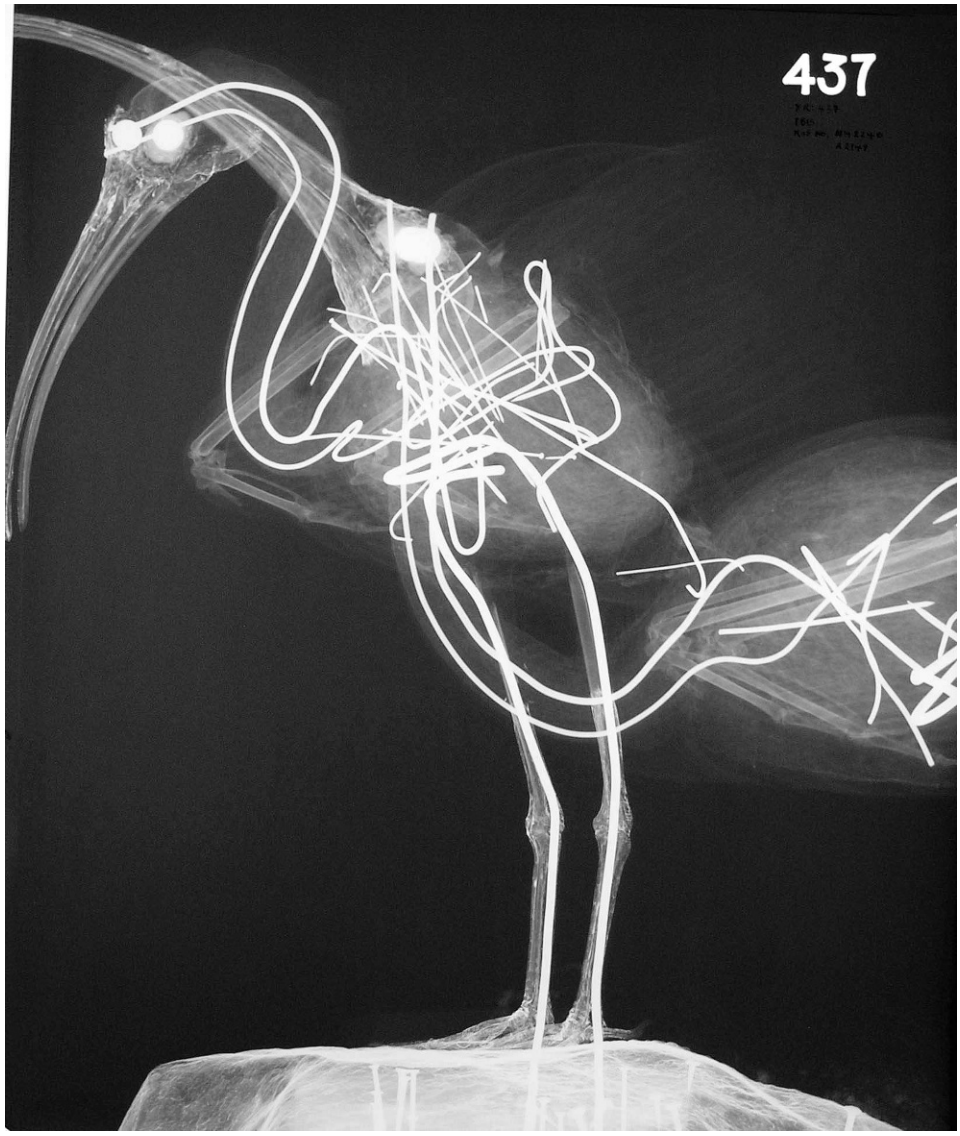

Figure 8. X-radiograph from a pair of Scarlet Ibis (*Eudocimus ruber*) NH.Z.289 and 290 showing metal armature.

by linking accession numbers to dates when specimens might have been collected and prepared.

At the Horniman Museum it now is accepted that the detected values only can be taken as relative measurements. It had been hoped that an outcome of this study would provide a more positive statement about ''safe'' levels of pesticides in the collections. As far as British Health and Safety directives are concerned, there is no safe level. Arsenic and mercury are cumulative toxic substances, and this must be understood by all staff and researchers who handle the collections. Despite its limitations, the survey has given us a clear indication of contamination, and as long as the potential for misinterpretation is understood by the users, and because the errors tend to overestimate rather than

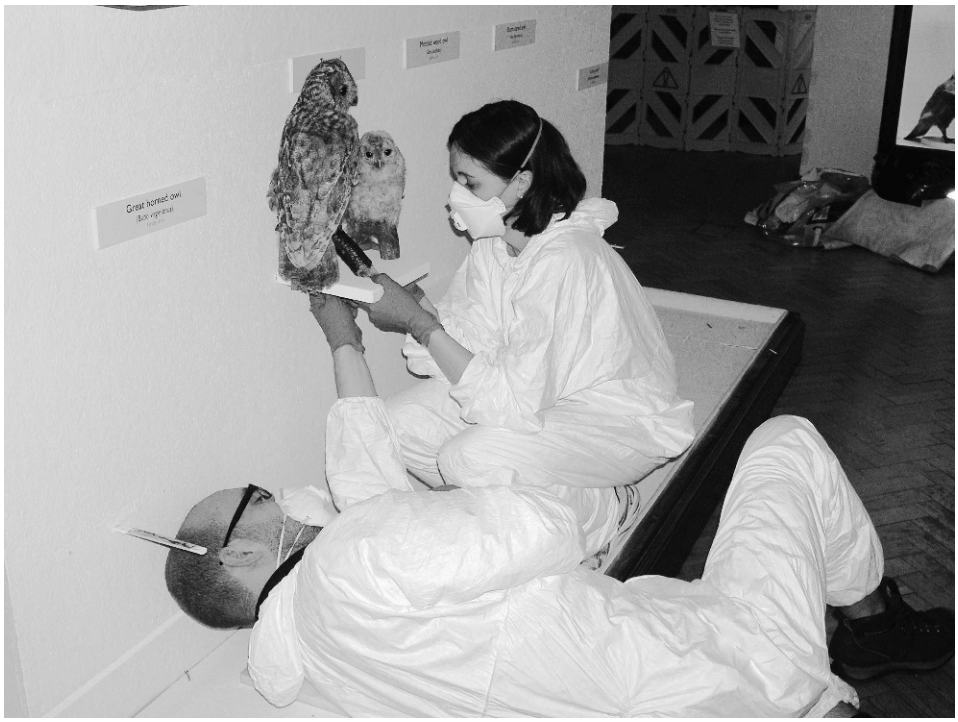

Figure 9. Team dismantling a bird display with full protective clothing.

underestimate the risk, these can be taken into account when writing health and safety protocols. In responding to the knowledge that pesticides are present, it is necessary to consider the sequence of events that involve specimens when they are removed from the gallery. They will be taken off the backboard, moved, packed, and stored and then at a later date, conserved, repacked, stored, and then finally installed back into the gallery. Handling damaged specimens can release arsenic and mercury powders to move from the specimens into the air. Staff could be working with the specimens for up to 5 hours a day for several months, making arsenic and mercury contamination through inhalation a real and severe risk. Protocols for protective clothing must be firmly in place (Fig. 9).

For future removal of specimens in the gallery, the introduction of a simple and clear way of indicating potential ''hot spots'' in the showcases has been devised. The arsenic content of individual specimens is colour coded with a highlighter pen on an image of each showcase, which is stored together with the relevant data and the printed copy of the results. A red outline is used for high-risk, yellow for medium-risk, and green for low- or no-risk specimens. As the spectra are checked for the presence of mercury the showcase images are annotated in blue.

Conclusions

This work exploring the possibilities of a hand-held XRF analyzer in the assessment of taxidermy specimens involves the use of equipment for purposes other than that for which it was originally designed, but positive results have been achieved with the Horniman Museum collections. This study has enabled the museum to identify the presence of arsenic and mercury in the collections, understand the complexities of

pesticide treatments employed, provide information for follow-up work on identifying the source of lead and tracking treatment history through museum records, and in particular it has aided in the development of a blueprint for future health and safety protocols for working on the collections. We intend to continue with this study and collaborate with the manufacturers as improvements to the XRF hand-held analyzer and the software are developed for museum use.

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INTEGRATED PEST MANAGEMENT CHALLENGES IN A RETROFITTED BUILDING FOR YALE PEABODY MUSEUM COLLECTIONS

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Abstract.—Yale University purchased the Bayer Pharmaceutical facility located in West Haven, Connecticut as part of campus expansion plans. The Yale Peabody Museum of Natural History was allocated 80,000 square feet within one of the building complexes of this facility, which originally was built in 1968. The process of converting this former manufacturing building into usable museum storage space introduced a new scenario for pest management. The goals were: to determine what pests already might be occupying the building and eradicate them, determine ways to seal out future pests, stabilize the climate to decrease pest infestation, and establish a monitoring program. Baseline pest data were collected via trapping throughout museum spaces before, during, and after retrofit construction. In conjunction with proposals from an independent, integrated pest management contractor, data from trapping were used to assess pest problems, and actions to eliminate these pests were initiated. A year-long survey of pests was performed after museum staff and collections occupied the building. The results showed seasonal variation in pest diversity and populations, which indicated the need for further building renovations to help reduce these populations. An outbreak of booklice (Psocoptera) has not responded to initial treatments and remains a concern.

INTRODUCTION

Yale University purchased the 136-acre West Haven facility in 2007 from the Bayer Pharmaceutical Company, incorporating 20 buildings, and naming it West Campus. The original purposes of these structures ranged from state of the art research laboratories to drug manufacturing production lines to an auditorium. The oldest building, circa 1968, contains spaces equaling 80,000 square feet now renovated for the Yale Peabody Museum of Natural History (YPM). These spaces originally were used as offices, drug manufacturing facilities, a cafeteria, and a warehouse; all were converted into collections and office spaces required to house an assortment of YPM specimens, artifacts, and archives. Approximately half of the YPM spaces are underneath a mezzanine, which contains a cement floored mechanical room and open areas with ducting, electrical conduit, and pipes below the roofline. All of these factors presented construction hurdles to the goal of creating a pest-resistant, climate controlled environment suitable for the storage of natural history collections.

The YPM began renovations in April 2008, starting with the demolition of office cubicles, unnecessary walls, and a kitchen. New spaces were retrofitted with new walls, new floors, electrical where necessary, and air-handling intake and outtakes. A second stage, with final electrical installation and troubleshooting occurred over an additional 3-month time frame after some collections materials had been put in place.

In total, portions of eleven different divisions moved from the New Haven campus to the renovated facilities on West Campus. Collections in the Anthropology division housed in the 175 Whitney Avenue were the first to move. Additionally, collections from the divisions of Geology, Invertebrate Paleontology, Vertebrate Paleontology, Entomol-

ogy, Invertebrate Zoology, Vertebrate Zoology, and Archives housed in the Kline Geology Laboratory (KGL) building were relocated to this new facility. Packing of the anthropology collections commenced in May 2008 and packing of KGL materials began in June 2008. Both of these moves continued over a 14-month period.

Even after the building was in use there were residual issues due to the building's age and changes made during retrofitting. The major issue was leaks found throughout areas of the building and were attributed to different causes. For example, a portion of the roof over one third of the YPM total space was redone to stop leaks in the "southern" portion of the building, which decreased the frequency and severity of problems. There also were leaks related to condensation from roof drains, duct work, and machinery, including a large catch basin located above collections spaces that was found to be leaking in a number of spots. Many of these leaks have been rectified but a few still are being addressed.

The original air-handling system was designed to support the daytime activities of the pharmaceutical company. The machines originally operated for 8 hours before shutting down during off-hours. Current activities of the museum require these systems to now run for 24 hours and their efficacy in maintaining required relative humidity and temperature conditions varies. By monitoring climate data, we were able to use seasonal corrections of air-handling set points to achieve consistency.

Attention to integrated pest management (IPM) concerns influenced each step of construction from planning to initiation. The three basic components of IPM in a museum setting are: prevention, monitoring, and treatment (Pinniger 2001). Pest outbreaks can be prevented by excluding pests from the area where collections are stored and also by creating conditions that, while safe for the objects, are not optimal for the pests (Pinniger 2001). The methods used for monitoring pests greatly depend on the resources available to the museum. The most frequently used method is monitoring with sticky traps, designed to capture insects and rodents. These traps need to be checked and changed at regular intervals or they can become attractants for pests (Alpert and Alpert 1988). Also, objects within the collection periodically should be checked for any infestations. If there is an infestation observed within a collection, the focus turns to treatment options. Historically, pest treatment was in the form of pesticides; pesticides now generally are avoided but still are used in extreme cases. Many laws and human health issues, as well as safety of the collections themselves and the associated costs, have led IPM specialists away from chemical treatments (Strang 1992). Most museums now choose to treat infested objects through cleaning, freezing or anoxia treatments (Kelley 2005).

A successful integrated pest management program contains all of these practices and further relies on the use of staff. Collections staff need to be trained on IPM procedures that they can use in all planning and work related to the museum collections (Pinniger 2001). It is essential that all persons involved with the collections and buildings in which they are housed, are aware of the issues related to the objects being stored. The Yale Peabody Museum used staff knowledge of IPM when retrofitting the West Campus building and in maintaining a collection-safe environment. The priority for collections staff was to monitor for pests in the building that might have been residual from previous tenants. Two trapping surveys were conducted to assess pest problems.

Trapping Study 1

Sticky trap surveys were used to gain baseline data about pests and potential hotspots. One month before construction began, a series of traps was placed throughout the YPM

spaces and in adjacent sections of the building. Traps were left in place for 1 week and then examined for any pests. Two months later, during construction, another 1-week trapping survey was conducted; the same locations were used for both periods, and new traps were used each time. When the major construction project was completed, an intensive 3-month trapping series was conducted. Again traps were set for 1 week before being examined; however, trap locations were changed, and no single location was used for 2 consecutive weeks.

Results and Discussion of Trapping Study 1

The initial postconstruction trap data indicated a large population of booklice (Psocoptera), isolated to one collection space and along another hallway, with peak numbers in a fluid preparation workroom. Booklice are known to damage insect collections, and other organic materials, documents, and labels are particularly of concern (Pinniger 2001). High populations of booklice indicate potentially damp and high-humidity conditions present in collections spaces. This situation initiated three responses: 1) the contracting of an outside IPM specialist to survey the building, 2) the formulation of an agendum to take immediate responses to the suggestions in the IPM report, and 3) the creation a comprehensive monitoring program.

Tom Parker of Pest Control Services, Inc. was contracted by the museum to perform a complete interior and exterior building survey to determine potential and current pest problems and look for solutions. Mr. Parker visited the West Campus facility and took a full tour encompassing 2 days. Using the initial pest trap data obtained by YPM staff and his own observations, he supplied a 38-page report, with additional informative appendices, detailing the measures that should be taken to rectify some of the problems. The major issues focused on sealing the ''building envelope'' and addressing the large population of booklice.

Mr. Parker's report resulted in an initial response to use a nonpesticide treatment in the building areas with high booklice concentrations. This procedure included a heat treatment in which the thermostats were set to maximum endeavoring to obtain a steady 90°F (32°C) temperature. High temperatures theoretically will decrease the relative humidity and eradicate the booklice through desiccation. Unfortunately, the heating system could not reach the optimal heat, attaining only 75–80°F (24–27°C) maxima, which were sustained for a 2-week period. In order to achieve the required temperatures, air returns were sealed and space heaters were placed in the three rooms with highest booklice densities. These rooms then reached the desired 90°F (32°C) temperatures, and conditions were maintained for 4 days to complete the treatment. Because booklice remained after the initial treatment, a second treatment course was chosen: the affected area was sprayed with a pyrethrin insecticide by a licensed pest management company at the suggestion of Mr. Parker. Pesticide treatment is in general a last resort for pest management in a museum setting; thus a pyrethrum derivative was chosen for its low toxicity. Special care was taken to treat only structural elements and not work surfaces.

Trapping Study 2

Upon full-time occupancy of the West Campus facilities, a standardized monitoring program was initiated in August 2009 to evaluate the seasonality of pest populations and any associated problems. Catchmaster Insect Trap and Monitor sticky traps with a 3 inch × 2.5 inch (7.6 cm × 6.4 cm) trapping surface were placed for an approximate 1-month period at predetermined locations throughout YPM spaces. Trap locations were chosen

based on the highest potential for accidental nontarget pest entry points and target pest species hotspots, while maintaining a comprehensive sample of the YPM spaces.

After approximately 30 days, the traps were switched out with fresh ones. The used traps were then frozen to kill any live pests caught on the traps and examined as time allowed. Data collected from each trap included the date and location of the trap, as well as the taxa and their abundance. Identification of pests was made to ordinal level and noted to family or below if known by the trap examiner. Traps were examined under a stereo microscope when available; several from the first series were examined by eye.

Concurrently, Onset HOBO data loggers, model: U14-001, were installed in collections areas throughout the YPM spaces. These data loggers record temperature and relative humidity at user-chosen intervals. The software used with these devices graphs the data and also allows exportation of data into an MS Excel file.

Data loggers in YPM spaces were set to record temperature and relative humidity every 30 minutes. Data were continuously recorded and downloaded intermittently in response to observed issues for justification of climate moderation. The air-handling system is prone to influence from outdoor conditions, and seasonal adjustments are needed to maintain temperatures and humidity within safe levels. Data from the climate monitors also was used to assess whether the pest populations were responding to fluctuations of temperature and relative humidity within the rooms. This then could be used to clarify whether the insects were responding to outdoor or indoor conditions. Additionally, baseline temperature and humidity data could be correlated with different pest species outbreaks to determine their specific requirements.

Results and Discussion of Trapping Study 2

Pest issues.—Trapping in almost every space in the YPM areas of West Campus yielded some type of insect activity, from nontarget outside invaders to recognized museum pest species. Most outside nontarget insects (species not known to be pests), represented in traps included ants (Hymenoptera: Formicidae), springtails (Collembola), and ground beetles (Coleoptera: Carabidae). The infestation of booklice in the fluid hallway and the invertebrate paleontology collections room continues to be a major issue. Other problems are the continued invasion of outdoor species and the inability to stabilize climate conditions in areas near collection spaces.

Evidence of the varied carpet beetle (Coleoptera: Dermestidae; *Anthrenus verbasci*) was found on a few occasions, most often as larvae or exuvia. Varied carpet beetles are known pests to natural history collections (Kingsolver 1988). Preliminary trapping has yielded low numbers of individuals, suggesting that a problem does not exist at this point. Evidence of beetle exuvia does indicate a living population of beetles living in the building, and therefore, the potential for infestation of museum specimens exists. The areas in which varied carpet beetles were in evidence are located adjacent to collection spaces; of special concern are the entomology and vertebrate zoology collections, where increased monitoring is required. Increased cleaning of these spaces will be recommended, requiring equipment to be moved from direct contact with the floor. Once again, sealing of external doors in these spaces should reduce the food source by exclusion.

Booklice were collected in almost every room throughout the YPM spaces where trapping was conducted. Most areas had populations low enough for booklice to be of limited concern as pests. Approximately one quarter of the total space had booklice in numbers that create concern for collections. Data indicate that populations peak in these

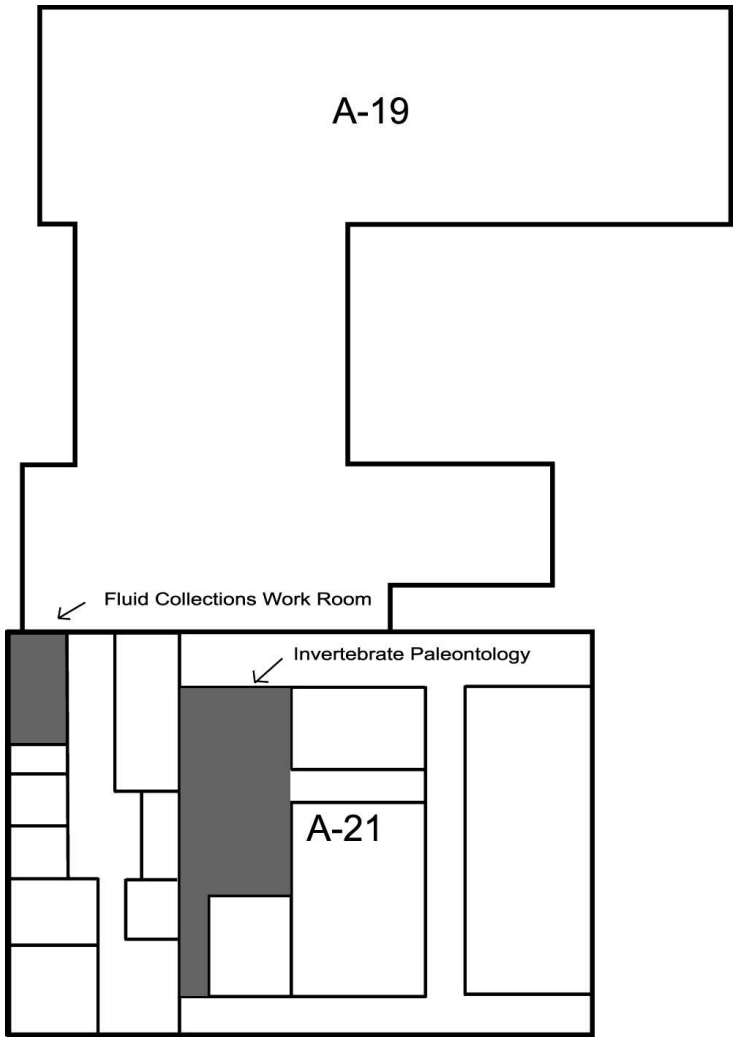

Figure 1. Yale Peabody Museum (YPM) West Campus spaces, illustrating the former building designations. Gray areas indicate booklice hotspots.

areas during the late summer into early fall, reflecting seasonal conditions and the air-handling system's inability to respond to the varying climate. The area of the YPM spaces originally designated as building A-19 (Fig. 1) had comparatively low numbers of booklice collected in traps. The overall abundance and lack of congruity in positive trapping locations indicates further measures do not need to be taken at this time.

Within the YPM area formerly referred to as the A-21 building, which was designed for drug manufacturing, a noticeable booklouse problem occurs (Fig. 1). The north side of the fluid collections hallway and an adjacent work room is one hotspot. Another hotspot is located on the south side of an adjacent hallway and in the invertebrate paleontology collections room. Most traps collected in these areas contained booklice, and included the traps with the highest number collected through out the building. One sticky trap, located to the right of the main door in the fluid collection workroom, peaked at over 500

individual booklice. These were mainly very small individuals, probably early instar nymphs. The trap to the left of the door during this same month also had 235 individuals, also with a large number of nymphs. The number of booklice in traps decreases as distance increases down the hall to the south. This hotspot does not appear to affect any areas to the north. Traps located 15 feet away showed only a slight response to this hotspot.

The invertebrate paleontology collections room also had an increased number of booklice. These also seemed be focused in the south part of the space, as well as the hallway adjacent to the southern double doors. These combined areas have the next highest density, averaging 21 insects per trap, of booklice trapped; some effect is noticed in adjacent collections rooms during peak population blooms.

Building and Operations

Although some renovation actions, such as sealing the building from the outside, have led to substantial decreases in the invasion of outside pests, open access in some areas remains. Additional measures are required to complete the exclusion process in addition to continued maintenance of previous efforts; the primary means of entrance appears to be outside doorways, through gaps under and between doors and through poor framing. Interior collections doors and door sweeps exclude the majority of the pests that enter the building but daily use can potentially increase pest access.

Within these areas another factor might contribute to this problem; during renovations, new walls were constructed, and frequently drywall used in construction still is wet. Wet drywall is a potential source of moisture for booklice. Once the drywall has fully cured and all moisture has naturally left, the habitat should no longer be optimal for this pest and the situation will resolve itself.

Parts of the fluid collections and invertebrate paleontology section of the building are directly underneath an open mezzanine that allows facilities access to the air handling, water, and steam pipes which run above the drop ceilings. The gap between the ceiling in these spaces and the roof is approximately 20 feet. Much of this space is filled with pipes, duct work, and walkways. The remainder of these areas is underneath a closed mezzanine, with air handling units and a large cement catch basin to collect condensate runoff. The open mezzanine section is not a clean area and that is a result of the following complications. Constant maintenance is required for the approximately 40-year-old systems and this area is accessed frequently by people making repairs. The roof was recently redone to fix the constant leaking occurring during winter snow melt and heavy rainstorms. During the roofing project, debris fell onto the top side of the drop ceilings. The collections spaces themselves were protected during this project by sealing the rooms with TuffWrap, sheets of a plastic material professionally installed, at the ceiling level. Finally, cleaning is not a priority because this is a mechanical area, even though it is separated only from collections spaces by a level of ceiling tiles.

Leaks are a recurring issue in many of the spaces, especially in the ''A-21'' area, compounding the moisture problem, reflected in the booklice population. Roof leaks mostly were fixed with the roofing project, although a few continue. Ineffectively insulated air handling duct work has resulted in leaks as temperature fluctuations create condensation, either by an absence of insulation or deterioration. Some roof drains run directly through collections spaces creating condensation and puddles; these pipes are currently being insulated. Leak locations do not correlate with booklice outbreaks and

likely are not a cause for this issue, but might contribute to the high booklice populations in other sections of the building.

A more important problem is the presence of the large catch basin for the runoff of air-handling system condensate runoff. This essentially is a large cement wading pool. One of the primary leaks in a collections space is tied directly to this basin, which was empty when the systems were not in use. Once these systems are running, leaks in the basin have become apparent and are now a source of water in one collection space. These all are sources of moisture for insects, and reduce the chance of desiccation, regardless of the building's relative humidity.

Conclusions

It is imperative that additional measures are taken to exclude insects and other pests from the entire building, by "sealing the building envelope." Door jambs, door and window seals, and door sweeps all should be re-examined for access points and fixed by recaulking framing and adding or repairing existing door sweeps. All collections areas should continue to be frequently cleaned, eliminating potential food sources that entice pest species. Collections staff must maintain a vigilant eye on the work of cleaning crews to ensure its adequacy. Management also should examine the possibility of cleaning areas above the collections space, specifically the mezzanine area. As is already in progress, all leaks should be rectified immediately, not only because they provide a source of moisture for pests, but they also potentially raise humidity in collections areas. High moisture areas also encourage mold growth, which is an additional food source and enticement for numerous pest species.

Booklice are the major concern in the retrofitted YPM spaces, because these insects are a known pest on insect collections, animal hides, and papers. It is possible that this problem will resolve itself as conditions stabilize and newly installed drywall dries out. A comprehensive monitoring program must be initiated to track the booklice population fluxes. Another treatment of pesticides administered by licensed technicians should be applied just prior to the observed population peak. This should reduce the current population, and with early instar die-off decreases the next generation's numbers.

Retrofitting existing buildings for natural history collections storage is a feasible plan from an IPM standpoint with varying concerns that should be assessed before collections are put into place. As is seen from the experiences of YPM staff, additional efforts to fix existing issues can require novel methods. Final recommendations for other institutions attempting a similar project are this: existing doorways and hardware inevitably will need to be overhauled to exclude pests; air-handling systems will require constant monitoring; and large-scale projects, such as a new roof, might be necessary to rectify issues that, while manageable for a common area, are not sufficient to house collections. A preparatory period to run all of the systems to see how they respond to seasonal changes is essential to stop many leaks prior to occupation. This time interval also would allow staff a chance to gain baseline pest data and perform necessary treatments of affected areas before collections materials are exposed to the pests and the treatments. Even these additional preventative measures will not solve all issues, and monitoring and maintenance will be required to insure the preservation of the natural history collections.

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EFFECT OF CONTAINER GLASS QUALITY ON PH IN NATURAL HISTORY WET COLLECTIONS

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Abstract.—Various authors recommend the use of borosilicate instead of soda lime glass in natural history wet collections. Alkali ion leaching from soda lime glass can cause deterioration of the glass containers and alter the pH in the fluid preservative with possibly detrimental effects on the enclosed specimens. However, empirical observations on the extent of such pH changes currently are not available, and the more expensive borosilicate glass is rarely in use to date.

This study compares the influence of soda lime glass and borosilicate glass on the pH in aqueous ethanol solutions of different concentrations, starting pH, and temperature. Large polyethylene bottles were filled with soda lime or borosilicate glass shell vials typically used in natural history collections and topped up with the respective test solution. The pH in the samples was repeatedly measured over time. The results show that soda lime glass contributes more strongly to the alkalinization of the test solution than does borosilicate glass. It is concluded that the acquisition of superior glass containers is justified, considering the immense effort required for the collection and curation of scientific specimens over centuries.

INTRODUCTION

The factors that influence pH levels in natural history wet collections are manifold. They originate from the preserved specimens themselves, but also from the chemical properties of the preservation fluid, glass or plastic containers, and paper labels, as well as from environmental factors; e.g., oxygen, carbon dioxide, temperature, light. Recently, Kotrba and Golbig (2009) addressed the problems of pH maintenance in ethanol-preserved natural history collections, and Carter (2009) presented the effect of pH on ethanol-preserved muscle tissue, together with introductory information and general literature references on this topic.

In the present publication we address another aspect of this complicated matter, the effect of container glass quality. Various authors have recommended the use of borosilicate glass instead of the cheaper, widely used soda lime glass (e.g., Simmons 1995; Moore 1999; Oberer 2001). Soda lime glass contains considerable amounts of alkali ions (most importantly Na^+), which are leached from the glass surface when submerged in water or fluid preservatives for long periods of time (White 1992; Bunker 1994; Cooper and Cox 1996; Oberer 2001; Lynch 2006). The leaching of cations from the glass is coupled with the diffusion of H^+ (or H_3O^+) into the glass, which in closed systems causes an increase in pH in the surrounding solvent (White 1992). In natural history wet collections, therefore, the leaching process not only can cause deterioration of the glass containers themselves but also can alter the pH in the fluid preservative with potential detrimental effects on the contained specimens. Borosilicate glass, on the other hand, is chemically highly resistant. The differences in chemical resistance between glass types clearly are evident from their assignment to different hydrolytic classes according to ISO 719. Whereas neutral glasses such as borosilicate glass are assigned to class HGB 1, indicating the highest hydrolytic resistance and very good chemical resistance against

acidic and alkaline solutions, soda lime glass is assigned to class HGB 3, indicating a considerably lower hydrolytic resistance.

Considering the high expenses required to establish and maintain natural history wet collections over decades or even centuries, every effort should be made to ensure the ultimate success of this effort, i.e., the actual preservation of the specimens. But although the recommendation of borosilicate glass containers has a sound theoretical basis in glass chemistry, it rarely has been implemented to date. This reluctance is a result of the considerably higher price of borosilicate glass but also of the lack of observations regarding the actual extent of pH changes due to glass quality in wet collections.

We used an empirical approach to assess the influence of glass quality (borosilicate vs. soda lime glass) on the pH in aqueous ethanol solutions of different concentrations and starting pH levels. The intention of this study was to get an initial general overview of whether the glass quality does cause a measurable difference and in what order of magnitude the difference might be.

Methods

The measurement of pH in alcohol solutions with an alcohol content of 70% or higher is known to be difficult and riddled with systematic errors (Frant 1995; Waller and Simmons 2003; Sound and Becker 2007). To eliminate such errors, the study was designed using comparative sample pairs (CSPs) with the only difference between the two samples of each CSP being the chemical composition of the tested glass shell vials. Because of the high material requirements (thousands of glass vials of both qualities) and the preliminary status of the study, no identical CSP duplicates for extensive statistic testing were provided.

We compared Schott AR-Glas® (soda lime silicate glass, Hydrolytic Class HGB 3) and Schott Duran® Borosilicate Glass 3.3 (Hydrolytic Class HGB 1). Two subsets of the experiment were independently run with a delay of half a year for the second subset. The first subset (A–E) received 76% ethanol, approximating the usual concentrations in natural history wet collections. The second subset (F–I) received 52% ethanol to reduce the problematic effects of high alcohol content on pH assessment.

The tested alcohol solutions were prepared in large containers before allotting them equally to the CSPs. The alcohol stock solution was 96% ethanol (UN 1170) with German standard denaturing (i.e., 1% methyl ethyl ketone, respectively butanone, with traces of methyl isopropyl ketone, ethyl isoamyl ketone, and denatonium benzoate). The stock solution was first diluted with distilled water to 76% or 52%. Subsequently, portions of these solutions were conditioned to moderately acidic and moderately and strongly alkaline conditions by adding small quantities of acetic acid or potassium hydroxide, respectively. The composition of the nine individual test solutions is shown in Figure 1.

Eighteen new 2-L polyethylene bottles (Kautex 303 LDPE) each were filled with 196 small soda lime or borosilicate glass shell vials with the following specifications: diameter = 12 mm, length = 50 mm, wall thickness = 1 mm, flat bottom. The bottles then were topped up to the neck with the respective test solution and carefully turned upside down several times to remove remaining air bubbles from the vials. Only a small air space remained in the neck of each bottle. The resulting samples simulated the maximum glass surface area per preservative fluid volume ratio that is found in the wet collection of the Zoologische Staatssammlung München (Figs. 2a, b) which amounts to approximately 0.5 m^2/L.

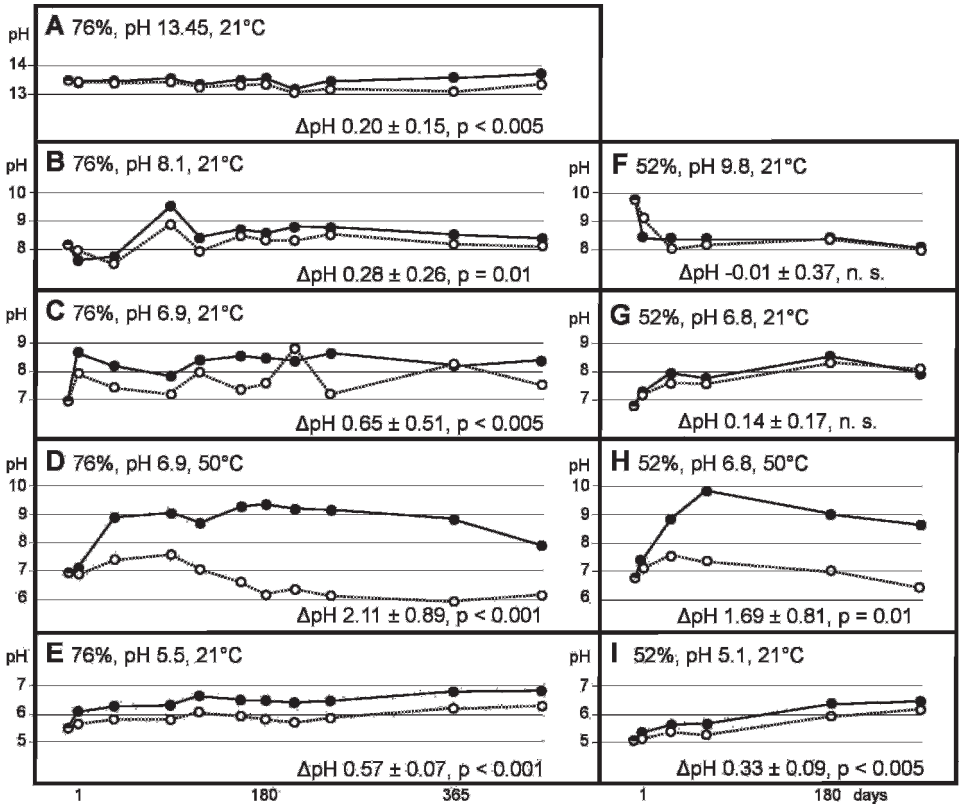

Figure 1. Effect of glass quality on the pH values in ethanol solutions of different concentration, pH, and temperature. At the top of each panel the test solution (concentration of ethanol, starting pH) and incubation temperature is specified; at the bottom are the average pH difference with the respective standard deviation and significance level as explained in the text. Full circles, soda lime glass sample; empty circles, borosilicate glass sample; half-full circles, starting pH.

CSPs A–E were incubated for 448 days and CSPs F–I for 266 days. All CSPs except D and H were incubated in an alcohol storage magazine with constant 21°C temperature. CSPs D and H were incubated in a heating cabinet at 50°C to speed up physicochemical reactions. As in most dissolution reactions, the rate of the leaching process is expected to increase with temperature as described by the Arrhenius equation (White 1992).

The pH in the samples was repeatedly measured over time; first monthly, then in larger time intervals. All measurements were taken using a Mettler Toledo InLab413/2M/SG Electrode. The electrode was calibrated with pH 4.01, 7.01, and 10.01 buffer solutions (Hanna® Instruments HI 70004, 70010, and 70007). It was rinsed in distilled water between each reading and frequently regenerated in neutral buffer for several minutes with subsequent recalibration. To further reduce the risk of errors due to electrode drift, the sequence of the 18 individual samples was randomized for each measurement.

The data were evaluated in two steps. First, the nine CSPs were evaluated individually. The respective statistics in Figure 1 refer to the changes between repeated measurements of the same samples over time. For lack of an a priori hypothesis regarding the development of the pH values over time, the data were evaluated by *t*-test, i.e.,

Figure 2. Comparison of experimental sample with actual sample from a natural history collection. (a) soda lime glass sample from comparative sample pair (CSP) D; (b) 2-L polyethylene bottle with glass vials containing Diptera specimens from the wet collection of the Zoologische Staatssammlung in München.

disregarding the time axis entirely. A two-sided *t*-test for paired samples was used to assess whether the two glass qualities performed equally (null hypothesis).

Subsequently three representative results of each CSP (average pH, pH after 180 days, pH at end of experiment) were compared across all CSPs. Again a two-sided *t*-test for paired samples was used to establish whether the two glass qualities performed equally.

Results

Figure 1 illustrates the observed changes in pH over time for each CSP (soda lime vs. borosilicate glass). The specific test conditions are indicated at the top of each panel; the average pH difference between the two samples across the repeated measurements is given at the bottom. The significance levels ($P = 0.001$, 0.01, or 0.05) indicate the probability that the compared glass qualities performed equally. The latter has to be accepted for CSPs F and G, where the probability is well above 0.05.

In all other CSPs the soda lime glass sample became more alkaline than the borosilicate glass sample. After 180 days the average pH difference across all nine CSPs was 0.76, at the end of the study it was 0.69, and the means across the repeated measurements (see above) differed by 0.66. For all three categories, the probability for the null hypothesis, i.e., that the two glass qualities perform equally, was less than 0.05.

In some individual CSPs a considerably larger pH difference occured. It was most pronounced in CSPs D and H which started with a neutral pH and were incubated at 50°C. Here the average pH difference was 2.11 (76% ethanol) and 1.69 (52% ethanol), with maximum values of 3.18 (76% ethanol) and 2.57 (52% ethanol). In the CSPs incubated at 21°C the pH difference was generally much smaller, averaging at 0.65 or less.

Comparing the respective CSPs of the two subsets, the pH difference was smaller in the subset with 52% ethanol. Within the subsets, the pH difference was smaller in CSPs with higher starting pH.

The data are not sufficient to statistically analyse the kinetics. However, it appears that, with the exception of the highly alkaline CSP A, the difference between the compared glass samples was mostly established within the first 3 months of the experiment and remained more or less stable afterwards.

In addition to the divergence between the compared samples of different glass qualities, there were trends that involved similarity of both samples of a CSP. In CSPs C, E, G, and I, which started with a neutral or slightly acidic pH and were incubated at room temperature, part of the observed pH increase involved both samples in parallel. The same applies for CSPs D and H, but only during the first months of the experiment. In these CSPs, which started with a neutral pH and were incubated at 50°C, the initial pH increase was followed by a decrease later on. In the borosilicate glass samples the pH even dropped below the starting pH into slightly acidic conditions. A moderate delayed decrease in pH also was evident in CSP B and at the very end of CSPs F and G, which started at neutral or moderately alkaline conditions. In CSP F, which started at a moderately alkaline pH but had only 52% ethanol, a strong drop in pH occurred in the beginning, which was unlike any of the other CSPs. In CSP A which had a strongly alkaline starting pH, the samples hardly deviated from the starting pH.

Discussion

Although pH measurements by electrode in alcohol solutions are known to be problematic, they can be regarded as reproducible and significant in studies looking at acidity changes, if the solvent background remains constant (Frant 1995; Carter 2009). This requirement is fully met by the present experimental design with CSPs that are identical apart from the tested glass vial quality. Therefore the results from direct comparisons within the CSPs theoretically can be regarded as reliable. Moreover, with exception of CSP F, the results are similar in the respective CSPs of both subsets of the experiment, indicating the repeatability of the experiment. However, although the patterns are similar, the individual points are relatively scattered, probably due to considerable measuring error, particularly in the neutral to slightly alkaline regime.

The presented empirical results show that soda lime glass has a more pronounced alkalinizing effect on aqueous ethanol solutions than borosilicate glass. The increase in pH observed in most CSPs is consistent with leaching of alkali ions, specifically Na^+, from the glass surface in exchange for H^+ (or H_3O^+) ions from the surrounding test solution. The pH increase is stronger in the samples with soda lime glass, which has a high Na^+ content compared to that of borosilicate glass. The observed difference is larger in the subset with 76% ethanol than in the 52% subset. This might be explained by the fact that, although the glass surface per solvent volume ratio is equal in all CSPs with respect to the entire test solution, it is twice as high in the 76% subset with respect to the contained volume of water. The observed difference is larger in samples with higher temperature and smaller in samples with higher pH as described for glass leaching processes (White 1992). According to the Arrhenius equation, physicochemical reactions occur faster at higher temperatures. Possibly pH deviations similar to those observed in the 50°C samples can be expected to occur also at room temperature after longer periods of time.

Whereas the observed differences within CSPs can be attributed exclusively to the sampled glass qualities, similar changes involving both samples are more difficult to explain. Although the alkalinization observed in the neutral and the slightly acidic samples is stronger in the soda lime glass samples, it is not absent form the respective borosilicate glass samples either. One possible explanation is that alkali leaching occurs to a smaller degree also in the borosilicate glass samples. Alternatively there could be other independent chemical reactions of which we are presently not aware.

The presence of additional, independent, and possibly antagonistic chemical reactions also is suggested by the yet-unexplained acidification observed at the onset of CSP F and in the later part of CSPs D, H, B, F, and G. A pH drop from 9.5 to 8.5 within the first days and then to 8.0 for the rest of the study also was observed in a control sample of Carter (2009) with 15 ml of plain 80% unbuffered alcohol contained in a 20 ml Wheaton glass scintillation tube. Possibly this effect is due to the uptake of CO_2 from the air, with the solution reaching an equilibrium at about pH 8.0.

Conclusions

In natural history collections it is necessary to stabilize the environmental conditions that were specifically chosen to preserve the specimens. Any factors that might bring about changes in these conditions are to be excluded. Although there is no generalized notion yet as to which specific pH is best for the preservation of any particular group of organisms, there is no doubt that the wrong pH can reduce or even destroy the scientific value of preserved specimens (references in Gotte and Reynolds 1997; Hargrave et al. 2005; Carter 2009).

Although the present study is preliminary, it provides empirical evidence that, at conditions comparable to those in natural history wet collections, soda lime glass vials contribute more strongly to the alkalinization of a contained preservative fluid than borosilicate glass vials. This constitutes another argument against the use of soda lime glass in natural history wet collections, in addition to the faster corrosion of said material as compared to borosilicate glass.

Considering the immense effort required for the collection, preparation, labelling, registration, determination, and description of scientific specimens, as well as their preservation, storage, and regular curation over centuries, a more extensive follow-up study and eventually the acquisition of superior glass containers at a higher price seem necessary and more than justified.

Acknowledgments

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FLAT FILE TO RELATIONAL: THE EVOLUTION OF A TYPE CATALOGUE OF INVERTEBRATE FOSSILS

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Abstract.—The Royal Ontario Museum began digitizing its collections of invertebrate, plant, and trace fossils in 1971. Since then, the database has undergone at least five platform transitions, starting with a PDP-8 computer using paper tape and eight-track magnetic tape, through the PARIS system of the Canadian Heritage Information Network (CHIN), and currently using MS-Access 2003. Each transfer has brought its own challenges and opportunities. In 1978, a type catalogue was published for which the content was generated from the collections database—a revolutionary alternative to manual typesetting, but one still requiring considerable human intervention. In 2008 the transfer from a flat file to a rudimentary relational platform was started. In addition to forcing an intensive data-cleaning exercise, this move has for the first time made it possible to create meaningful records for each publication event for a given specimen, previously only recorded through ungainly abbreviations and annotation. Priority is being given to a recently adopted orphaned collection, significant historical collections, and material currently subject to intensive active research. An important result of this transfer is the ability to generate up-to-date type catalogues for significant sections of the collection and to make them available as downloadable PDFs on the Web, thus starting to satisfy the requirements of the International Code of Zoological Nomenclature (ICZN) to publish lists of types.

Introduction and History

The Royal Ontario Museum (ROM) began digitizing its collections of invertebrate, plant, and trace fossils in 1971 with a PDP-8 computer using the BASIC programming language, to paper tape and eight-track magnetic tape. Records were limited to 1,024 characters, with a fixed-field format, necessitating considerable coding and abbreviation (Waddington et al. 1978). Records were in all upper case, and many categories of information were combined to limit allocation of precious characters to empty space. The decision was made to use a system of text abbreviations for geological information rather than adopting one of the numeric coding systems in use at the time (e.g., see Cohee 1967). An in-house coding system also was developed for suprageneric classifications, particularly super- and subtaxa, using the *Treatise on Invertebrate Paleontology* (Moore et al. various dates) as the standard. Since that time, the database has undergone at least five transitions, including the PARIS database of the Canadian Heritage Information Network (CHIN) from 1981 to 1995 (see Cox 1986; CHIN 2009a, b). In 1995, the data were migrated from PARIS directly into a flat-file database using MS Access V. 2.0. More recently, this was upgraded to MS Access 2003. Through the migration to CHIN and back to an in-house system, basic locality fields have been added, most of the geological and locality abbreviations have been expanded, and mixed case is gradually being adopted, field by field. The end users of the system had little to no say in the platforms and programs used.

In the early 1970s, the invertebrate palaeontology collections consisted of less than 28,000 catalogued specimens or lots. Documentation comprised: a catalogue register with the catalogue number, genus, species, geological period, and basic locality; a specimen label with the same information; and two sets of paper cards with slightly expanded information, filed taxonomically and stratigraphically. Inevitably, there also was a considerable backlog of uncatalogued material. A single catalogue number could

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LEPTOPLASTUS LATUS Matthew          --          Cotypes 17
   Matthew, G.F., Trans. Roy. Soc. Can., 1st ser.,Vol.
   IX, Sect. IV, 1891, pl. XIII, figs. 10a-c.
   Lower Ordovician, Bretonian.
   Navy island, St. John, New Brunswick.
   Cotypes - Roy. Ont. Mus. Pal. 7963.
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Figure 1. The record for *Leptoplastus latus* (ROM 7963, old number 333cm) from Fritz's type catalogue.

represent a single specimen or a lot of many individual specimens of the same taxon. Another property common to invertebrate palaeontology collections is the presence of rock slabs bearing multiple specimens, often representing multiple taxa. For slabs, the practice has been to assign a single catalogue number to the slab, but to make a separate database record for each taxon. In a flat file this can result in several full records for a single object.

The first subset of the collection to be input was the collection of type and figured specimens, because that was the most diverse section of the collections in terms of taxonomy and locality, and we wanted to test the functionality of the fields, such as they were. The basic reference for this collection was a series of type catalogues produced between 1941 and 1946. (Fritz 1941, 1942, 1943, 1944, 1945, 1946). The type collection at the time numbered about 900 specimens, including many thesis types. Because many early species were described from syntypic series rather than single holotypes, each early record represents a lot of one to several individual specimens (Fig. 1).

In 1978, a type catalogue was published for which the content was generated from the collections database—a revolutionary alternative to manual typesetting, but one still requiring considerable human intervention (Waddington et al. 1978). The type collection had grown to about 1,700 specimens, mostly due to the addition of one large monograph. Records were extracted from the database, formatted, and then edited before going to print. At the time, we were bound by the quirky inputting rules of our system, which included all upper case and ad hoc abbreviations.

Limitations of the Flat File

By this time some records included multiple citations, but these were all strung together in a memo field, so were not really searchable (Fig. 2). This condition was the result of the limitations of our initial fixed-field file format (which limited the field size), coupled with a decision to complete the data entry before allotting limited resources to making yet another change in the database structure. Any comments about, for example, designation of a lectotype, had to be relegated to a general remarks memo field. There was only one

LEPTOPLASTUS LATUS MATTHEW
7963 [333CM] P-SYN
U CA, OR L O,
ST JOHN GP ?
[ST JOHN,BRETONIAN,L ORDOVICIAN]
NAVY IS,ST JOHN,NB
O263;MATTHEW GF,CAN REC SCI,1891,P461-462;
MATTHEW GF,TRANS ROY SOC CAN,VOL 9,SECT
4,1892,P54-55,PL13,FIG 10A-C
REMARKS: C-GF MATTHEW;D-MACKENZIE ;LABELLED
COTYPES;UNCERTAIN WHICH SPECS FIG'D ; 17 SPEC

Figure 2. The record for *Leptoplastus latus* ((ROM 7963, old number 333cm) from the 1978 type catalogue.

field for type designation. We also had devised a rather idiosyncratic method of abbreviating references when there were multiple citations, and had no central location for the full publication references except for a card file. We developed a couple of laboriously hand-edited addenda to the 1978 catalogue (notably brachiopods and trilobites, to accompany major symposia) and made them available as PDF on request; however, these enjoyed only a very small circulation. The International Code of Zoological Nomenclature (ICZN) recommends that every institution in which name-bearing types are deposited should publish lists of such specimens in its possession or custody (ICZN 1999, article 72F). The time was long overdue for the ability to generate a new type catalogue from the database.

Migration to Relational Database

In 2008 we began in earnest the job of converting our flat file to a rudimentary relational database. The first goal of this transition was to normalize the publications information so that a type catalogue could be generated. To this end, the main database initially was split into two related tables.

In the flat file, a slab bearing more than one fossil would have an individual record for each taxon, resulting in multiple records per slab. A single catalogue number is assigned to the physical entity of the slab, on the theory that it only can be in one place. Thus, the first step was to map all the taxonomic records to a single specimen parent record. The parent record (dubbed SlabHost) bears all the information common to the slab or lot; e.g., acquisition and registration information, geographic and geological, location records, dimensions. There is provision for adding links to images and for future recording of conservation/preparation data. Additional relational tables for locality and geological data will be the focus of future projects.

Each individual taxon, or potentially each individual specimen on a slab, now gets its own record in an identity table (Ident), which maps to the appropriate SlabHost record via the number of record for the slab. The Ident table includes taxonomic information and other details specific to the individual specimen on a slab (e.g., partial specimen, gender), including the old memo field with concatenated publication information.

The initial transfer resulted in 50,348 Ident records (derived directly from the original flat file) mapping to 47,966 SlabHost records.

A third table, Citations, contains a separate record for each individual citation of a given specimen. Thus, a single specimen might be cited as a syntype, a lectotype, and a figured or referred specimen in different publications, and might be assigned to different taxa in the different publications; this information now can be unambiguously recorded. Finally we have a running bibliography database (Publications table) of all papers in which ROM specimens have been cited (Table 1). Figure 3 shows schematically the relationship between the tables.

Input forms have been developed that nest the related tables for each SlabHost parent record. The SlabHost form has four screens. Nested within the first screen are the stacked one-to-many Ident subforms of three screens each. Each Ident subform hosts one to many stacked Citations subforms as applicable (Figs. 4, 5).

Figures 1, 2, 4, and 5 are progressive representations of the same specimen lot (old ROM number 333cm) consisting of a lot of 17 syntypes of *Leptoplastus latus* first described by G. F. Matthew in 1891, and assigned to *Sphaeropthalmoides latus* by R. D. Hutchinson in 1952. In 2006, F. Terfelt reassigned the species to *Westergaardia lata* and selected a lectotype and a figured specimen from the original syntypic suite. These two

Table 1. Categories of information in the relational tables. Key index fields are indicated in ***bold**.

SlabHost (Parent record)
***CID—automatic counter (numeric primary key)**
Catalogue numbers (catalogue, accession, other numbers assigned to the specimen or lot)
Locality information (geographic, stratigraphic, georeferencing)
Provenance (acquisition details, collector, dates, previous ownership history)
Location (exhibits and loans history, location in storage)
Dimensions of slab
Link to images
Ident (daughter taxonomic record)
***RID—automatic counter (numeric primary key)**
***CID—link to SlabHost (foreign key)**
Catalogue numbers
Identification of record (genus, species, author, suprageneric taxa)
Previous identification (relict of legacy database)
Type designation (most significant designation)
Publication (concatenated abbreviated references—relict of legacy database)
Specimen description (part, gender, individual dimensions)
Link to images
Citations (daughter publication record)
***RefID—automatic counter (numeric primary key)**
***RID—link to Ident (foreign key)**
***PubID—link to Publications (foreign key)**
Name published as
Type designation (e.g., holotype, lectotype, figured specimen)
Publication reference
Citation (e.g., page, figures)
Publications (References in which ROM specimens are cited)
***PubID—automatic counter (numeric primary key)**
Long and short versions of reference
Primary author
Publication year
Database status

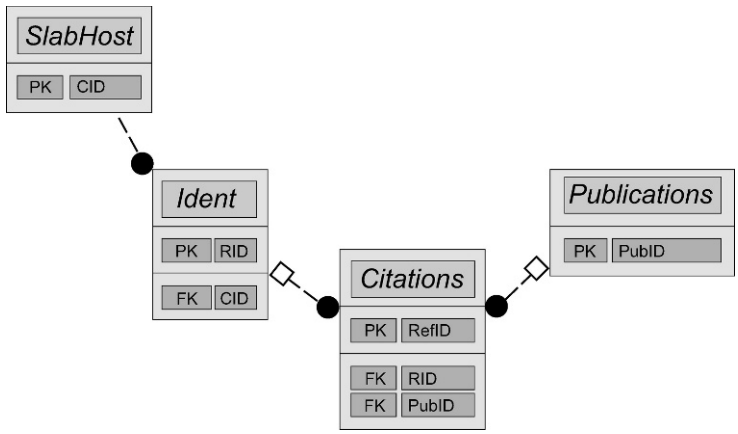

Figure 3. Entity relationship diagram for the ROM Invertebrate Palaeontology database. In a one-to-many relationship, a single record in the parent table can relate to more than one daughter record. (PK = Primary Key, FK = Foreign Key).

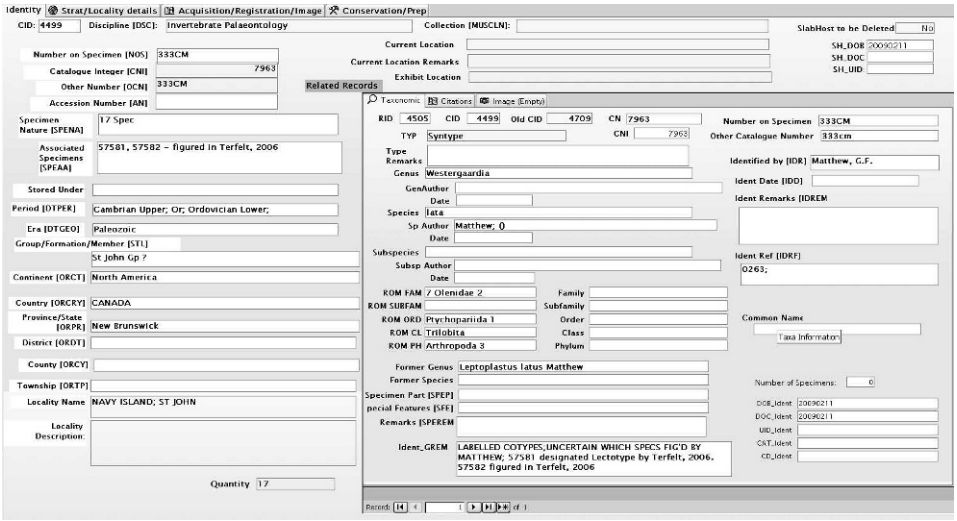

Figure 4. SlabHost input form (first of four SlabHost screens), showing the identity table (Ident) subform embedded (first of three Ident screens), for old number 333cm. In this instance there only is one related Ident record. There could be many Ident subforms stacked here.

specimens have been isolated from the original lot and given new ROM catalogue numbers. The record of their old number has been retained, and the specimens still are stored with the original syntypic suite. The genus and species of record in Ident have been changed, but the original identifications are retained with each publication event recorded in the Citations table. The records for the newly numbered specimens still retain

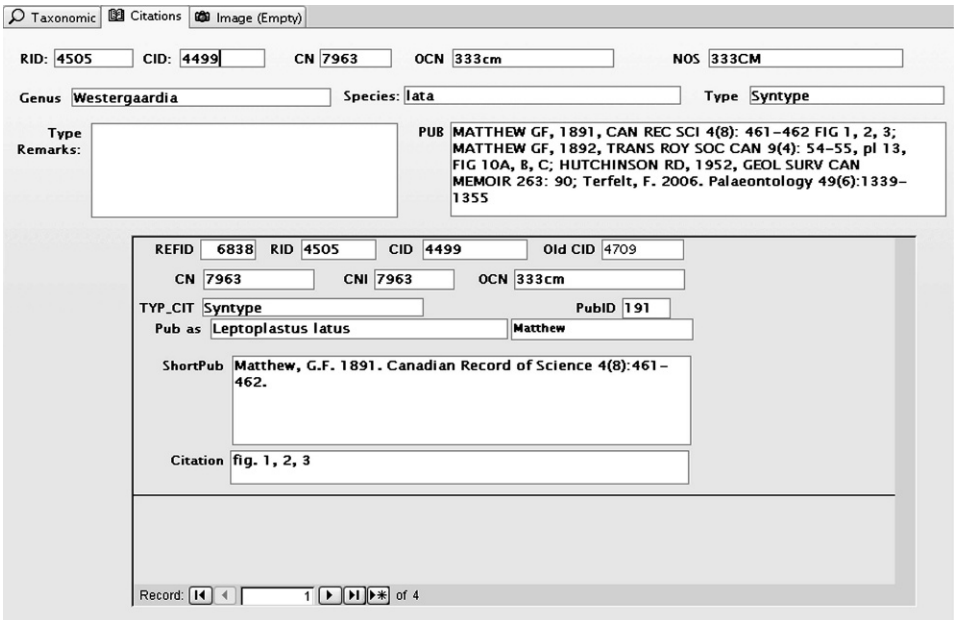

Figure 5. Second screen of one identity table (Ident) subform for old number 333 cm, opened to show the first of four embedded Citations subforms, each recording a different publication event for that specimen.

Westergaardia lata

ROM 57582 **Old No.** 333cm Westergaardia lata Figured Specimen pl.4, fig. 6
Terfelt, F. 2006. Palaeontology 49 (6) :1339-1355.

ROM 57582 **Old No.** 333cm Sphaeropthalmoides latus Referred Specimen p. 90
Hutchinson, R.D. 1952. Geological Survery of Canada, Memoir 263:1-124.

ROM 57582 **Old No.** 333cm Leptoplastus latus Syntype pl.13, fig. 10A, B, C
Matthew, G.F. 1892. Trans. Roy. Soc. Can. 9 (4) :33-65.

ROM 57582 **Old No.** 333cm Leptoplastus latus Syntype fig. 1, 2, 3
Matthew, G.F. 1891. Canadian Record of Science 4 (8) :461-462.

ROM 57581 **Old No.** 333cm Westergaardia lata Lectotype pl.4, fig. 8
Terfelt, F. 2006. Palaeontology 49 (6) :1339-1355.

ROM 57581 **Old No.** 333cm Sphaeropthalmoides latus Referred specimen p. 90
Hutchinson, R.D. 1952. Geological Survery of Canada, Memoir 263:1-124.

ROM 57581 **Old No.** 333cm Leptoplastus latus Syntype pl.13, fig. 10A, B, C
Matthew, G.F. 1892. Trans. Roy. Soc. Can. 9 (4) :33-65.

ROM 57581 **Old No.** 333cm Leptoplastus latus Syntype fig. 1, 2, 3
Matthew, G.F. 1891. Canadian Record of Science 4 (8) :461-462.

ROM 7963 **Old No.** 333CM Westergaardia lata Referred Specimen
Terfelt, F. 2006. Palaeontology 49 (6) :1339-1355.

ROM 7963 **Old No.** 333CM Sphaeropthalmoides latus Referred Specimen p. 90
Hutchinson, R.D. 1952. Geological Survery of Canada, Memoir 263:1-124.

ROM 7963 **Old No.** 333CM Leptoplastus latus Syntype pl.13, fig. 10A, B, C
Matthew, G.F. 1892. Trans. Roy. Soc. Can. 9 (4) :33-65.

ROM 7963 **Old No.** 333CM Leptoplastus latus Syntype fig. 1, 2, 3
Matthew, G.F. 1891. Canadian Record of Science 4 (8) :461-462.

Figure 6. Section of MS Access report producing a catalogue of the G. F. Matthew type and figured specimens, showing the entry for *Westergaardia lata*.

the link to the entire citation trail, because the first three citation records refer to the original entire suite or lot of 17 specimens.

It is finally possible to generate a type catalogue (Fig. 6) as a report in Access, in which the publication history of the specimen is maintained. The version shown here is sorted by taxon, using the taxon of record, which is the genus and species to which the specimen was most recently referred. The original lot of 17 specimens has been split into three lots of one, one, and 15 specimens, each with four citations.

So far, the separation of the original flat file into two relational tables is complete. The most onerous part was telescoping the numerous records for a single slab into one single parent record with related taxonomic records. This required considerable data cleaning, deletion of duplicate records, selecting which record to keep as the source for the SlabHost table, and validating that Ident records mapped successfully to the correct parent record. We continue to come across the odd record where an error in the original flat file has resulted in false mapping, with the creation of very odd-looking records and loss of data.

These are repaired by checking back with the original flat file and re-entering the affected records. Splitting off locality and geological data into their related tables should be a relatively straightforward exercise. Another planned step is to relate the loans database to the main specimen database in order to create a loans history for each specimen.

Current activity is focused on populating the Citations table. Priorities have been: a collection of about 900 orphaned specimens transferred from McMaster University; monographs with a large number of specimens only cited once; historic collections, with multiple references for many of the specimens; significant small active collections; and incoming specimens.

We started with a flat file of 50,700 records (excluding the Burgess Shale collection), including 8,900 type, figured or referred specimens cited in 440 publications. An additional 1,000 or more type and figured specimens are pending but not yet received into the collection. Including specimens added since the migration that are not in the legacy flat file, we now have 49,500 SlabHost (parent) records, with 51,800 related Ident (taxonomic) records. About 5,000 of the SlabHost records represent accessioned lots that have not been sorted and identified and so have no records in Ident. At time of writing, 5,100 records have had their citations updated, of which eight have five citations, 67 have four citations, 129 have three citations, and 372 have two citations, for a total of 6,123 Citations records cited in 219 publications.

Discussion

The migration to the beginnings of a relational database has had many benefits. The first is the forced data cleaning to prepare for the migration. In the process, selected sections of the collection, in particular the type collection, are undergoing reorganization and inventory that has not been done in some cases since the 1970s. The original goal of improving reporting capabilities for publication citations is being realized. Although there are no current plans to make the database available on the Web, as subsets of the type collection are completed, downloadable PDF type catalogues will be posted on the ROM's Web site (www.rom.on.ca/invpal). Once the citations are completed, we plan to move forward with further splitting of taxonomic data, which currently is expressed in a nonintuitive system of numeric and text coding. This will simplify searches, and will facilitate possible future inclusion in a distributed database. Another high priority is to link the loans database to the main database so as to be able to track loans more readily. Although our database does not follow any of the prescribed models for relational databases, it has enabled us to take advantage of limited human and financial resources and minimal programming capabilities to convert a highly customized flat file into a relational version with greatly enhanced functionality.

Acknowledgments

Brad Millen conceptualized the splitting of the flat file, and did the actual mechanical transfer, as well as creating input forms and trouble shooting. Peter Fenton participated in many hours of planning and testing, and helped with the figures. Amy Yovanovich, a summer intern from the Museum Management program at Sir Sanford Fleming College, databased the McMaster Collection, and her work has provided the base for the publications database and the incentive to get moving on this project. Paul Morris provided insightful and constructive criticism of an earlier draft.

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WORKING TOWARD STANDARDIZATION: A SURVEY OF CURATION PROCEDURES IN INVERTEBRATE PALEONTOLOGY COLLECTIONS

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Abstract.—Invertebrate Paleontology (IP) collections are one of the most important resources available to paleontologists. They serve as vast repositories of data on invertebrate fossils, including potential data for future paleontological research. Collections are essential resources whose care and curation need to be documented. Published guidelines for the curation of collections are in place, but there has not been a consensus as to how to establish best-practice standards. Setting standards will lead to consistency in the curation, organization, and use of all invertebrate paleontology collections, but standards cannot be set without a clear understanding of how the current curation practices vary.

Based on a survey of curation procedures in 23 invertebrate paleontology collections there are four major areas of concern that need to be addressed to make standardization of collections possible: 1) data capture and uncurated backlogs; 2) type organization; 3) secondary type designations; and 4) preventative conservation practices. A comparison of collection procedures in other collection disciplines was useful in finding innovative solutions to common problems. Staff at invertebrate paleontology collections need to work together to address shared issues and look to other collection disciplines as a means to work toward standardization and bridge the gaps between the disciplines.

Introduction

Natural history museums are one of the most important resources available to paleontologists. They have inspired generations of children to become paleontologists, and serve as vast repositories of data on invertebrate fossils, including potential data for future paleontologic studies (Briggs 2000; Erwin 2000; Lieberman and Kaesler 2000). IP collections, however, like other resources, have unique challenges. Many have poor or incomplete geographic or stratigraphic data, which limits their usefulness for paleontologic studies involving biostratigraphic and evolutionary studies. Based on this, some paleontologists have suggested that museum collections are not useful in addressing current interests in paleontology, such as the patterns of biodiversity through time. Others, however, have shown that despite their unique challenges, museum collections still remain a valuable resource and provide a wealth of knowledge about the patterns of biodiversity through time (Allmon and Poulton 2000; Cundiff and Kaesler 2000; Lieberman and Kaesler 2000; Allmon 2005). Collections are essential for research in all areas of paleontology and the main goal of the staff is to provide the physical documentation of paleontological research by making available, through curation, representative samples of and information about every taxon in the history of life (Allmon 2000). How paleontology collections are curated affects their use and importance to the paleontological community. Research is greatly enhanced by having well-curated specimens fully documented in a retrievable database (Lieberman and Kaesler 2000).

Because much of invertebrate paleontology research is based on collections, it seems practical that collection staff would document the procedures they follow for management and curation. The earliest guidelines for the management of collections were published by Dr. G. Brown Goode, Assistant Secretary of the Smithsonian Institution in charge of the US National Museum, in *The Principles of Museum*

Administration (Goode 1895). These were not specific to paleontological or geological collections, but applied to museums as a whole, covering the essential guidelines for proper collection management (Bassett 1979a). The first geological-specific guidelines were published in 1941 in *Geology in the Museum* (North et al. 1941), the first survey on the status of invertebrate paleontology collections was reported in 1977 in *Fossil Invertebrates—Collections in North American Repositories 1976* (Glenister et al. 1977), and the first paleontological-specific guidelines were published in 1979 in *Curation of Palaeontological Collections* (Bassett 1979b). Since the early 1980s, the following publications have discussed guidelines for management and curation of geological and paleontological collections:

1) Brunton et al. (1985), *Guidelines for the Curation of Geological Material*;
2) Knell and Taylor (1989), *Geology and the Local Museum: Making the Most of Your Geological Collection*;
3) Collier et al. (1990), *Procedures for Recording Specimen-Related Data*;
4) National Park Service (NPS) (1990), *Museum Handbook, Part I, Museum Collections, Appendix U: Guidelines for Curatorial Care of Paleontological and Geological Collections*;
5) Howie (1992), *The Care and Conservation of Geological Materials; Minerals, Rocks, Meteorites and Lunar Finds*;
6) Collins (1995), *The Care and Conservation of Palaeontological Material*; and
7) White and Allmon, eds. (2000), *Guidelines for the Management and Curation of Invertebrate Fossil Collections*.

The most recent guidelines (White and Allmon 2000) were the result of a National Science Foundation (NSF) funded workshop held on 7–14 June 1996 in Washington, DC. The main objectives of this workshop were to gather quantitative data on the size and status of North American invertebrate paleontology collections, to develop common standards and definitions for collection acquisition, management and curation, and to discuss the problems of computerizing and databasing collections. The resulting published guidelines were intended as the first step toward establishing standards for invertebrate paleontology collections and for the establishment of best practice procedures.

Although guidelines for curation and care of collections are in place, there has not been a consensus as to which should be the standard to follow. The reasons that standards should be set for the management and curation of invertebrate paleontology collections are as follows:

1) Standard procedures are reliable methods that should work well for collections, regardless of size;
2) Standard terminology leads to consistent records that will give reliable information when needed (Holm 1998);
3) Standards should be the benchmark for the appropriate use of the collection, and, when followed, are good indicators of performance (Stanley 2004);
4) Standards give curators and collection staff a tool with which to state a case for making more resources available for the curation of the collection;
5) In cases where nonpaleontologists are responsible for curating the collections, standards provide an authoritative introduction to the special needs of the collection and resources for further guidance (Stanley 2004);

6) When collection facilities are being newly built or renovated, standards state the required security and environmental controls necessary;
7) When staff apply for grants, standards help grant-giving organizations judge whether a collection is likely to follow through and use the funds responsibly; and
8) Most importantly, standards insure the availability and use of collections by future generations.

Setting standards will lead to consistency in the curation, organization, and use of all invertebrate paleontology collections. Researchers familiar with one type of collection organization easily will be able to use collections across the country.

In recent years, there has been some discussion about setting standards of curation for invertebrate paleontology collections, but standards cannot be set without a clear understanding of how the current curation practices vary. From discussions with invertebrate paleontology collection managers at annual meetings (e.g., Society for the Preservation of Natural History Collections; Geological Society of America), it seems that curation practices do vary among invertebrate paleontology collections, especially regarding how collections are databased and organized. Some regular procedures seem to be followed in some collections, including the use of published guidelines or ones produced within that institution. Internally established and handed down, procedures were found to be the prominent style of guidelines in some other disciplines (Ford and Simmons 1997). With a history of published guidelines, it is interesting that a set of guidelines has not been chosen as the standard to be followed in all IP collections. Because of this, it is difficult to get a sense of where IP collection curation procedures stand and how these procedures compare across collections. The curatorial staff currently does not have the mechanism to compare their collections with others.

By surveying a representative sample of collections and developing an overall view of curation procedures in invertebrate paleontology, this research addresses the following major objectives: 1) document the current state of curation procedures in many major invertebrate paleontology collections in North America; 2) shed some light on the reasons behind the lack of an accepted standard for the management and curation of invertebrate paleontology collections; 3) look at the feasibility for standardizing curation procedures in the future, and help move collections towards a best-practice standard by defining the advantages and disadvantages; and 4) compare the curation procedures in invertebrate paleontology with procedures in other collection disciplines, as a means to find innovative solutions and bridge the gaps between the disciplines.

Research Methods and the Survey Process

A list of potential invertebrate paleontology collections to survey was compiled using various criteria. A listing of the collections (and their abbreviations) included in this study is given in Table 1. Collections were selected if they were: 1) major collections included in the 1996 survey in Allmon and White (2000; Tables 2 and 3); 2) major collections listed in the 2002 survey by the National Research Council (NRC 2002; Table 4) that were not included in the 1996 survey (i.e., PRI, VMNH); or 3) additional collections with significant holdings not included in the 1996 or 2002 surveys (i.e., SNOMNH, NYSM). Once a final list of museum collections and their contacts was determined, introductory letters were sent via email to request a museum visit or participation in an online survey (Appendix 1). Collection visits and online surveys were conducted between February 2006 and January 2007. An effort was made to visit as many of the major IP collections as

Table 1. List of museums surveyed (visits and online surveys) with abbreviations for each museum.

Abbreviation	Museum
Visits	
AMHERST	Amherst Museum of Natural History, Amherst, MA
AMNH	American Museum of Natural History, New York, NY
BMS	Buffalo Museum of Science, Buffalo, NY
FMNH	The Field Museum, Chicago, IL
MCZ	Museum of Comparative Zoology, Cambridge, MA
NMNH	National Museum of Natural History, Washington, DC
NYSM	New York State Museum, Albany, NY
PRI	Paleontological Research Institute, Ithaca, NY
RMSC	Rochester Museum and Science Center, Rochester, NY
YPM	Peabody Museum of Natural History, New Haven, CT
Online surveys	
BURKE	Burke Museum of Natural History, Seattle, WA
CMC	Cincinnati Museum Center, Cincinnati, OH
CMNH	Carnegie Museum of Natural History, Pittsburgh, PA
FLMNH	Florida Museum of Natural History, Gainesville, FL
KUMIP	University of Kansas Natural History Museum, Lawrence, KS
LACM	Natural History Museum of Los Angeles County, Los Angeles, CA
LSU	Museum of Natural Science, Louisiana State University, Baton Rouge, LA
ROM	Royal Ontario Museum, Toronto, Ontario, Canada
SNOMNH	The Sam Noble Oklahoma Museum of Natural History, Norman, OK
SUI	University of Iowa, Iowa City, IA
TMM	Texas Memorial Museum, Austin, TX
UCMP	Museum of Paleontology, Berkeley, CA
VMNH	Virginia Museum of Natural History, Martinsville, VA

possible; however, the factors in determining which collections would be visited and which would be asked to participate in an online survey included: 1) the cost of travel to the relevant museum; 2) the proximity of a collection to other collections being visited; and 3) the time needed to arrange and conduct a museum visit.

For all collection visits, meetings with curatorial staff were arranged and a tour of the collection provided. Based on the information acquired during this itinerary, a survey questionnaire was completed with the curatorial staff. Follow-up for collection visits was done via email if any information needed to be clarified. For the online survey, requests were initiated via email with further follow up upon completion to clarify the information given in the online survey.

When collection staff did not respond to a particular survey question, that collection was not removed from the calculation of percentages, thus a conservative statistic is given. This analysis was used to develop an overall view of the status of curation in invertebrate paleontology collections, look for curation consensus among IP collections, and detect areas of IP curation in need of improvement. To better assess the possibility of setting standards for invertebrate paleontology collections, further research, including what had and had not worked for other types of collections and museums, was conducted and compared to this survey analysis.

Analysis of Survey Results

To determine the current state of curation in invertebrate paleontology collections, a survey of curation procedures was conducted by visiting 10 collections and sending online

Table 2. Results of the 1996 survey of the major invertebrate fossil collections in North America (modified from Allmon and White 2000). The number of specimen lots (groupings of more than one specimen) and individual specimens are given. Museum abbreviations are given in Table 3. Two collections, ANSP and ROM, gave visit totals for 4- and 2-year periods, respectively.

	Total		Systematic		Stratigraphic		Teaching		Types		Prof. visits	Stud. visits	Loans	Out. lns.
Museum	Lots	Specimens	Lots	Specimens	Lots	Specimens	Lots	Specimens	Lots	Specimens	1991–1996	1991–1996	1991–1996	1996
AGS		300,000				300,000		50		350	UA	UA	10	30
AMNH		4,000,000		3,500,000		500,000				30,000	UA	UA	30–40	35
ANSP	108,000	1,000,000	69,000	470,000	32,000	500,000		2,000	5,100	28,000	41 (4 yr)	20 (4 yr)	12	51
BMS	30,000	120,000	29,000	119,500						500	UA	UA	5	8
BURKE		2,600,000						500		1,000	25	26	6	18
CAS		506,000		150,000	350,000	350,000		1,000		5,000	50	25	15	30
CMC	5,800	29,000	5,500	28,700						312	42	18	3	4
CMNH	92,000	530,000	46,000	300,000	40,320	230,000	88,700	500,000	54	3,277	52	11	9	26
FLMNH	190,000	1,300,000	136,800	957,000	43,700	306,000	5,700	32,000	3,800	5,000	33	117	29	66
FMNH	320,000	2,000,000	272,538	1,702,000	47,717	298,000				18,500	51	74	21	160
GSC	110,000	1,130,000			110,000	110,00				130,000	UA	UA	25	150
KUMIP		756,000		750,000				600		6,200	12	60	6	40
LACM		3,500,000				3,500,000				8,000	UA	UA	20	40
LSU	28,263	331,709	18,453	18,453	6,061	300,000				13,256	UA	UA	7	8
MCZ		1,000,000		700,000		100,000		5,000		10,000	UA	UA	10–15	50–75
NJSM	8,074	24,222			7,974	23,992				100	22	9	20	100
NMNH		31,000,000		23,700,000	7,000,000	7,000,000		1,000		300,000	UA	UA	197	UA
OSU		500,000								3,000	UA	UA	15	40
ROM	300,000	300,000								8,000	45 (2 yr)	9 (2 yr)	27	45
SUI	90,000	1,000,000		~700,000		300,000				25,000	103	14	25	50
TMM	83,000	3,800,000	4,501	20,000	83,000	3,758,000			18,000	22,000	UA	UA	10	35
UIL		125,000				120,000		1,000		5,000	UA	UA	2	20
UIN		500,000						5,000				10–20	2	10
UMMP		2,000,000		200,000		1,800,000				60,000	52	10	50	200
YPM	350,000	4,500,000	120,000	1,900,000	155,000	2,600,000	5,000	20,000		35,000	116	75	32	160

Prof. = Professional.
Stud. = Student.
Out. lns. = Outgoing Loans.
UA = Data not provided.
~ = Approximate number given.

Table 3. Institutions and their abbreviations are listed in Table 2 (modified from Allmon and White 2000).

Abbreviation	Museum
AGS	Alabama Geological Survey, Tuscaloosa, Alabama
AMNH	American Museum of Natural History, New York, New York
ANSP	Academy of Natural Sciences, Philadelphia, Pennsylvannia
BMS	Buffalo Museum of Science, Buffalo, New York
BURKE	Burke Museum of Natural History, University of Washington
CAS	California Academy of Sciences, San Francisco, California
CMC	Cincinnati Museum Center, Cinncinnati, Ohio
CMNH	Carnegie Museum of Natural History, Pittsburgh, Pennsylvania
FLMNH	Florida Museum of Natural History, University of Florida
FMNH	Field Museum of Natural History, Chicago, Illinois
GSC	Geological Survey of Canada, Ottawa, Canada
KUMIP	Museum of Invertebrate Paleontology, University of Kansas
LACM	Natural History Museum of Los Angeles County, Los Angeles, California
LSU	Museum of Natural Science, Lousiana State University
MCZ	Museum of Comparative Zoology, Harvard University
NJSM	New Jersey State Museum, Trenton, New Jersey
NMNH	National Museum of Natural History, Smithsonian Instituition
OSU	Department of Geology, Ohio State University
ROM	Royal Ontario Museum, Toronto, Ontario
SUI	Department of Geoscience, University of Iowa
TMM	Texas Memorial Museum, University of Texas
UIL	Department of Geology, University of Illinois
UIN	Department of Geology, University of Indiana
UMMP	Museum of Paleontology, University of Michigan
YPM	Peabody Museum of Natural History, Yale University

survey requests to staff at an additional 13 collections. The collections surveyed show a representative sample of invertebrate paleontology collections as a whole. The objective of this survey was to develop an understanding of the effective models of curation in invertebrate paleontology collections and determine the feasibility of setting standards for such collections in the future.

Due to the cost limitations of collection visits, there is a bias toward collections located in the Northeast; however, the online surveys help to overcome that bias by including collections from across the United States and Canada. Results of surveys completed from 10 collection visits and the 13 online survey requests were combined and their findings presented together.

The results in this analysis can be divided into six areas of the collection management process: 1) general collection information; 2) processing of specimens; 3) storage of main collection; 4) conservation of specimens; 5) access and use of collections; and 6) preparation of specimens. The results from each of these areas of curation will be presented independently.

General Collection Information

Holdings and staff.—The holdings of the 23 collections surveyed ranged from 10,000 to 42 million specimens (Table 5). In comparing the size of collections included in both 1996 and 2002 surveys with this survey, the numbers vary little in the holdings. Overall, the total number of specimens has increased slightly, with the most noticeable increase

Table 4. The 17 largest fossil collections in the USA (modified from NRC 2002). Table arranged in descending order of the holdings of each respective collection.

Abbreviation	Museum	Holdings (million specimens)
NMNH	National Museum of Natural History, Washington, DC	31
VMNH	Virginia Museum of Natural History, Martinsville, Virginia	10
UCMP	University of California Museum of Paleontology, Berkeley, California	5
YPM	Peabody Museum of Natural History, Yale University, New Haven, Connecticut	4.5
AMNH	American Museum of Natural History, New York, New York	4
TMM	Texas Memorial Museum, University of Texas, Austin, Texas	3.8
LACM	Los Angeles County Museum of Natural History, Los Angeles, California	3.5
PRI	Paleontological Research Intsitution, Ithaca, New York	3
FLMNH	Florida Museum of Natural History, University of Florida, Gainesville, Florida	2.6
BURKE	Burke Museum of Natural History, University of Washington, Seattle, Washington	2
UMMP	University of Michigan Museum of Paleontology, Ann Arbor, Michigan	2
FMNH	Field Museum of Natural History, Chicago, Illinois	1.3
USGS	U.S. Geological Survey Paleontological Collection, Lakewood, Colorado	1.2
ANSP	Academy of Natural Sciences, Philadelphia, Pennsylvania	1
MCZ	Museum of Comparative Zoology, Harvard University, Cambridge, Massachusetts	1
SUI	University of Iowa Paleontological Collection, Iowa City, Iowa	1
KUMIP	University of Kansas Paleontological Collection, Lawrence, Kansas	0.8

being the number of type specimens listed. For several collections (e.g., AMNH, FLMNH, LACM), there is a more precise count of type specimens than there was in 1996. This likely is due to the increase in databasing initiatives in museums and more funding for the rehousing and databasing provided in recent years by the NSF. Two collections that have benefited greatly from this type of funding are the MCZ and PRI; both have rehoused and databased their type collections.

An average of approximately 20 professionals and 14 students visit collections each year, and the average number of loans per year was approximately 30 (Table 6). The overall use of collections (i.e., the number of visitors and loans per year) has remained close to the results in the 1996 survey, with slight increases in the number of student visitors and loans. It is difficult to precisely assess the number of visitors and loans because these numbers can vary greatly from year to year (results presented are based on numbers for 2006 to 2007).

The category and number of staff working in each collection was compared across collections. The staff categories include curators (the primary in-house researchers), collection managers or curatorial associates (day-to-day managers of the collection), curatorial assistants, student assistants, volunteers, and other curatorial staff. With the exception of the NMNH, which has a staff consisting of a collection manager, 10 collection manager staff, and 40–50 volunteers to care for its 42 million specimens, most collections average one to three full-time staff who are responsible for the curation and management of the collection (Table 7). Many collections rely heavily on student assistants and volunteers to complete the huge tasks of organizing, rehousing, and databasing the collection.

Table 5. Results for collection size for each of the 23 collections surveyed. The estimated number of specimen lots (groupings of more than one specimen) and number of individual specimens are given. Empty fields represent areas where it is unclear if it indicates absence of specimens or no data were provided. Museum abbreviations are defined in Table 1.

	Total		Systematic		Stratigraphic		Teaching		Types	
Museum	Lots	Specimens	Lots	Specimens	Lots	Specimens	Lots	Specimens	Lots	Specimens
AMHERST		12,000								8
AMNH		4,500,000		719,000		1,500,000				24,387
BMS	27,571									500
BURKE		2,750,000				2,750,000		300		550
CMC		500,000		60,000		2,500		500		3,000
CMNH		800,000		750,000		50,000		5,000		12,100
FLMNH		4,300,000		1,040,142		383,387		28,320		3,971
FMNH		2,000,000								18,500
KUMIP		850,000								6,500
LACM		3,500,000		11,000		3,500,000				10,444
LSU	26,426		21,694			4,732				2,945
MCZ		1,065,554		1,004,104		61,450				13,000
NMNH		42,000,000		423,750						
NYSM		1,000,000						200		17,000
PRI		2,500,000								13,000
RMSC		10,000								100
ROM		200,000								9,300
SNOMNH		800,000								9,000
SUI		>1,000,000		1,000,000		50,000		1000		25,000
TMM		4,000,000		50,000		3,500,000		50,000		20,000
UCMP		2 to 4,000,000		50,000		1.5 to 3,500,000		1000		11,882
VMNH		5,000,000		5,000		5,000,000		1,000		10
YPM		4,000,000		1,600,000		2,400,000		1,600,000		35,000

Table 6. Number of visitors and number of loans per year for each of the 23 collections surveyed.

Museum	Professional visits per year	Student visits per year	Loans per year
AMHERST	5	3	4
AMNH	7–8	6–7	13–17
BMS	7	3	15–20
BURKE	18	400	10
CMC	10	10	7
CMNH	45	2000	225
FLMNH	32	64	28
FMNH	10	10	20
KUMIP	7	23	5
LACM	30	20	20
LSU	1.6	1	3.5
MCZ	7	3	15–20
NMNH	100s[a]	NA	150–200
NYSM	10–15	10	10–15
PRI	12[a]	NA	17
RMSC	—[b]	—	—
ROM	10	6	15–20
SNOMNH	10	6	34
SUI	14	3	10
TMM	79	106	38
UCMP	12	4	18
VMNH	10	25	5
YPM	23	31	36

[a] Visitor data not separated into refined categories.
[b] Information not provided.
NA = Category not applicable.

Guidelines for curation and management.—An important part of this survey was to determine what guidelines, if any, are being used for the curation and management of IP collections. Figure 1 shows the overall responses by the available guideline(s) used. In total, staff of 12 collections (52%) use the guidelines given in White and Allmon (2000). Of those, staff of five collections use the guidelines in White and Allmon, but in conjunction with the guidelines given by Collier et al. (1990), Collins (1995), Society for the Preservation of Natural History Collections (SPNHC 1994), or National Park Service (NPS 1990). In seven collections (30%), staff use either their own departmental or institution's guidelines; in two collections (9%) staff use no guidelines; and in two collections (9%) each, staff exclusively uses the guidelines from Collins (1995) or the United States Geological Survey (US Department of the Interior 2006), respectively. For the seven collections (30%) in which their own departmental or institutional guidelines are used, it is difficult to know how these guidelines compare with any of the published guidelines. Institutional guidelines usually give a broad generalization of how specimens in all collections within a museum or institution should be curated, but it is unclear if the in-house guidelines for the seven collections were formulated from published information. Regardless of the type of guidelines utilized, they are documented in a curation procedures manual for 14 (61%) collections.

Historic collections and major taxonomic groups represented.—These data will be provided to The Paleontological Society Collections Committee, who has expressed an interest in facilitating the availability to its members. One objective of this project was to survey historic paleontology collections and provide information on their location and

Table 7. Number of curatorial staff for each INVERTEBRATE PALEONTOLOGY collection surveyed. Numbers are expressed in Full Time Equivalents (FTEs). Museum abbreviations are given in Table 1.

Museum	Curators	Collection manager/ Curatorial associate	Curatorial assistants	Student assistants	Volunteers	Other
AMHERST	0	1	0	0	0	1 Director, 1 Education Coordinator
AMNH	2	1	0	3	13	4 Research Associates, 1 Preparator
BMS	1	0	1	0	10	
BURKE	2	1	0	1	8	
CMC	1	0	0	7	6	
CMNH	0	1	0	0	8	6 Research Associates
FLMNH	1	1	2	2	12	
FMNH	2	1	0	0	2	
KUMIP	1	1	1	2	0	
LACM	0	1	0	0	1	2 Research Associates
LSU	2	1	0	0.5	1	
MCZ	1	1	1	2	0	
NMNH	12	1 CM, 10 CM Staff	11	0	40–50	1 Illustrator, 1 Volunteer Coordinator
NYSM	1	1	1	1	2	
PRI	1	1	0	0.5	3	1.5 NSF-funded staff for databasing
RMSC	1	0	0	0	0	
ROM	4	0	0	2	0	3 Technicians
SNOMNH	1	1	0	3	6	
SUI	0	1	0	3	0	4 Faculty
TMM	0.5	0.5	0	2	10	
UCMP	3	2	0	2	0	
VMNH	8	2	2	2	3	
YPM	1	1	1	0	3	1 Postdoc

CM = Collection Manager.

status (Appendix 2). Historically, large collections were divided into smaller collections and sent to many different museums. As a result, paleontologists spend a great deal of time tracking down type specimens or specific collections that are important to their research. Information on the availability of historic collections will give researchers the opportunity to locate and examine all relevant material for their studies. This resource also will give IP curatorial staff a means to compare and seek additional data on their own collection and communicate with colleagues who care for similar collections.

During this survey project, I found that the James Hall collection, a collection of fossil invertebrates acquired during Hall's employment as State Geologist and State Paleontologist of New York, is reposited in at least four different museums. Namely, the AMNH holds the type material from the Hall collection, whereas the FMNH, MCZ, and NYSM all have portions of the nontype material. In addition, during my visit to the NYSM I found significant holdings of the W. D. Gebhard Collection, a collection of fossil invertebrates from the Silurian and Devonian of New York State. The MCZ also has part of the Gebhard collection, but neither institution was aware that other portions of the collection existed. Immediately after this discovery, information was exchanged on

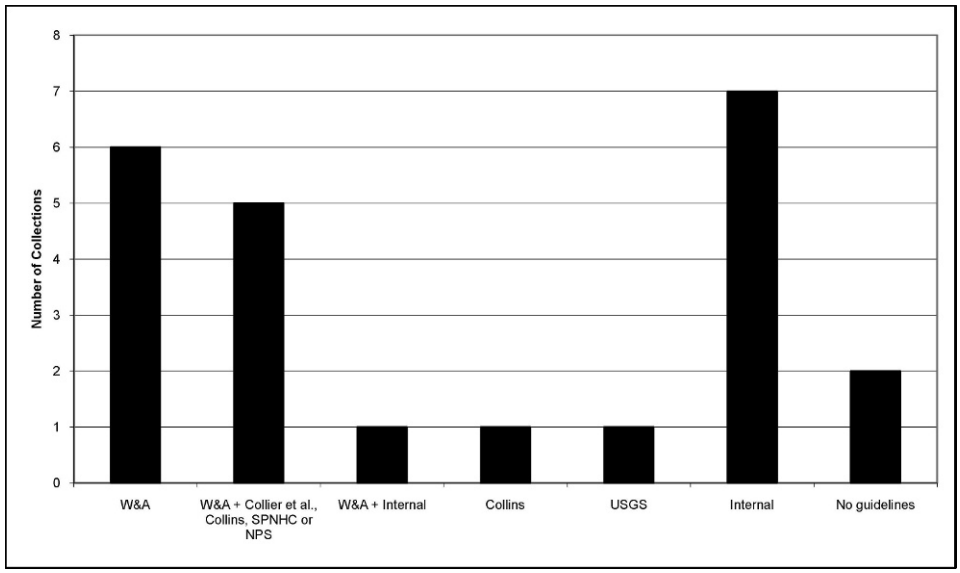

Figure 1. Type of guidelines used for the curation and management of the 23 collections surveyed. The graph represents the overall responses vs. the available guidelines used. Notations are as follows: W&A = White and Allmon (2000); Collier et al. = Collier et al. (1990); Collins = Collins (1995); SPNHC = Society for the Preservation of Natural History Collections (SPNHC 1994); NPS = National Park Service (NPS 1990); USGS = United States Geological Survey (US Department of the Interior 2006); and Internal = individual or institutional guidelines.

the holdings at both institutions, which exemplifies the importance of the information to each collection. Due to the difficulty of obtaining permits and costs of collecting, historic collections are becoming crucial for research. Information on the location and status of these historic paleontology collections most likely will spark renewed interest in their importance and use.

Data on the strengths in taxonomic group(s) indicates the overall holdings of each IP collection surveyed and specifies what makes these collections important (Appendix 3). This is useful to paleontologists because it gives them information on where the significant collections of certain taxonomic groups are located. For example, a researcher working with brachiopods will know that the larger NMNH and YPM have holdings, but also will know to contact staff of smaller collections such as the CMC and CMNH.

Processing of Specimens

This area of curation can be divided into the fundamental processes of acquisition and accession, handling of type material, taxonomic identification and updates, labeling, archiving collection documents, and data capture. This information gets to the heart of the curation procedures of a collection.

Acquisition and accession.—The acquisition (specimens acquired and transferred to a museum) and accession (legally accepting and recording a specimen as a collection item) procedures are the integral legal steps for the institution as a whole. These steps assure that all international, federal, state, and local laws and regulations have been followed, and the museum can accept the material without problems. The remaining specimen curation by the IP collection process should begin only after these essential steps are completed.

Table 8. Types of specimen acquisition utilized by the invertebrate paleontology collection surveyed.

Museum	Field collecting	Gifts and/or donations	Purchased	Graduate student and/or curator collection	Other museums and institutions
AMHERST	X	X	X	—	X
AMNH	X	X	X	X	—
BMS	X	X	—	—	—
BURKE	X	X	—	X	—
CMC	—	X	—	—	X
CMNH	X	X	X	X	X
FLMNH	X	X	—	—	—
FMNH	—	—	—	X	X
KUMIP	X	X	—	X	X
LACM	—	X	—	—	X
LSU	X	X	—	X	—
MCZ	X	—	X	—	—
NMNH	X	X	X	X	X
NYSM	X	X	—	X	X
PRI	X	X	X	X	X
RMSC	—	X	—	—	—
ROM	X	X	X	X	X
SNOMNH	X	—	—	X	X
SUI	X	X	—	X	—
TMM	X	—	—	X	X
UCMP	X	—	—	X	X
VMNH	X	—	—	—	X
YPM	X	X	X	X	—

X = Acquisition method used.
— = Acquisition method not used.

Among the collections' staffs surveyed, specimen material was acquired from field collecting, gifts and donations, purchases, material acquired for in-house research (e.g., graduate student and curator collections), or from other museums and institutions (Table 8). Most respondents reported two or more of these means of acquisition, indicated that historically, specimens have been acquired from numerous sources.

The majority of the respondents surveyed (78%) have a formal accession process to fully document material coming into the collection. Many respondents (70%) indicated that they require a Deed of Transfer or Deed of Gift form be filled out to transfer ownership of the specimens. In addition, further documentation, including permits, is required, showing that the specimens were legally collected. Collection representatives were not asked specifically about their procedure for acceptance of tax deductible donations of specimens, but four indicated that they require additional Gift-in-Kind paperwork as part of accepting tax deductible donations. Because of the legal liabilities, approval by the departmental or divisional chair and/or the museum director before the accession process is complete often is required.

Handling of type material.—The process of cataloging type material is the same as it is for the main collection, including labeling and numbering, taxonomic identification, organizing, and data capture (for most collections, data capture involves entering specimen information into a database system). Type material is handled separately because these are the specimens that are designated as the name bearer for a specific scientific name published in the scientific literature. This material can be a single specimen or series of specimens upon which a taxonomic species is based.

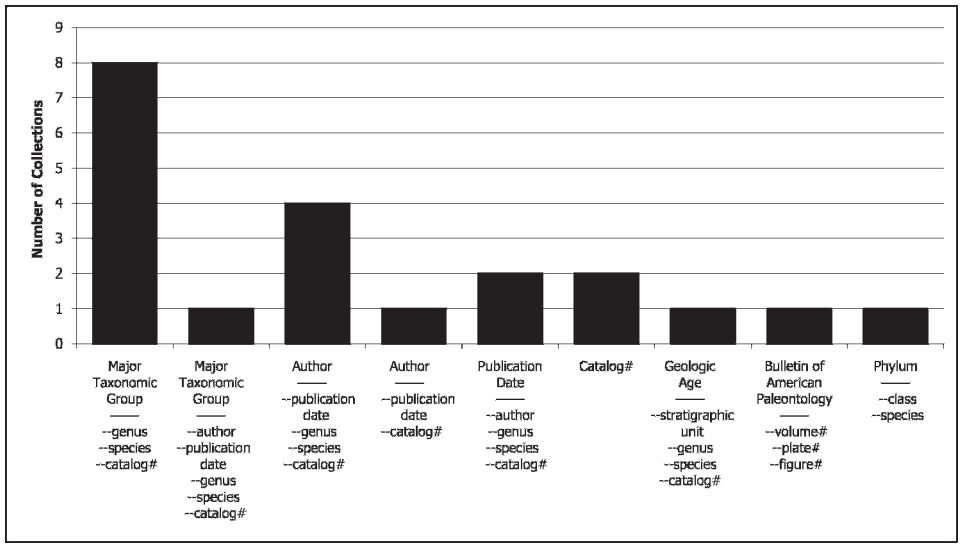

Figure 2. The arrangement of type material used by each of the 23 collections surveyed, if primary and/or secondary types are kept separate from the general collection. The graph represents the overall response vs. the type of arrangement used. Figure is arranged in descending order of the primary type of arrangement used. "—" indicates the subsequent heirarchy of arrangements within the primary arrangement.

Primary types.—These are specific specimens upon which the description of a new species is based (i.e., holotype, paratype, lectotype, and neotype; Frizzell 1933). In the majority of collections (83%), types are cataloged and databased with the proper reference information, including publication and taxonomic history. In only 13% of collections, their type collections have not been databased. In most collections (91%), primary types are stored in a separate area; locked cabinets are used in one collection. In the remaining collections (9%), primary types are stored in the general collection.

The organization of type material in the 23 collections surveyed varied more than expected. White (2000) stated that most IP collections organize their type material either taxonomically or by author and date of publication, but in some collections, type material is dispersed throughout the general collection. This survey found several additional methods of type organization, including organization by geologic age, journal, catalog number, and only the publication date. Only 39% of respondents report that they arrange their type collection by major taxonomic group (Fig. 2) if primary and/or secondary types were stored separately from the general collection. The majority of the remaining collections (30%) have types arranged by author or publication date, two collections (9%) have types arranged by catalog number, and one collection each has types arranged by geologic age, phylum, or specific journal. The one collection, PRI, which has types arranged by a specific journal, does so because all type specimen descriptions are published in its own journal, the Bulletin of American Paleontology. In two collections (9%), the type collections are small enough to fit into one drawer or cabinet and do not require further arrangement.

Secondary types.—These are referred, measured, or figured specimen in the original description that are not the primary type (Cato et al. 2003). Because most collections (91%) have primary types stored in a separate area, representatives were asked how they store their secondary types. In 19 collections (83%), secondary types are stored with

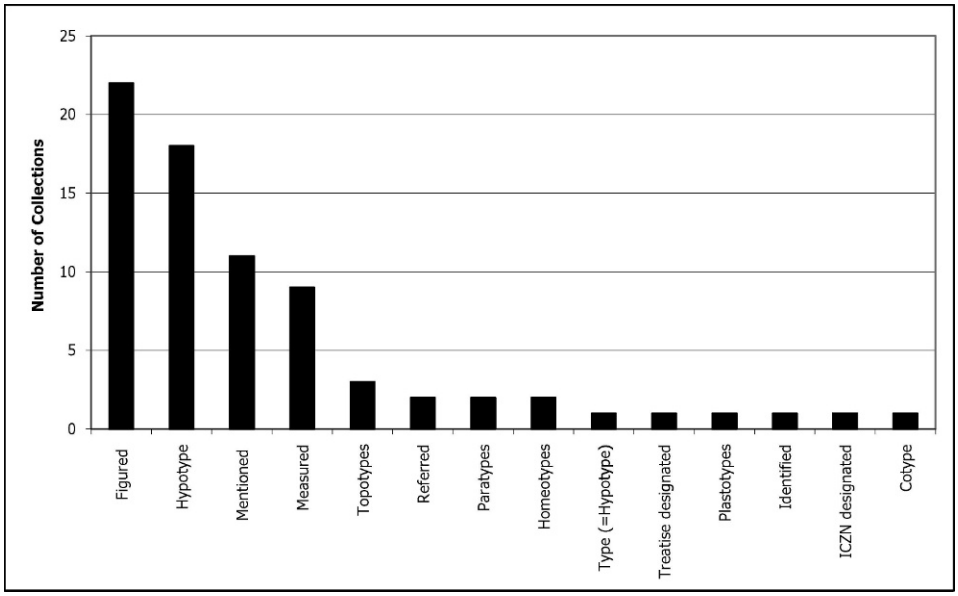

Figure 3. "Secondary" type designations used in the 23 collections surveyed. The graph represents the overall responses vs. the specific designation used and are arranged in descending order of the designation used. Although these designations are called "secondary types" by the relevant collection, only paratype and cotype are recognized by ICZN.

primary types; in three (13%), secondary types are stored in the general collection; and in one collection secondary types are stored separate from primary types and the general collection. The following names can be used for secondary type material: hypotype, figured, mentioned, measured, referred, identified, cotype, paratype, plastotype, homeotype, and type (= hypotype) (Fig. 3). All of this terminology is confusing because paratype and cotype are the only terms with any standing in the International Commission on Zoological Nomenclature (ICZN).

Taxonomic identifications and updates.—Collection representatives were asked when the taxonomic identifications and/or stratigraphic data were last updated for any part of the collection. Eight (35%) stated that updates to specimen and locality data are ongoing, six (26%) have had updates within the last year, four (17%) have not been updated in a year or more, and five gave no response to this specific question. To evaluate how the taxonomic identifications of specimens are addressed, representatives were asked if they bring in relevant researchers specifically to identify or reidentify part of the collection and update stratigraphic data. The majority (65%), indicated that they do not bring in dedicated experts, however, 11 of the respondents said they ask visiting researchers to update the identifications and stratigraphic data of the material on which they are working. In three of these collections, curators and/or the collection managers update specimen information, and staff in one collection use journals and recent publications for updates.

Bringing in experts serves as a means to address uncurated backlogs (White 2000) and move collections through the continuum of curatorial activity (Hughes et al. 2000; White 2000). Once an expert has updated specimen information, staff can easily capture this

information and add it to the collection database. IP staff at the Museum of Comparative Zoology (MCZ) and the University of Iowa (SUI), have had been successful at bringing in experts, and finance this activity from their internal budget and with NSF funding, respectively.

Labeling.—As discussed earlier, label information for the type specimens is robust (Fig. 2); labeling is an important part of the cataloging process. Specimens that are not properly numbered and labeled easily can be misplaced within the collection. To evaluate the labeling process for the collection overall, museum representatives were asked about the type of numbering system used for specimens and how they organize and store associated labels and documents. In all collections, there is some type of sequential numbering system in place with a standard collection prefix (e.g., MCZ 100000). In some collections (30%), separate prefixes for each major collection or catalog series is used. In most collections (65%), labels are stored with specimens, and associated documents in a separate file, whereas in 22% of collections, both labels and associated documents are stored with the specimens.

Archiving collection documents.—Original and supporting documentation is an essential part of any collection. Documents such as field notes, correspondence, catalogs, maps, and photographs provide information on the acquisition, provenance, and use of specimens. Archiving these documents should be part of the curation process because the information they provide is irreplaceable and enhances the collection's value. To evaluate collection archiving, collections were asked if they have a registrar or other individual who is responsible for archiving collection documents. The majority of collection respondents (52%) indicated that they have a registrar, but in all collections surveyed, it is collection staff who archive documents, with copies of some paperwork, such as loan invoices, accession forms, correspondence, field notes, and photographs that are sent to the registrar and/or institutional archives if these exist at their institution.

Data capture.—Because data capture in IP collections can be from a variety of data sources, collection representatives were asked to provide information on their initial data entry process and the data sources used for specimen and locality data. For all collections, respondents indicated that the main data sources were card catalogs, collection catalogs/ledgers, specimens and labels, literature, capture sheets or cards, and field notes. Nineteen respondents (83%) indicated that they use two or more sources for data entry.

For maximum utilization, computerization is an important part of the data capture process and, in most IP collections, staff currently are working to database their collection. To determine the status of databasing, collection representatives were asked about the type of database system they use, if they plan to upgrade to a new system within the next 5 years, and what that upgrade might be. Figure 4 shows the types of database systems and the number of collections in which each system is being used. In six collections (26%), staff members plan to upgrade to a new database system within the next 5 years. In three of these collections, data will be moved to Specify; in the remaining three collections, data will be moved to KE EMu, Mesonyx, or Arctos. In 61% of the museums or institutions surveyed, the same database system is used in all collections. For the majority of collections (57%), a standard or policy for databasing collections has been put in place by the museum staff. In 57% of the IP collections surveyed, less than 10% of their collections are databased. Respondents from five collections (22%) reported 20–40% of their databasing was complete, and in three collections (13%), 50% or more databasing has been completed.

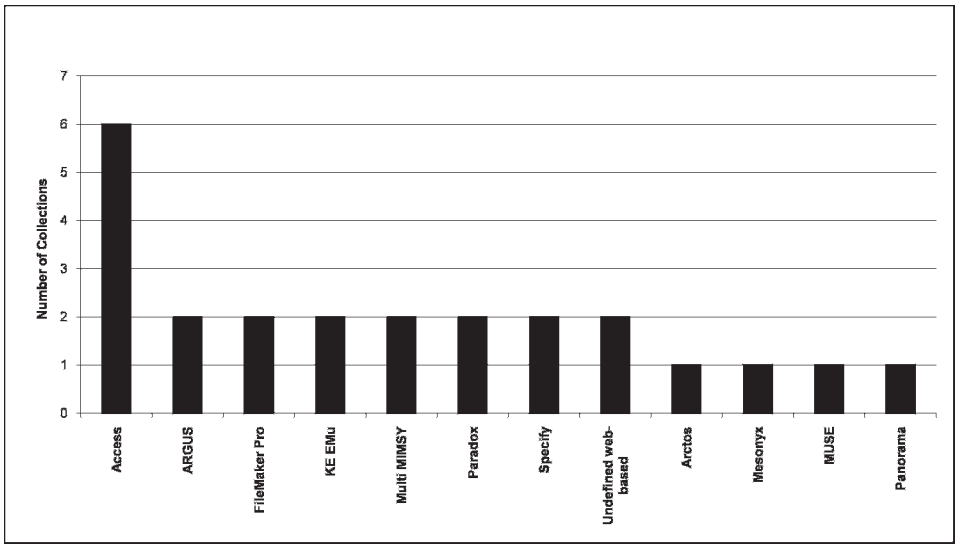

Figure 4. The database system used in each of the 23 collections surveyed. The graph represents the overall response vs. the type of database system used. Figure is arranged in descending order of the system used, and systems with equal use are arranged alphabetically.

The majority of collection representatives (74%), reported using the *Treatise on Invertebrate Paleontology* (Moore et al. 1953–2009; Paleontological Institute 1998–2005) as their main taxonomic data dictionary. The survey revealed a variety of data dictionaries or equivalent being used by IP collections, including the USGS National Geological Lexicon Database (GEOLEX: The Department of the Interior and United States Geological Survey 2007a); Geographic Names Information System (GNIS: The Department of the Interior 2007b); Gazetteers, Geological Society of America Correlation Charts (Dunbar 1964); Integrated Taxonomic Information System (ITIS 2007); Paleobiology Database (2007); Lexique Stratigraphique International (Fabre 1983); uBio (Marine Biological Laboratory 2007); taxonomic publications; recent journals and publications; and knowledge of the curator or another expert.

Storage of Main Collection

Arrangement.—The arrangement of specimens within a collection can vary depending on the level of curation of material and how the collection historically has been used. In the majority (48%) of IP collections, the arrangement of the collection is a combination of taxonomic, stratigraphic, and geologic age, resulting from the level of curation and size of uncurated backlog (Fig. 5). In many collections, separate stratigraphic collections still are maintained that might never be incorporated into the general collection, because researchers often want to easily access material from a specific age or stratigraphic unit.

If all or part of the collection was taxonomically arranged, the majority of respondents (52%) reported that they use the *Treatise on Invertebrate Paleontology* (Paleontological Institute 1998–2005) as the standard for this arrangement. In three of the collections that arrange specimens taxonomically, expert suggestion and/or current literature are used in addition to the Treatise. In two collections (9%), either current literature or other

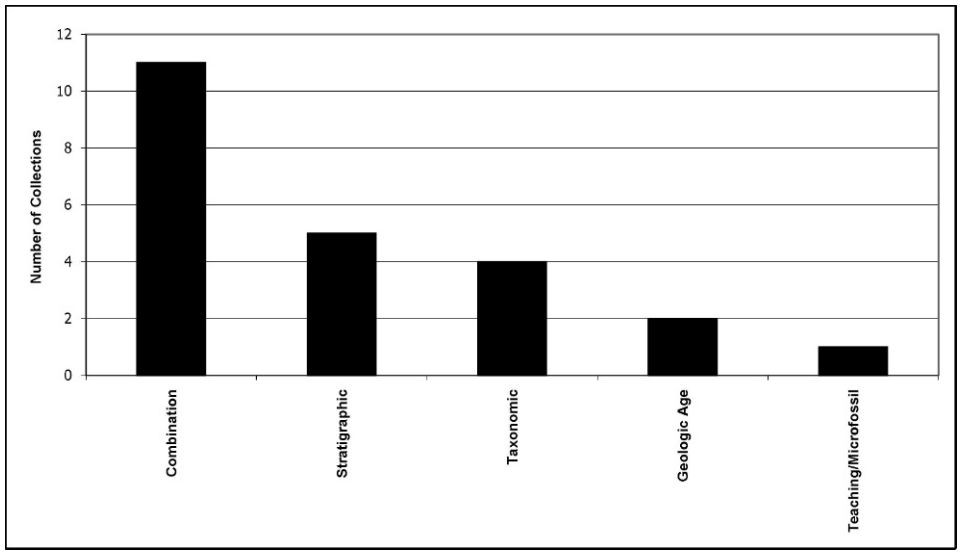

Figure 5. The arrangement of collections, specifically of nontype material, used in the 23 collections surveyed. The graph represents the overall response vs. the arrangement utilized in descending order. The arrangement noted as "Combination" indicates a combination of taxonomic, stratigraphic, and geographic arrangement.

publications are used as the main source for specimen arrangement; and in one collection, staff use their own data dictionary. Interestingly, eight collection representatives (35%) gave no response to the query of storage arrangement for taxonomic collections.

Conservation of Specimens

IP collections, because the nature of the material, have been considered to be robust and indestructible, with minimal conservation required other than repair of broken specimens (White 2000). An increasing awareness of the problems of preservation of fossils and the prevention of further deterioration increasingly has been the focus of conservation practices. To assess the status of conservation practices, representatives of each IP collection was asked for information on the adhesives and consolidants used for repair of specimens and the preventative conservation practices they follow. Three types of adhesives and consolidants for repair of specimens were reported: 1) polyvinyl butyrals (PVB), which are acetone- or ethyl alcohol-soluble and include Butvar and the similar Arcryloid B72; 2) polyvinyl acetates (PVA), which generally are water-soluble and include Elmer's glue, Vinac, and Jade R; and 3) PaleoBond, a cyanoacrylate or super glue, developed specifically for fossil specimens. Some type of PVB was used in eight collections (35%); some type of PVA was used in four collections (17%); a combination of PVB and PVA was used in three collections (13%); a combination of PVB and PaleoBond was used in three collections (13%); and all three types of adhesives and consolidants were used in one collection. No responses were received from representatives of four collections (17%).

Survey data showed good preventative conservation practices in place in a number of collections. Temperature and relative humidity are monitored in 13 collections (57%); an Integrated Pest Management (IPM) program is in place in 12 collections (52%); and pollutants are monitored in three collections (13%). In a few collections (13%), steps also have been taken to monitor for and prevent pyrite disease (oxidation of the mineral

pyrite). In three collections (13%), no preventative conservation practices are in place, probably due to the misconception that there are few conservation issues for fossils.

Access and Use of Collections

The primary purpose of IP collections is for research by and training of paleontologists and systematists. Access and use should be limited, but only to the extent to ensure the security of the collections and to protect specimens from damage or loss. To evaluate access and use, collection representatives were asked about their policies for specimen use, collection requests, and specimen retrieval.

Specimen use.—Student or thesis collections. Many museums have graduate students working in or associated with the collections who are compiling field collections for their thesis or dissertation work. To assess how this material is handled, representatives were asked about their policies for student and thesis collections. In 13 collections (57%), some type of policy is in place for collections compiled for graduate studies. Of the 13 collections that have a policy for student collections, 10 respondents indicated that students are required or expected to reposit the material collected during their studies, and in three collections, students are given the option to reposit material in the collection or keep it for their own use.

Teaching and exhibition.—It is important to have policies in place to ensure the security and conservation of specimens being used for teaching or exhibition. This was shown in the fact that in the majority of collections (65%), there are special requirements for this type of use.

Loan policies.—A loan is a temporary transfer of a specimen or lot of specimens, generally for research, for a specified period of time. All incoming and outgoing loans should be documented with a clear understanding of the loan agreement. To evaluate the accessibility of loan policies, collection representatives were asked if their loan policy was available online. In seven collections (30%), a loan policy is posted online, but in the remaining 16 collections either the policy is not posted online or they do not have a written policy. Loan policies were not evaluated specifically because of a lack of written policies for some collections and reluctance of other respondents to give out copies if their policies were not available online.

Destructive sampling.—Destructive sampling usually is a technical analysis that involves the selection and removal of a specimen from a lot, or a portion of a single specimen, for invasive study (Cato et al. 2003). In IP collections, certain taxa, especially if members are small, cannot be studied without some form of preparation or sampling that is potentially somewhat destructive. For example, some groups, such as bryozoa, corals, and sponges must be sawed then polished, or thin sectioned, for proper identification and study. Care must be taken to ensure that well-preserved specimens are not destroyed and sampling should only be allowed when the potential knowledge gained outweighs the sacrifice of the specimens (Cato 1993). In 19 collections (83%), destructive sampling of specimens is allowed; in three collections (13%), it is not allowed; and representatives from one collection did not respond to the question.

Of the 19 respondents who indicate that destructive sampling is allowed, eight do not allow destructive sampling of type material, rare or unique specimens, or specimens that are limited in number. In six of the 19 collections, destructive sampling is allowed on a case-by-case basis; in three collections, prior permission is required; and in one collection only stratigraphic collections may be sampled. All products, data, and any resulting publications must be returned to sixteen of the 19 collections; in one collection only thin

sections are required to be returned; and in another, materials are required to be returned on a case-by-case basis.

Specimen requests.—Photographic requests. Researchers, visiting or not, often request photographs of specimens for comparative purposes and/or if they plan to describe and publish on specific specimens in the collection. Permission to photograph and replicate specimens must be documented and conditions (e.g., copyright permissions) must be specified to ensure that the photograph or replica will be used in the legal and proper manner. In 19 collections (83%), photographic requests are accepted, but in three collections (13%), such requests are not accepted. In 21 collections (91%), visitors are allowed to take photographs, but in one collection, this is not allowed. In nine collections (39%), staff require permission forms for photographic requests, whether photographs are taken by the institution or visitor. Staff at 10 collections (43%), charge a fee for commercial use of photographs, including those at nine collections who require permission forms. Respondents from six collections (26%) indicate that the museum or institution must be credited as the source in the photograph caption.

Specimen and locality data requests.—Outside researchers often request specimen and locality data. Generally, specimen information for researchers is provided and not censored in any way. In 21 collections (91%), specimen and/or locality data requests are accepted; in one collection, neither is accepted; and there was no response from one collection representative. There is an ethical obligation by collection staff to ensure that sensitive information, such as detailed locality information, is not released to the general public or commercial fossil collectors (Simmons 2006). Data for commercial or public use is limited from 15 collections (65%); these data are limited on a case-by-base basis in four collections (17%); in two collections (9%), these data are not limited anytime; and there was no response from representatives of two collections (9%).

Specimen retrieval.—Being able to retrieve specimens from the collection is an essential part of the curation and management of collections. Databasing of collections has helped make specimen retrieval a more efficient process by allowing data on a specimen's location within the collection to be captured. To evaluate the specimen-retrieval process, collection staff were asked what process or finding guide they use. Fourteen collection respondents (61%) report that they have both electronic (e.g., database search, interactive maps) and hard copy (e.g., lists, floor plans, maps) guides that are used for specimen retrieval. In three collections (13%), only an electronic guide is available; in two collections (9%), only a hard-copy guide is available; and in two collections (9%), staff rely on memory or the organization of the collection.

Preparation of Specimens

Having the proper lab facilities to prepare and study specimens is an important part of IP collection management. Table 9 lists the lab facilities that each collection has available in their department or institution. Nearly all collections (91%) have facilities for digital photography, which is important as the requests for digital images increases. In many cases, researchers can compare and identify a specimen from a series of high-resolution images showing the various orientations of the specimen. The majority of collections (85%) also have proper facilities and equipment for the preparation of various types of specimens that assist research (e.g., fume hood for acid prep; cutting, polishing and thin sectioning equipment; vibro and air abrasion equipment for fine prep work).

Table 9. Laboratory and preparation facilities available to the 23 surveyed collections. Abbreviations for the type of facility or equipment are given in order of the category. Museum abbreviations are given in Table 1.

Museum	DP	DR	D X-ray	X-ray	FH	Vibro	AA	C/P	TS	SEM	CL	GIS	MCE	Micro	WS	CT
AMHERST	X	—	—	—	X	X	—	X	X	—	—	—	—	—	—	—
AMNH	X	X	—	X	X	X	X	X	X	—	—	—	X	—	—	—
BMS	X	—	—	—	X	X	—	X	X	—	—	—	—	—	—	—
BURKE	X	—	—	—	X	X	X	X	X	—	—	—	—	—	—	—
CMC	X	—	—	—	X	X	X	—	—	—	—	—	—	—	—	—
CMNH	X	—	—	—	—	X	X	X	X	—	—	—	—	—	—	—
FLMNH	X	X	X	X	X	X	X	X	X	—	—	—	—	—	—	—
FMNH	—	—	—	—	X	X	—	X	X	—	—	—	—	—	—	—
KUMIP	X	—	—	—	X	X	X	X	X	X	—	—	—	X	X	—
LACM	X	X	—	—	—	X	—	X	X	—	—	—	—	—	—	—
LSU	X	—	—	—	X	X	—	X	X	—	—	—	—	X	X	—
MCZ	X	—	X	—	X	X	X	—	—	—	—	—	—	—	—	—
NMNH	X	X	—	X	X	X	X	X	X	X	—	—	—	—	—	X
NYSM	X	—	—	—	X	X	—	X	X	—	X	—	—	—	—	—
PRI	X	—	—	—	X	X	X	X	X	—	—	—	—	—	—	—
RMSC	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
ROM	X	—	—	X	X	X	X	—	X	—	—	—	—	—	—	—
SNOMNH	X	—	—	—	X	X	X	X	X	X	—	X	—	—	—	—
SUI	X	X	—	—	X	X	X	X	X	—	—	—	—	—	—	—
TMM	X	—	X	X	X	X	X	X	X	—	—	—	—	—	—	—
UCMP	X	—	—	—	X	X	X	X	X	—	—	—	—	—	—	—
VMNH	X	—	—	—	—	—	X	X	X	X	—	—	—	—	—	—
YPM	X	—	—	—	X	X	—	X	X	X	—	—	—	—	—	—

DP = Digital Photography.
DR = Dark Room.
D X-ray = Digital X-ray.
X-ray = X-ray machine.
FH = Fume Hood.
Vibro = Vibro Tools.
AA = Air Abrasion.
C/P = Cutting and Polishing.
TS = Thin Sectioning.
SEM = Scanning Electron Microscope.
CL = Conservation Lab.
GIS = Geographic Information System.
MCE = Molding, Casting, and Etching.
Micro = Microscopes.
WS = Wet Sieving.
CT = CT Scan.
X = Available facility.
— = Information not provided.

Discussion and Conclusions

A major goal of this project was to elucidate the current state of curation procedures in major invertebrate paleontology collections in North America to educate and inform the museum and paleontological communities. It also is hoped that it will stimulate discussions about the standardization of curation procedures and the future of invertebrate paleontology collections. This survey revealed four major issues with curation procedures in invertebrate paleontology that need to be addressed because they also affect discussions about standardization: 1) data capture and uncurated backlogs; 2) type organization; 3) secondary type designations; and 4) preventative conservation practices.

Data capture and uncurated backlogs.—The staff of 23 IP collections surveyed use 12 different database systems, with the largest number of collections using Microsoft Access. All of the database systems used vary widely, but this is not a critical issue as long as data can be imported/exported easily and efficiently, especially when shared by means of online searches (e.g., Paleontology Portal, Global Biodiversity Information Facility [GBIF]) and integrated with other initiatives (e.g., Paleobiology Database). Allmon (2000) noted that IP collections are one of the largest but least databased natural history collections, with only about 8% of collections in the USA being completely databased and none of the major collections having more than 30% of their collection databased. As this survey illustrates, IP collections still are still behind in data capture, but initiatives are increasing. For example, the majority of the surveyed collections (57%) have less than 10% of their collection databased and only a few (13%) have 50% or more. Most collections (83%), however, do have their type collections databased. To facilitate research and promote collaborative use of collections, a major goal for museums should be to further increase the databasing of their collections.

Another issue related to the availability of IP collections is the uncurated backlogs. White (2000) discusses the perception that IP collections have large uncurated backlogs and these collections, along with the data they hold, are in danger of deterioration due to custodial neglect. The level of curation needed for IP specimens differs significantly from other biological specimens because IP specimens are far more durable and require less immediate attention. Although it is true that some IP collections (i.e., field, stratigraphic) can be maintained with minimal effort and at a lower level of curation (Hughes et al. 2000), backlogs still exist for other collections (i.e., systematic), and curatorial staff need to address these backlogs to make collections more accessible.

Uncurated backlogs can be defined as: 1) unsorted material, such as field collections that were collected, possibly decades ago, and never unpacked; 2) uncataloged material; 3) unidentified material or material with outdated taxonomic names that could be updated with the proper expertise; 4) material with incomplete locality or stratigraphic data that could be updated with the proper expertise; and 5) cataloged material not registered in a manner promoting accessibility (i.e., databased).

To address uncurated backlogs, IP collections need the proper resources (i.e., expertise to update specimen data, money, staff time) to initiate and complete such a project. Staff for two collections (MCZ and SUI) obtain funding to bring in experts to update specimen data and help defray their uncurated backlog. Not all collections, however, have funding readily available, especially small collections with limited resources. IP collection staff need to find innovative ways to address these historical problems, including looking outside the discipline to other natural history collections. Herbarium staff, for example, have begun an initiative to address uncurated backlogs and capture data for all specimens in US herbaria by 2020 (Rabeler and Macklin 2006). The key elements for success in this initiative are to: 1) develop a set of community standards, including a standard mechanism for exchanging data between collections and developing community-wide authority files; 2) share data entry across the community, focusing on eliminating multiple entries for the same data and sharing the georeferencing burden; and 3) increase data capture rates with a focus on maximizing efficiency and minimizing costs.

A similar initiative could be applied to IP collections, because both collections have many of the same issues when it comes to capturing specimen data. These issues include: a number of duplicate specimens and localities; a large number of specimens to georeference; slow rates of specimen data capture; and limited resources.

Table 10. McGinley's curation status levels (modified from McGinley 1989). The table indicates the level of curation of a given collection, including its conservation and curation status.

Level	Description
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 inventory complete.
8	Physical curation complete, individual specimen label data captured.
9	Physical curation complete, specimen label data captured, research data captured.

The first major step in considering an initiative of this nature will be to determine the curation status, size and type of uncurated backlogs in IP collections. Adrain et al. (2005, 2006) provided a model approach with a collection survey based on the McGinley Levels (McGinley 1989, 1992; Table 10) and the Curatorial Continuum (Hughes et al. 2000; White 2000; Table 11). These methods help to evaluate a collection, assess the curation status, and prioritize curatorial tasks to attain a desired curation standard. Although the McGinley Levels were originally developed for entomology collections, they have been successfully adapted to other natural history collections (Huxley 1994; Williams et al. 1996; White 1998; Lieberman and Kaesler 2000). For IP collections specifically, Adrain et al. (2005, 2006) found the McGinley method to be a useful tool in tackling uncurated backlogs when applied to the collection at the University of Iowa and a portion of the collection at the Natural History Museum, London. Staff at three of the IP collections included in this

Table 11. The continuum of curatorial activity for Invertebrate Paleontology collections (modified from Hughes et al. 2000; White 2000).

Grade 1	Grade 2	Grade 3	Grade 4	Grade 5
Acquired. Accessioned.	Sorted by locality (including geologic age and collecting event). Description of collection recorded and disseminated at some level to the scientific community.	All of level 2 plus: Collection sorted by major taxonomic group or geologic characteristic. Locality data linked to collection with preliminary label or a private or institutional series of numbers.	All of level 3 plus: Taxon indentified or problem solved (e.g., biofaces). Taxon or assemblages sorted. Fully prepared. Boxed.	All of level 4 plus: Taxon or locality lots cataloged. Marked with catalog numbers. Fully labeled. Arranged within taxonomic or geologic framework. Lot data (including acquisiton history and locality) captured electronically. Collection description fully disseminated to the scientific community.

survey already have used McGinley Levels to survey their collections, namely the University of Kansas (KUMIP), the University of Iowa (SUI), and the Peabody Museum of Natural History (YPM). McGinley Levels, along with the Curatorial Continuum (a continuum of five stages of activity that describe the various states of curation for IP collections), are useful and promising methods for addressing uncurated backlogs.

In addition to these survey methods, another way to help address backlogs is to prioritize collections that need curation. Criteria to help establish this ranking should include: 1) the nature of specimen preservation (to insure that specimens with conservation problems are given attention); 2) the association of other faunal elements of the collecting event (to make sure relevant specimens are curated together); 3) the quality of the original documentation (good documentation allows data to be entered quickly into the database); 4) the completeness of taxonomic identification (the presence of identifications allow for data to be entered quickly into the database); and 5) the level to which the collection already has been databased (collections that are partially databased can be entered quickly because some information, such as locality data, already has been added to the database).

Type organization.—The organization of type material among the 23 collections surveyed varied more than expected. Other organizations, in addition to using taxonomic or author and publication date, also include geologic age, journal, catalog number, and only publication date. Hughes et al. (2000) strongly advocate that type specimens be kept separate from the general collection and arranged taxonomically. Whether the arrangement is by original taxonomic designation or by revised designation does not matter as long as the usage is consistent in a collection. In the majority of collections (39%), a taxonomic organization is used for type collections. Researchers also prefer this organization (Hughes et al. 2000) and this organization is the preferred standard in many other natural history collections (informal MCZ survey). In organizing and storing types, IP collection staff should: 1) separate type material from the general collection, preferably in locked cabinets or in a secure location; 2) arrange it taxonomically for ease of retrieval for researchers; and 3) to move toward standards as with other natural history disciplines.

Secondary type designations.—Historically, type usage has been confusing among IP collections. Howell (1929) noted four groups of type specimens: 1) basic types (i.e., holotypes, cotypes [or syntypes], paratypes, lectotypes, and neotypes); 2) supplementary types (i.e., pleisotypes [or hypotypes], heautotypes, and allotypes); 3) unessential published types (i.e., figured and cited specimens to which reference is made in a published book or paper, but which add nothing to our knowledge of the form of a species); and 4) unessential unpublished types (i.e., topotypes, metatypes, homeotypes, and ideotypes). The first two groups were considered as essential types and the last two were considered unessential types. Frizzell (1933) recommended that the general use of type terms be restricted to genotype, syntype, holotype, paratype, lectotype, neotype, hypotype, topotype, homoeotype, and plastotype.

Collier et al. (1990) recognized three groups of type specimens: 1) primary types (i.e., holotype, paratype, syntype, lectotype, paralectotype, and neotypes); 2) secondary types (i.e., hypotype, figured, measured, mentioned); and 3) other types (i.e., isotype and topotype). Brunton (1995) listed two groups of types: 1) types defined by the author of the species name at the time of its first published description (i.e., holotype, syntype, and paratypes) and 2) types defined by authors after the original description of the species (i.e., lectotypes, paralectotypes, and neotypes). Two lesser categories of types, topotypes and metatypes, also were recognized by Brunton along with cited, referred, or figured

specimens. White (2000) recognized the terminology problems and suggested using Frizzell (1933) for older designations historically known as "types."

Not surprisingly, this survey found numerous different secondary type designations being used throughout IP collections (i.e., hypotype, figured, mentioned, measured, referred, identified, cotype, plastotype, homeotype, and type [= hypotype]). In addition, the usage of secondary types has not been consistent within IP collections. The importance that collections give secondary types, figured, and mentioned specimens also has varied. Many other natural history collections, following ICZN rules, officially do not recognize secondary types nor figured and mentioned specimens as "types." In these cases, information on figured and mentioned specimens are tracked in the database and publication information might be included on labels, but these specimens are not separated out as "types" or given any type designation. The varying usage and expansion of type designations in IP collections are confusing and inconsistent not only compared with other natural history collections, but among IP collections, themselves.

The International Commission on Zoological Nomenclature (ICZN 1999) and the *Treatise on Invertebrate Paleontology* (Moore et al. 1953–2009; Paleontological Institute 1998–2005; Selden 2007) recognize only primary types, and not secondary types. IP collections staff need to reevaluate the type designations they use and the importance given to each. As with other biological collections, IP collections staff should follow ICZN as the authority for type designations.

Preventative conservation practices.—White (2000) states that fossils are robust and indestructible with minimal conservation issues, but in recent years, conservation practices have increased awareness of the preservation problems in fossil collections that can lead to conservation issues. This survey shows that in many collections (48%) some preventative conservation practices are followed, and in several collections (22%) robust preventative conservation practices are in place (i.e., Integrated Pest Management [IPM], monitoring for pollutants), but there still are a number of collections (30%) in which no preventative conservation practices are followed. This likely is due to the misconception that there are few conservation issues for fossil collections.

IP collections staff, as a whole, should take further steps to improve their preventative conservation practices. Although fossils have few conservation issues, because they are rocks, problems are encountered with the way some fossils are preserved (e.g., fossils replaced by the mineral pyrite during their fossilization). These specimens are sensitive to humidity, and the pyrite oxidizes with the introduction of water vapor causing destruction of the specimen (Howie 1978; Waller 1987). In addition, the associated documents (e.g., labels, collection catalogs, field notes) for the collections do have conservation issues and if destroyed can reduce the value of the specimens (Hawks and Williams 1986). Most IP collections are housed in a building with other natural history collections, some of which have great conservation issues. Preventative conservation practices, such as IPM, might not seem initially that important to IP collections staff, but collections should have a "good neighbor" policy so problems do not migrate to other areas of the museum and cause harm to the collections that are more sensitive. Good preventative conservation practices are recognized as integral to other natural history collections, but IP collections staff need to embrace these practices and adapt them to their needs, as well as their museum's needs.

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Appendix 1

Survey questionnaire used during museum visits.—A version of this questionnaire was also posted online for access by collections staff doing online surveys.

Survey Questionnaire: Curation Procedures in Invertebrate Paleontology Collections

GENERAL COLLECTION INFORMATION

Museum _____

Contact Person _____

Size of Collection (If possible, give number of individual specimens rather than specimen lots. Also please state if this number is an estimate.)

Total _____
Systematic _____
Stratigraphic _____
Teaching _____
Types _____
On exhibit _____
Other, please specify _____

Number of Staff

Curators _____
Collection Manager/Curatorial Associates _____
Curatorial Assistants _____
Student Assistants _____
Volunteers _____
Other, please specify _____

Number of Vistors per year

Professional _____
Student _____
Other, please specify _____

Number of Loans per year

Professional _____
Student _____
Other, please specify _____

What guidelines do you generally follow for the curation of your collection? Check all that apply.

White and Allmon, 2000 _____
Collins, 1995 _____
Collier et al. 1990 _____
Other, please specify _____

Do you have these guidelines or similar guidelines documented in a curation procedures manual for your collection?

Yes _____
No _____

What taxonomic group is your collection known for? If more than one please specify.

PROCESSING

Acquisition/Accession

How were most of your specimens acquired? Check all that apply.

Field collecting _____
Gifts/donations _____
Purchased _____
Grad student or Curator collections _____
From other museums or institutions _____
Other, Please specify _____

What is your accession process (ie the formal acceptance into custody of an acquisition and the recording of such act.)

Cataloging - Types

How are type specimens cataloged?

Where do you keep primary types?

In a separate area _____
In the general collection _____
Other, please specify _____

Where do you keep secondary types?

With the primary types _____
In the general collection _____
Other, please specify _____

What designations do you use for secondary types? Check all that apply.

Hypotype _____
Figured _____
Mentioned _____
Measured _____

Are there others you use?

Do you catalog secondary types in the same way you do primary types?

Yes _____
No _____

If no, how are secondary types cataloged?

How is your type collection organized?

Major taxonomic group - genus - species - # _____
Author - publication date - genus - species - # _____
Publication date - author - genus - species - # _____
Other, please specify _____

If a type specimen has been figured in more than one publication how is that specimen stored and labeled? (Ex. Figured by two or more authors or published under two or more taxonomic names)

How are publication history and taxonomic history noted on labels?

Taxonomic Identifications

Do you bring in experts to identify or reidentify part of the collection and update stratigraphic data?

Yes _____
No _____

If no, how are specimens identified and stratigraphic data updated?

When was the last time your collection or parts of your collection were updated?

Data Entry Process

What process do you follow for initial data entry? Check all that apply.

Data entry from card catalogs _____
Data entry from collection catalogs _____
Data entry from specimens and labels _____
Data entry from the literature _____
Data entry from collated capture sheets or data entry sheets _____
Other, please specify _____

Labeling

What type of numbering system do you use?

How do you organize and store associated labels and other documents with specimen info?

Store with specimen _____
Store in separate file _____
Other, please specify _____

Archives

Does your museum have a registrar?

Yes _____
No _____

Which of the following is the Registrar responsible for? Which are collection staff responsible for? Which are your intitutional archives responsible for? Check all that apply for each column.

	Registrar	Collection Staff/ Dept. Archives	Institutional Archives
Loan invoices			
Accession forms			
Correspondence			
Field notes			
Catalogs			
Maps			
Photographs			
Computer disks			
Reprints			
Other, please specify			

Databasing

What type of database do you use?

KE EMu _____
Specify _____
MUSE _____
Other, please specify. _____

If you plan on upgrading to a new database in the next 5 years, what might it be?

In your museum do all or some of your departments or collections use the same database system?

Yes _____
No _____

What data dictionaries do you use? (For example, Treatise on Invertebrate Paleontology, USGS National Geologic Lexicon Database (GEOLEX), USGS Geographic Names Information System (GNIS), etc.)

Has your museum set standards/policy for databasing collections?

Yes _____
No _____

What percent of your collection is databased?

What type of backup do you have for your database? Check all that apply.

Paper or hard copy _____
Computer or server backup _____
Other, please specify _____

STORAGE

Arrangement/Organization

What is the organization of your collections?

Taxonomic _____
Stratigraphic _____
Geographic _____
Combination _____
Other, please specify _____

What classification do you use if the collection is arranged taxonomically?

Treatise _____

Expert suggestion _____

Other publications, please specify _____

Do you keep historic or special collections separate?

Yes _____

No _____

What historic or special collections do you have?

Are you also responsible for modern extant collections or modern equivalents to your collections?

Yes _____

No _____

If so, which modern extant collections do you care for?

Is there any difference in the way you curate and care for these collections?

Conservation

In treating and restoring specimens, what adhesives and consolidants do you use?

What preventative conservation practices do you have in place? Check all that apply.

Monitoring for temp and relative humidity (RH) _____
Monitoring for pollutants _____
Intregrated Pest Management (IPM) _____
Others, please specify _____

ACCESS and USE
Staff, Students, Visitors

Do you have policies for student collections/thesis collections?

Yes _____
No _____

If so, do you require students to reposit thesis collections in your collection or are they allowed to take their collections with them?

Teaching/Exhibition

Do you have special requirements for specimens that will be used for teaching or for exhibition?

Yes _____
No _____

Loans

Is your loan policy posted online?

Yes _____
No _____

If no, can a copy be acquired for this survey?

Photographic Requests

Do you accept requests for photographs of specimens?

Yes _____
No _____

Do you allow visitors to take photographs of specimens?

Yes _____
No _____

If yes, are there permission forms and do you charge a fee?

Are there special considerations for these requests?

Data Requests

Do you accept specimen data requests?

Yes _____
No _____

Do you accept locality data requests?

Yes _____
No _____

If you do accept these requests, is the data limited in any way (ie, only a general description given rather than a detail description)?

Destructive Sampling

Do you allow destructive sampling of some specimens?

Yes _____
No _____

If yes, what are the criteria and special considerations?

What do you require the researcher to provide in return?

3D reconstructions _____
Thin sections _____
Other, please specify _____

Specimen Retrieval

What process or finding guide do you use for specimen retrieval? Check all that apply.

Electronic - interactive maps, searches, etc. _____
Hard copy - lists, floor plan, maps _____
Other, please specify _____

PREPARATION

What lab setups do you have? Check all that apply.

	Departmental	Institutional
Digital photography		
Dark room for film photography		
Digital X-ray		
X-ray		
Chemical - fume hood for acid prep		
Mechanical		
vibro-tools		
air abrasion		
cutting and polishing		
sectioning		
Other, please specify		

Thank you for your participation. Results will be shared with the museum and paleontologic communities upon completion of the survey process.

Additional Thoughts/Comments:

Appendix 2. *Historic collections*.—These data represent the location of historic collections in the 23 collections surveyed. "—" indicates that no data were provided by collection staff.

Museum	Collection
AMHERST	Denton Collection
	Sawyer Collection
AMNH	James Hall Type Collection
	G. Arthur Cooper Brachiopod Collection
	Paris Basin
	Shugar Smith Collection (Plio–Pliestocene Mollusks of Florida)
	Florissant Fossil Beds, Insects
BMS	Hamilton Age Fossils, Devonian
	Hitchcock Collection
	Brett Collection
BURKE	—
CMC	Cincinnatian Type Series
	Max J. Kopf Paleozoic Echinoderm Collection
	Budenbach Hunsruck Fossils
	Burgess Shale, Walcott and Caster Collections
	Devonian Corals, Falls of the Ohio
	Burlington Crinoid Types of Miller and Girley
	South American Fossils collected by K. Caster
	Type Ordovician Trace Fossils of R. G. Osgood
	Trilobite ontogenetic series of Hu Chung-hung
	Casts of European Homaloza and primitive Echinoderm Types, Bohemia
	Casts of Himalayan Trilobite Types
CMNH	Upper Jurassic Solnhofen of Germany
	Lower Carboniferous, Belgium
	Upper Devonian Glass Sponges, Western New York
	Late Mississippian Bear Gulch
	Carboniferous Reef Faunas
	Lower Devonian Hunsruck Echinoderms

Appendix 2. Continued.

Museum	Collection
	Lower Carboniferous Gilmore City
FLMNH	—
FMNH	Mazon Creek
	James Hall Collection
	Nitecki Collection
	Marx Collection
KUMIP	Diana James Collection
	Snell Collection
	J. D. Stewart Collection
	J. Harlan Johnson Collection
	Hamilton Quarry
	Cambrian Collection
	Amoco Fusulinid Collection
LACM	UCLA Collection
	CIT Collection
	USC Collection
	CSUN Collection
	Alexander Stoyanow Collection, Cretaceous Mollusks of Arizonia
	George Statz Collection, Oligocene Arthropoda, Germany
	Robert J. Staton Jr. Collection, Tertiary Faunas, California
LSU	H. B. Stenzel Collection
	Tulane University, Vokes Collection
	Rust Collection, Trenton Falls
	McDonald Collection, Newark Supergroup
	H. J. Plummer Collection, Microfossils
	Wells College Collection
MCZ	J. M. Schary Collection, Bohemia
	J. Barrande Collection, Bohemia
	F. H. Day Collection, Silurian Dolomites
	C. D. Walcott Collection, Trenton Falls
	Haeberlin Collection, Solnhofen
	Percy Raymond's Burgess Shale
	L. G. DeKoninck Collection, Paleozoic France and Belgium
	Patten's Eurypterids from Oesel
	P. Cloud Collection, Glass Mountains Brachiopoda
	Shaler Memorial Expedition Collection
	Kummel Collection, Triassic Ammonites
	Gould Collection, Pleistocene land snails
	W. D. Gebhard Collection
	H. G. Bronn Collection
	Whiteley Collection, Trenton Falls
	James Hall Collection, Paleozoic Bivalves
	O. H. St. John Collection
	A. Hyatt Collection
NMNH	C. D. Walcott Burgess Shale Collection
	Solnhofen
	Amber
	Cleared leaves
	Dawson Collection
	O. C. Marsh Dinosaur Collection
	G. A. Cooper Brachiopod Collection
	Springer Collection
NYSM	Ruedemann's Graptolite Collection

Appendix 2. Continued.

Museum	Collection
	Gilboa Plant Fossils
	James Hall Collection
	W. D. Gebhard Collection
	J. M. Clarke Collection
	Victor Tallinton Collection, Eurypterids
	W. Goldring Collection
	R. H. Flower Collection
	D. W. Fisher Collection
	Cornell's Type Collection
PRI	Gilbert D. Harris Collection
	Katherine V. W. Palmer Collection
	Cornell Collection
	Syracuse Collection
	SUNY Binghamton, Banks Collection
	SUNY Buffalo Collection
	University of Rochester, Brett Collection
	Alfred University Collection
RMSC	Sam Ciurca Eurypterid Collection
ROM	Burgess Shale
	Mazon Creek
	Bear Gulch
SNOMNH	Decker Collection, Graptolites
	Amsden Collection, Silurian-Devonian Brachiopods
	Sutherland Collection, Silurian–Carboniferous Brachiopods and Corals
	Stitt Collection, Cambro–Ordovician Trilobites
	Amoco Collection, majority of field collections
SUI	Samuel Calvin Collection
	Belanski Collection
	Amoco Condont Collection
	Amoco South Florida Collection
TMM	Dumble Survey Collection
	Rio Bravo Collection
	Singley and Askew Collection
UCMP	Whitfield Collection (Paleozoic Mid-Eastern USA)
	2nd Geological Survey of California Collection,1873
	Cloez Collection, Eocene Paris Basin
	Insects in amber from Chiapas, Mexico
	Western North America/Alaska, Menlo Park
VMNH	—
YPM	Schuchert's Brachiopod Collection
	Beecher's Bed Trilobites
	June R. P. Ross Bryozoa Collection
	Charles A. Ross Fusulinid Collection
	Anticosti Collection
	Devonian Brachiopoda and Mollusca from NY
	Sam Ciurca Eurypterid Collection

Appendix 3. *Taxonomic group(s) and prominent material*.—These data show the strengths in taxonomic group(s) and material that promotes the importance in the 23 surveyed collections.

Museum	Material
AMHERST	Dinosaur trackways
AMNH	Cephalopoda
	Paleozoic, New York
	Tertiary Mollusks
	Cretaceous Bivalves of South Dakota
BMS	Eurypterids
	Crinoids
BURKE	Cenozoic Mollusks
	Cenozoic Crabs
CMC	Cincinnatian Type Series
	Bachiopoda
CMNH	Trilobites
	Carboniferous Reef Faunas
	Glass Sponges
	Lower Carboniferous Brachiopoda
	Carboniferous Gastropoda
FLMNH	Molluska
	Echinodermata
FMNH	Mazon Creek
	Brachiopods
	Crinoids
KUMIP	Fusulinids
	Cambrian Fossils
	Ostracoda
	Paleozoic Midcontinent
LACM	Pleistocene Mollusks
	Pacific Coast, North America
	Cretaceous Mollusks
	Western North America
LSU	Foraminifera
	Ostracoda
MCZ	Trilobites
NMNH	Echinodermata
	Brachiopoda
	Foraminifera
	Bryozoa
NYSM	Eurypterids
	Graptolites
PRI	Cenozoic Mollusks
	Atlantic and Gulf Coast
	Northeastern US Paleozoic
RMSC	Small synoptic collection
ROM	Burgess Shale
SNOMNH	Paleozoic Midcontinent
SUI	Paleozoic Crinoids
	Cephalopoda
	Conodonts
TMM	Cephalopoda
	Brachiopoda
	Bivalves
	Echinodermata
	Porifera
	Corals

Appendix 3. Continued.

Museum	Material
UCMP	Molluska
	Insects
	Corals
VMNH	Cenozoic Mollusks
YPM	Brachipoda
	Eurypterids

ON THE DEVELOPMENT, MAINTENANCE, AND USE OF A MODERN POLLEN REFERENCE COLLECTION

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Abstract.—This paper describes the procedures used at the Royal Alberta Museum for development, long-term maintenance, and care of a collection of reference pollen samples. The Pollen Reference Collection is used primarily as comparative material to aid in identifications of subfossil pollen of late Quaternary age that is mostly derived through processing sediment from palaeoenvironmental sites in Alberta. The collection can also be used for aeropalynology and melissopalynology as well as pollen-focused research in several other fields, including archaeology, forensics, and plant systematics. Processing involves concentrating and staining pollen derived from plant material collected in the field or from herbarium sheets. The main objective is to obtain a clean pollen residue that preserves pollen characteristics critical for identification. Residues are stored in silicone oil so that they do not deteriorate in long-term storage. The techniques that have been tested and developed for the preservation of this collection at the Royal Alberta Museum may be more widely applicable to similar collections held in institutions elsewhere.

Introduction

The investigation of late Quaternary palaeoecology, climate change, and landscape history often relies on subfossil pollen records derived from lake sediments or peatlands as a source of information. Modern pollen reference collections are used extensively in these studies to support the taxonomic assignments of subfossil pollen grains extracted from cores and sediments. For records of Holocene (postglacial) age, the degree of evolutionary change in plants appears to have been small enough so that the assumption that modern pollen can be used to verify identifications of subfossil material is justified. Similarly, modern pollen reference material is useful, at least at the generic level, for records extending back into the late Miocene, up to about 10 million years ago (see Traverse 1988). The development of modern pollen reference collections is therefore a significant and necessary complementary activity to such palaeoecological studies. These reference collections can also be used to aid identifications in many other fields, including aeropalynology (airborne pollen related to allergies) and melissopalynology (pollen contained in honey), as well as in archaeology, forensics, and plant systematics.

This paper describes the collection, processing, and storage methods that are used for the development and maintenance of the Pollen Reference Collection (PRC) at the Quaternary Environments Laboratory, Royal Alberta Museum, Edmonton, Alberta, Canada. The development of reference collections is discussed in several texts elsewhere, including Traverse (1988) and Wood et al. (1996). However, these are not written from a conservation or curatorial perspective. There are also many practical details involved in the long-term curation of these collections that are only learned through experience. I also emphasize the philosophy or thinking behind the collection's development. This discussion is directed to other museum curators or researchers intending to establish similar pollen reference collections.

Scope and Objectives of the Modern Pollen Reference Collection

The Royal Alberta Museum's Pollen Reference Collection (PRC) currently (November 2010) consists of about 950 prepared slides, representing about 630 different taxa from about 75 plant families. These are mainly interior western Canada taxa so that they form

a sound comparison with the pollen records being investigated from the same region. Obtaining reference pollen from the same region as the studied records is important so that any regional or clinal variation in pollen size or morphology is captured.

There are several useful published pollen atlases or keys available, such as Bassett et al. (1978); Lewis et al. (1983); Faegri et al. (1989); Moore et al. (1991); Crompton and Wojtas (1993); Jones et al. (1995); and Kapp et al. (2000). However, none of these deal specifically with material from western Canada and, even when they include discussion of taxa that have broad ranges, they do not necessarily capture the range of variation, especially in size, that can be expected. Although these compilations are very useful for helping to narrow down searches during the identification phase of pollen counting, identifications should always be confirmed by examination of reference material from the same region as the record being studied. These published compilations are also, by their nature, selective and only offer a few examples for any plant family.

In the Asteraceae (Compositae), for example, Kapp et al. (2000) provide descriptions and drawings of pollen grains for just 14 species, whereas Moss (1983) lists 246 species in this plant family for Alberta, and Looman and Best (1987) list 266 species for the Canadian prairies. Plants within this family produce pollen that show two very distinct morphotypes: tricolporate pollen (with three pores and three colpi or furrows) or fenestrate pollen (with large openings or lacunae). These two types are often associated with plants in the subfamilies Tubuliflorae and Liguliflorae, respectively, following Faegri and Iversen (1975). Within these morphotypes, especially the tricolporate category, taxa are often stenopalynous (i.e., the pollen types from different taxa show little variation), making identification to the genus level difficult using light microscopy. However, there are some taxa in the Asteraceae, such as *Artemisia*, whose pollen can be distinguished to the genus level, and which have considerable interpretive significance and yield important ecological information in Quaternary palynology. A comprehensive modern pollen reference collection is invaluable in these circumstances. The PRC currently contains examples of 81 species in the Asteraceae.

Modern pollen collections from hybrid zones are also important. In northwestern Alberta, along the eastern slopes of the Rockies, mountain and boreal forest plant taxa often hybridize. For example, intergrades between jack pine (*Pinus banksiana* Lamb.) and lodgepole pine (*Pinus contorta* Douglas ex Loudon) are common (see Rweyongeza et al. 2007). Therefore ''pure'' examples of pollen from these taxa may not provide the full range of variation to be expected in the subfossil record.

As part of any coring or sampling project, I collect representative reference pollen material. Usually, I do lake coring in the winter, so this reference collection activity requires an additional summer season visit to the field area. In order to collect pollen from plants that flower at different seasons (e.g., spring and fall flowering plants), several field visits might be required. As a result, the PRC has good representation of pollen types from regions that have been the focus of my studies in recent years, especially the central Rockies and the Cypress Hills in Alberta and the Melfort area of central Saskatchewan. The PRC often has multiple samples of the same taxon but from the different areas, ensuring good representation of the range of variability in the pollen type.

Plants use several mechanisms to disperse their pollen. Active dispersal by insect vectors (entomophily) is common, as is more passive dispersal by wind (anemophily). Water dispersal (hydrophily) is comparatively rare (Proctor et al. 1996). A few plant families use birds, bats, or other mammals as pollen dispersal agents (Proctor et al. 1996). It is especially important to get good reference samples from most of the anemophilous

taxa in a study area, because these are the most frequent pollen types to be encountered in subfossil records. Quaternary palaeoecology has a major focus on forest history, perhaps in part because so many tree taxa are anemophilous, at least in the temperate regions where the research approach was developed; therefore, these taxa form a substantial component of subfossil pollen assemblages. By this means, a single sample site can yield a broad perspective on regional landscape change.

The PRC focuses on pollen from native plant taxa. However, it does include good representation of some major weed taxa, many of which are exotics, such as narrow-leafed plantain (*Plantago lanceolata* L.) and Russian thistle (*Salsola kali* L.). Although these taxa should not be encountered in the older levels of subfossil records, it is important to be able to recognize them so as to identify any indication of contamination (e.g., through processing) or disturbance (e.g., through sediment mixing) in those assemblages. For the same reason, the PRC also includes a few examples of pollen types from horticultural or agricultural plants, such as tomato (*Solanum lycopersicum* L.) and lilac (*Syringia* spp.). Corn (*Zea mays* L.) so far has not been found in pollen records from Alberta, although it is an important indicator for indigenous agriculture in other areas, such as at Crawford Lake in southern Ontario (McAndrews and Boyko-Diankanow 1989). It is one of those pollen types for which we are always alert when looking at pollen records from the prairie ecoregion, and therefore it is also represented in the PRC.

The PRC also includes some examples of native North American taxa that are exotic to Alberta, such as oak (*Quercus*), walnut (*Juglans*), and ash (*Fraxinus*). These are usually single slides that were obtained by ''trade'' with other institutions and therefore are not supported by voucher specimens or residues at our institution. Such taxa do occur occasionally in subfossil records, most likely as a result of infrequent events, such as storms tracking up from the southeastern USA and depositing exotic pollen. Bouchet-Bert (2002) found a single grain of walnut (*Juglans*) in a record from Kearl Lake in the Oil Sands region of northeastern Alberta, and Beaudoin (1984) found a single grain of Mormon tea (*Ephedra*) in a record from Sunwapta Pass, Jasper National Park. A record from Lake O'Hara in the Canadian Rockies contained occasional oak (*Quercus*) and Mormon tea grains in the lowermost zone, dated at >10,000 years BP (Reasoner and Hickman 1989). Pollen types present in such low abundance have little overall interpretive significance for these records, but they can encode useful information about rare events. For instance, Campbell et al. (1999) documented an unusual influx of jack pine and white spruce (*Picea glauca* [Moench] Voss) pollen in the eastern Canadian arctic in June 1998 as a result of strong winds associated with a low pressure system over central Quebec, about 3,000 km away.

Sources of Reference Pollen: Fieldwork and Herbaria

The best source of modern reference pollen is from field collections made directly from plants by trained botanists. Flowers (from angiosperms) and male strobili (from gymnosperms) can be collected in the field and stored for later processing. The objective is to get fully mature pollen, so collections should be made from fully formed and partly-open flowers. Immature or unopened flowers often do not yield useful pollen. Fully open flowers usually do yield pollen but they may be contaminated with pollen from other taxa, either through insect visitors or by passive air fall from nearby plants. Flowers that are ''over'' can sometimes still yield pollen, although the yield is usually small. Care needs to be taken with plant taxa that are monoecious (i.e., have separate male and female

Table 1. Laboratory procedure for preparation of modern pollen reference material.

Separation of pollen from plant material
1. Put plant material (a few anthers, strobili, or flowers) in a 150 ml beaker.
2. Add 10% sodium hydroxide (NaOH) solution and warm on hotplate.
3. Filter through small porcelain filter (approximately 700 μm openings) into a second beaker.
4. Rinse residue on filter and macerate with glass stirring rod to free pollen. Rinse thoroughly with distilled water.
5. Transfer solution from beaker to 50 ml Nalgene® tube. Centrifuge. (It might take several steps to transfer all liquid.) Transfer to 15 ml tubes at final stage.
6. Wash with distilled water, centrifuge, decant, and disperse.
Acteolysis
7. Wash with about 10 ml of concentrated glacial acetic acid.
8. Centrifuge, decant, and disperse.
9. Make up 9:1 acetic anhydride:concentrated sulphuric acid (H_2SO_4), in a glass measuring cylinder. For 8 samples, use 72 ml acetic anhydride and 8 ml concentrated sulphuric acid. Carefully add 10 ml of the acetolysis mixture to each sample.
10. Warm tubes for 2–3 minutes in hot water bath.
11. Centrifuge, decant, and disperse.
12. Glacial acetic acid wash. Centrifuge, decant, and disperse.
13. Distilled water wash. Centrifuge, decant, and disperse.
Staining and dehydration
14. Add 1 drop of safranin stain.
15. Add TBA (tertiary butyl alcohol or butanol). Mix, centrifuge, decant, and disperse.
16. Transfer to glass vials, washing tubes thoroughly with TBA.
17. Centrifuge to remove as much TBA as possible.
18. Add a few drop of silicone oil to residue and mix well.
19. Leave tubes open (in fume-hood or in dust-free place!) overnight to allow TBA to evaporate.

flowers on the same plant) or dioecious (i.e., have male and female flowers on separate plants) to collect male (pollen-bearing) flowers.

I usually use a small whirlpak bag (Fisherbrand®, either 3 inches × 7 inches or 4.5 inches × 9 inches [7.62 cm × 17.78 cm or 11.43 cm × 22.86 cm]) and fill it with about 20–30 flowers or flower clusters. These bags are sterile and I do not break their seal until they are used, so contamination from outside sources is minimized. Although only the anthers are the source of pollen, it is usually too difficult to collect individual anthers in the field. It is generally better to collect entire flowers in the field and separate anthers from other floral parts in the laboratory. Insect-pollinated taxa generally produce lower amounts of pollen per flower than anemophilous taxa, and so it is advisable to collect more material from these plants so as to yield a quality pollen residue. On return to the laboratory, these bags are stored in the refrigerator at a temperature of about 3°C until processed. Because of their high moisture content, flowers stored this way will usually degrade. The samples often appear as a rotten, brown, pungent soup by the time they are processed. This does not appear to harm the usefulness of the pollen for identification purposes and usually pollen recovery is good even from samples with a very unpromising appearance and revolting effluvium.

Some authors recommend drying or dehydrating fresh pollen-bearing material, for example by adding glacial acetic acid or acetone (Traverse 1988), or by adding preservatives, such as 95% ethyl alcohol (Jones et al. 1995). Traverse (1965) recommends placing fresh material directly in vials of glacial acetic acid. This dehydration would be necessary if the acetolysis procedure (see Table 1) were to be performed directly on the

material. Because I do not start processing with the acetolysis procedure, I have not found such dehydration or preservation procedures necessary at the collection stage. On the contrary, I find that the degradation of the material before processing provides a better comparison with the subfossil material. Degradation artificially ''ages'' fresh pollen, largely through colour changes (probably resulting from oxidation) and damage or disappearance of the grain contents. Because pollen is identified by characteristics of the highly resistant exine or outer layer, the loss of internal contents (intine and cytoplasm) is not critical.

Ideally, flower samples should be supported by voucher specimens from the source plants collected at the same time and deposited at an institutional herbarium as outlined by Jones et al. (1995). Field methods for collecting plant specimens for herbaria are described by Jones and Luchsinger (1986). These plant specimens can be used to verify the taxonomic assignments of the pollen samples. Obviously, getting the identifications correct is crucial; incorrectly identified pollen reference samples are of little use and will be misleading. Specimen and sample numbers should be cross-referenced between both collections. Although in practice many pollen types can be distinguished only to the genus or sometimes the family level, all plants from which field collections are made should be identified to the lowest taxonomic level, at least to species. Because few palaeoecologists are trained botanists, this often requires co-operative work with other specialists to verify identifications. As with other field collections, researchers should be careful not to collect from rare or endangered plants or isolated populations where such activities could affect the continued survival of a viable population.

Pollen can also be obtained from plant specimens already deposited in institutional herbaria. These sources have the advantage that the plants are already identified. Jarzen and Jarzen (2006) provide detailed procedures for collecting from herbaria. Material collected from herbarium sheets is already dried and therefore can be stored without refrigeration in small kraft coin envelopes until processed (Jarzen pers. comm. 2010). It does bear repeating, however, that such sampling requires the greatest level of care on the part of the collector so as not to damage the original specimen. Pollen samples from such collections should always include a cross reference back to the original herbarium specimen, so that any taxonomic revisions can be reflected in the PRC's database. Ideally, the herbarium's database also should contain a cross reference back to the pollen reference collection, so that researchers in future can go directly to the pollen slide and not request additional material from the same herbarium sheets.

Laboratory Processing and Comments on the Procedures

Pollen is extracted from anthers or strobili in the laboratory by standard pollen processing techniques. These are outlined in the literature (e.g., Traverse 1988; Faegri et al. 1989; Moore et al. 1991; Bennett and Willis 2001). The procedure used in our laboratory is detailed in Table 1. It is similar to that used for subfossil pollen samples, except that the steps for removal of clastic inorganic material (such as silt and clay) are not needed. The objective is to produce a pollen concentrate from the flowers or strobili. This concentrate is then used to prepare slides. It takes about half a work day (about 4 hours) to process one batch of eight samples in our laboratory; the number of samples per batch is constrained by the number of tube holders in the available centrifuge.

Most chemicals used in this laboratory procedure are hazardous (see Wood et al. 1996). Processing should take place in a fume hood using safe laboratory practices. All personnel should wear personal protective equipment (such as lab coats, safety glasses,

and chemical-resistant gloves). Before starting the procedure, personnel should familiarize themselves with information presented in the Material Safety Data Sheet (MSDS) for each chemical they will be using (see www.ilpi.com/msds/). Spent chemicals should be collected and saved for disposal in accordance with local regulations. To prevent cross contamination, all tubes and glassware should be cleaned thoroughly between batches.

Fresh pollen usually has a waxy or oily coating that is hydrophobic and causes the pollen grains to float in water. In angiosperms, these coatings include sticky substances and are known as ''pollenkitt'' (Traverse 1988; Moore et al. 1991) or, in the Brassicaceae, as tryphine (Pacini and Hesse 2005). Bisaccate conifer grains are also buoyant, an adaptation related to their pollination mechanism (Leslie 2010). These factors can cause problems in processing because it can be difficult to get the pollen to sink during the centrifugation steps (Table 1). This problem is particularly acute with conifer pollen. Thus, some sample can be lost. Kapp et al. (2000) describe the Wodehouse technique, a minimalist approach to preparing fresh pollen in which grains are degreased with a drop of alcohol, before being mounted in glycerine jelly. Alcohol acts as a surfactant that breaks the surface tension of the hydrophobic pollen coating.

Comments Selected Steps of the Procedure

Step 1.—Generally, there is no need to remove the anthers from fresh flowers before processing because these large plant fragments are removed at this initial processing stage.

Step 2.—Treatment with sodium hydroxide (NaOH) solution helps to break down and disaggregate the organic material. The hydroxide solution hydrolyzes cellulose (Traverse 1988). Many authorities (Faegri et al. 1989; Moore et al. 1991) prefer to use the less harsh 10% potassium hydroxide (KOH) solution for this step, and it gives satisfactory results (Jarzen pers. comm. 2010). The samples should not be allowed to boil on the hotplate; gentle warming for not more than 10 minutes is usually sufficient. Prolonged heating or boiling will increase the concentration of the hydroxide solution and can cause damage to the pollen grains (Moore et al. 1991). The exact amount of NaOH or KOH solution used is not critical; add enough to cover and thoroughly soak the sample. I usually dispense this solution from a 500 ml polyethylene wash bottle.

Steps 3 and 4.—I use Coors^{TM} brand Porcelain Gooch Filtering Crucibles. The openings are small enough to remove most plant fragments and debris but wide enough so that large pollen grains and pollinia (clumps of pollen grains that are dispersed as a unit) can pass through. Use distilled or purified water. Directing a gentle water spray from a wash bottle into the filter helps wash the pollen out of the plant residue. The liquid in the beaker will look yellowish-brown or brown but should be largely debris-free.

Most pollen grains fall in the 20 μm to 80 μm range. Some single grains may be larger. subalpine fir (*Abies lasiocarpa* [Hook.] Nutt.) pollen grains can be up to 125 μm in maximum dimension (Kapp et al. 2000: 42) and squash (*Cucurbita pepo* L.) grains can be up to 200 μm in diameter (Nepi and Pacini 1993: 531). Large pollen grains (more than 100 μm in maximum dimension) are found in several other plant families, including the mallow family (Malvaceae) (Culhane and Blackmore 1988) and the evening primrose family (Onagraceae), in which grains of some taxa can be up to about 160 μm in size (Kapp et al. 2000). Pollen types that usually occur in larger aggregations, especially tetrads (groups of four) or polyads (groups of many), also can be in the 150 μm range. Some insect-pollinated plants, especially in the orchid (Orchidaceae), dogbane

(Apocynaceae), and milkweed (Asclepiadaceae) families, typically produce pollen in large clumps, called pollinia; these can be 500 μm or more in maximum dimension (Verhoven and Venter 1998; Kapp et al. 2000).

The maceration should be done gently with a rounded-end glass rod. The intent is to free the pollen from the anthers or strobili without fragmenting or shredding the plant material.

Step 5.—Because of the volume of liquid, it usually is more efficient to start with 50 ml tubes and then transfer to 15 ml tubes for the remainder of the processing. Usually, it takes several centrifugations to spin down all the liquid. The 15 ml Nalgene® polypropylene tubes have a conical base and moulded graduations (www.nalgenelabware.com/default.asp). The tubes have good chemical resistance. It is possible to use glass tubes for this procedure, and some palynologists prefer them (e.g., Traverse 1988), although they have a tendency to break in centrifugation. For this reason and because of their chemical resistance, I prefer to use the polypropylene tubes.

Tubes should be clearly labelled before use. I generally number the tubes (1 to 8) and record which sample is assigned to which tube on a standard tally-sheet at the start of the procedure. Labels need to be as permanent and readable as possible; so-called indelible markers generally are not when in repeated contact with chemicals. I use two methods to mark tubes. I score the number on the tube, near the top, with a diamond marker or graver, of the same type that is used to engrave glass. I also affix a label to the tube using a high-quality chemical-resistant lab labelling tape (available from BelArt; www.belart.com). These labels occasionally need to be replaced. It is good practice also to label the openings in the test-tube stand in the same order with the same numbers. Bucket positions usually are numbered on centrifuge rotors. To minimize errors, tubes always should be placed in the same order in the stand, and in the centrifuge, and filled or processed in the same order. The most common novice mistake is mixing up the samples and tubes.

Tubes should be balanced before placing them in the centrifuge. Because the amount and weight of plant material (and later pollen residue) vary among samples and tubes, visual inspection of the volume of material and liquid in the tube is an unreliable guide for balancing. I use a small purpose-made metal tube balance (Fig. 1a) and add liquid to the tubes (in this step, distilled water) as appropriate to ensure balance.

Centrifuge speeds and times are dependent on the make and model of equipment available. Traverse (1988) recommends centrifuging for 3 minutes at 2,500 rpm. Generally, I centrifuge for about 2 or 3 minutes at about 2,500 rpm; if the liquid in the tube remains cloudy, I repeat the centrifugation. Lentfer et al. (2003) provide additional guidance on selecting appropriate centrifuge times.

Step 6.—Distilled or purified (e.g., reverse osmosis [RO]) water should be used for all steps and for making up the reagents used in the procedure. This is to avoid introducing possible contaminants from unfiltered tap water, despite the low probability of this (see Traverse 1988; McAndrews 1998). To check for contamination, I run a blank through the procedure with every few batches and inspect the resulting residue, following McAndrew's (1998) recommendation.

For washing or mixing steps, the residue needs to be thoroughly mixed with the liquid (water or reagent). I use small wood (birch) applicator sticks, available through standard laboratory suppliers. These are long enough (15 cm) that they can be used safely, but narrow enough that they can stir up sediment from the conical base of the tubes. Sticks only are used once (i.e., for one tube and one stirring operation) and then discarded to

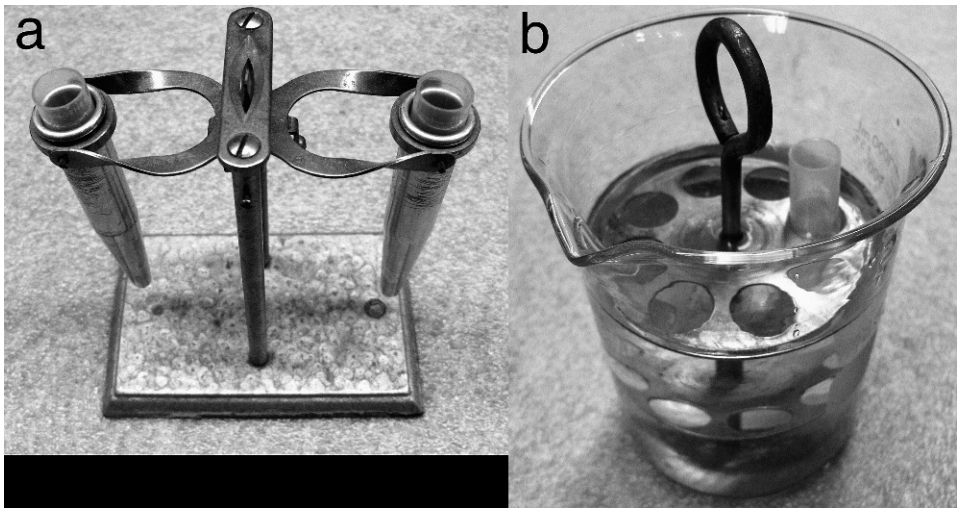


Figure 1. (a) A centrifuge tube balance, supplier unknown. (b) A simple water bath set-up for pollen processing; one 15 ml tube is shown. The holder consists of three steel plates welded along a central spindle. The base plate ensures that the entire holder and tubes can, if necessary, be removed from the water bath without any of the tubes falling out. The container is a 1,000 ml Pyrex beaker, which is set on a hotplate. Water level in the beaker should be monitored (levels can drop significantly during the several hours required to process a batch of samples) and water replenished if necessary.

eliminate the possibility of cross-contamination. Alternately, a vortex mixer can be used to mix the residue and liquid, although I find it takes some practice to use this safely and avoid splattering the sample out of the tube.

After centrifugation, and after the supernatant has been decanted, the residue will have accumulated in a small pellet at the bottom of the tube. It is important to disperse the sediment so that the reagent used in the next step can mix thoroughly with the residue. To disperse the sediment, firmly grasp the centrifuge tube at the top with one hand, and flick the bottom of the tube with the fingers of the other hand. This loosens the pellet, which usually then forms a slurry in the tube.

Step 7.—Glacial acetic acid dehydrates the sample. The acid can be dispensed using either a 500 ml polypropylene wash bottle (preferably of a type with a closable spout) or an acid-resistant bottle-top dispenser. The amount of acid used is not critical; 10 ml usually is sufficient. Both chemicals (acetic anhydride and sulphuric acid) used in the next wash are highly reactive with water, especially the acetic anhydride, which reacts explosively. Therefore, the sample must be dehydrated thoroughly before proceeding with acetolysis. Care must be taken to ensure that the residue is thoroughly mixed with the glacial acetic acid reagent. If it is not, and there is a small water drop left at the bottom of the conical tube after Step 8, when the acetolysis mixture is added (Step 9), the sample can shoot rapidly and violently out of the tube.

Step 9.—The acetolysis procedure is an acid hydrolysis that removes cellulose from the plant material in the residue, as well as the pollenkitt and cytoplasm from the grains (Moore et al. 1991; Wood et al. 1996). The purpose of this step is to remove all other plant material except for the pollen grains. Pollen exines, comprised of more chemically-resistant sporopollenin, withstand this treatment, although even they will degrade with prolonged treatment. Some plant families (e.g., Orchidaceae) produce pollen that has

very low sporopollenin content (see discussion and references in Wood et al. 1996) and these can be degraded by this treatment. Pollen with thin or fragile exines can also be degraded (Hess and Waha 1989). If, during final inspection of the pollen preparation, few or no grains are found or the grains are badly degraded, then it is advisable to improve recovery by preparing a second batch, using a shorter acetolysis time.

The acetolysis mixture should be made up fresh for each batch of samples. It oxidizes and deteriorates with time, turning brown, and then is ineffective. Thus it must be freshly made immediately before use. The sulphuric acid should be carefully added drop by drop to the acetic anhydride. Mixing should take place in the fume hood; the reaction between the chemicals is exothermic (it generates heat) and the solution becomes warm. The mixture has a syrupy consistency. Because of the explosion hazard, any surplus acetolysis mixture should not be poured into the sink. I decant any spent acetolysis mixture into a labelled waste bottle for later disposal.

I find it difficult to pour the fresh acetolysis mixture directly from the measuring cylinder into the sample tubes. I pour (very carefully!) the mixture into a clean glass beaker, and then pour from that into the tube. I do this for two reasons. First, the amount of acetolysis mixture is limited and inadvertently pouring too much into one tube leaves insufficient mixture for the remaining samples; pouring into the beaker first allows the amount added to each tube to be controlled more easily. Second, because the mouth of the 15 ml tubes is narrow, it is easy to spill or drip some of the mixture from the cylinder while pouring; I find it safer and more efficient to use the beaker. Hold back a few ml of mixture to balance the tubes before centrifuging.

Step 10.—For a water bath, I use a specialized but simply made metal tube holder in a beaker (Fig. 1b). Faegri et al. (1989) and Moore et al. (1991) recommend the use of a boiling water bath for acetolysis. I find this too dangerous, because the tubes have a tendency to bump about in the boiling water and there is a danger of splashing. I have the water hot—just below boiling point.

Opinions vary as to how long to heat during the acetolysis procedure. Traverse (1988) recommends 10–12 minutes, Nilsson and Praglowski (1992) recommend 5–10 minutes, Bennett and Willis (2001) recommend 2–4 minutes, Moore et al. (1991) and Faegri et al. (1989) recommend 3 minutes. I prefer a shorter acetolysis time because I feel that the danger of pollen destruction outweighs the limitations of having some extraneous plant material remaining. As with other steps in this laboratory process, this is largely a matter of judgement and experience. The volume of material usually decreases markedly during acetolysis. Longer heating times mighty be necessary if there is a large amount of intractable plant material.

The outside of the tubes should be dried off with a paper towel before centrifugation. Wet tubes can stick in the centrifuge buckets and be difficult to remove. Tubes can be allowed to cool down for a few minutes before centrifugation, although note that the acetolysis reaction will continue during the cool-down phase.

Step 14.—The question of stained vs. unstained pollen residues is largely a matter of preference. Some palynologists prefer not to use stain. Others (e.g., Faegri et al. 1989) regard staining as useful for distinguishing features of the exine. Unstained pollen usually has a pale beige tinge and does not stand out as clearly as stained pollen on the slide. It has, to borrow a term from petrography, low relief. I stain subfossil samples because I find it helps in the identification process and in photography. Specifically, the differential uptake of stain can be useful for distinguishing pollen from other plant material on the slides. Also, different pollen types tend to take up stain differently, which can be a useful

distinguishing characteristic. Therefore, I stain reference pollen so that it can be readily compared with the subfossil material (see Faegri et al. 1989).

I use safranin-O as a stain, which gives the pollen a pink tinge. This is a commonly-used stain in palynology (Faegri et al. 1989; Moore et al. 1991) and in other biological studies. Traverse (1988) lists some other stains that have been used in pollen work. Care has to be used in adding stain, because pollen that is stained too darkly will have surface texture details obscured. It is usually better to stain lightly.

Step 15.—Butanol (also known as tertiary butyl alcohol or TBA) dehydrates the residue so that it will mix properly with the silicone oil. TBA has a melting point of 25.6°C and thus can ''freeze'' or solidify at room temperature. TBA can be brought to a liquid by placing its container (usually a plastic storage bottle or wash bottle) in a slightly warm water bath.

Step 19.—The TBA should be completely evaporated from the sample. If the laboratory temperature is low (see above), then this evaporation can be encouraged by placing the tubes on a barely warm hotplate.

Storage and Maintenance of Pollen Residues and Slides

Several different storage media are employed in Quaternary palynology. The choice of storage medium depends on how the residues are to be used. Pollen residues can be stored temporarily in distilled or purified (e.g., RO) water if ''fixed'' mounts (see below) are to be prepared. However, this is not an option for long-term preservation.

Traverse (1988) recommends storing pollen residues in glycerine jelly, and reports that some were still usable after 40 years. Jarzen (pers. comm. 2010) informs me that sealed glycerine jelly mounts in his collection prepared 48 years ago still are usable. However, Chapman (1985) reports that some residues stored for 30 years in glycerine jelly had some dehydration (80% of samples) or were unusable (6% of samples). Glycerine jelly affects pollen size, causing grains to swell; Moore et al. (1991) report that some grains can increase in size by 1.25 to 1.5 times. This is not desirable because pollen grain size is an important diagnostic character. On the other hand, if slides are prepared immediately after the residue is processed and measurements are made straightaway, then the impact of the swelling factor on the pollen size measures should be minimized. Glycerine jelly is vulnerable to ambient laboratory conditions, such as humidity and temperature changes. However, storage in glycerine jelly is reversible, meaning that grains can be removed from the medium and used for other analyses, such as scanning electron microscopy (SEM) or transmission electron microscopy (TEM) imagery.

Silicone oil has been the medium of choice for most Quaternary palynologists ever since it was originally recommended by Anderson (1960). I store pollen residues in silicone oil with a viscosity of 1,000 cst (centistokes). This has flow characteristics resembling thin honey. Lower viscosity oil is too watery and tends to spread and flow too fast over the slide for easy slide preparation. It is important not to add too much silicone oil at the end of processing. Too much oil thins the pollen preparation, making it difficult to prepare useful slides. Faegri et al. (1989) recommend using 2,000 cst viscosity silicone oil, which I have used and prefer. However, it is more difficult to obtain silicone oil at this viscosity because it has to be specially blended, whereas 1,000 cst usually is more readily available. According to Praglowski (1970), the lower-viscosity oil is also preferable because it penetrates more quickly into the grains, minimizing collapse or distortion of the exine. Silicone oil is manufactured by Dow Corning and sold as ''Xiameter® PMX-

200 Silicone Fluid'' with 1,000 cst viscosity (www.xiameter.com). It is distributed by Univar Canada (www.univarcanada.com).

Residues stored in silicone oil do not dry out and can be stored indefinitely at room temperature. The silicone oil does not appear to cause swelling or degradation of the grains and hence is an ideal medium for long-term maintenance of the collection. Because subfossil samples in our laboratory are also stored in silicone oil, this means that measurements taken on the reference material will be directly comparable with those from the subfossil samples, a definite advantage for identifications. Silicone oil has a refractive index (RI) of about 1.4, providing reasonable contrast with pollen grains. Acetolyzed or fossil sporopollenin has an RI of about 1.48 (Traverse 1988) and work cited by Anderson (1965) indicates that fresh pollen exines have an RI ranging from 1.55 to 1.60. Silicone oil's main disadvantage is that it is not reversible, or only reversible with great difficulty, meaning that grains stored in silicone oil cannot readily be used for other purposes, such as SEM imagery. Silicone oil is miscible in benzene but this no longer is used in most laboratories because of its toxicity and is definitely not recommended. Bennett and Willis (2001) report that silicone oil is soluble in diethyl ether and indicate that it is possible to wash residue into a tube with diethyl ether if additional processing is needed.

Residues are stored in labelled glass vials (e.g., Fisherbrand®, shell glass vials with Tite-Seal polyethylene closure, 15 mm × 45 mm, 1 dram). Although the amount of residue is usually not anywhere close to 1 dram, smaller vials (e.g., 0.5 dram) are not usually robust enough to withstand repeated opening. Older samples in our collection are stored in 1 dram borosilicate glass vials with black phenolic screw-top closures with polyvinyl-faced pulp liners (Fig. 2a). However, these have a shoulder at the screw top and are not as satisfactory. Vials are stored in trays in order of accession (Fig. 2b).

Preparing Slides

In stratigraphic palynology, ''fixed'' mounts, in which the pollen is attached to the slide by resin and does not move, are the norm (see Traverse 1988). Such mounts allow grains to be relocated on the slide, provided that co-ordinates are recorded with an England Finder™ slide (Traverse 1988). This relocation is especially important for type specimens. Some researchers in Quaternary palynology also prefer fixed mounts but usually use glycerine jelly for this purpose (Moore et al. 1991). Nilsson and Praglowski (1992) provide detailed instructions for this technique. This mounting technique is reversible in that it allows the mount to be undone so that individual grains can be removed for other analyses, such as examination by SEM or TEM. However, most Quaternary researchers prefer to have pollen in liquid mounts so that the grains can be rolled by gentle pressure on the cover slip. This allows grains to be orientated so that critical or diagnostic identification features can be seen. Hence the prevalence of silicone oil as a long-term storage and mounting medium. In this simplest situation, the storage medium and mounting medium are the same, obviating the need for any additional preparation before making up slides. Various other mounting media have, however, been used for fossil pollen; Collinson (1995) includes more details on these.

Before preparing a slide, pollen residues should be well stirred, using a wooden toothpick or applicator. To prevent cross-contamination, a fresh applicator should be used for each sample. Pollen tends to settle at the bottom of the vial over time and this mixing ensures that the residue is evenly distributed or suspended in the oil. It also prevents clumping of the pollen grains.

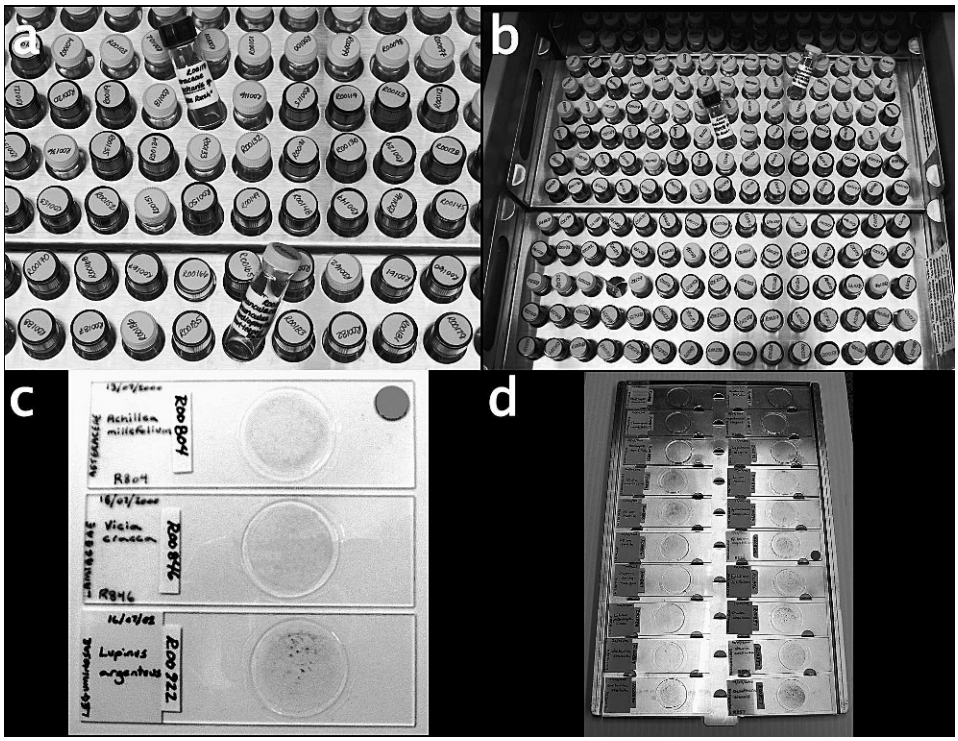


Figure 2. (a) Two types of storage vials used for pollen residues. (b) Pollen residues archived as part of the collection. (c) Three reference pollen slides. In these cases, the labels are written on frosted-end slides. (d) Flat tray storage for reference pollen slides.

A small drop of the pollen suspension is used to prepare a slide. Depending on the concentration of the residue, the oil drop might need to be thinned with more silicone oil on the slide. Once applied to the slide, the drop should be left to rest for a few minutes to allow any small air bubbles to disperse. The cover slip should then be slowly lowered onto the oil drop. One side of the cover slip should be lowered first so that it just touches the oil drop, and then the opposite side lowered so that the oil spreads and forms a good contact with the glass. Care needs to be taken to ensure that there are no bubbles trapped under the cover slip.

Only enough pollen suspension should be applied so that it spreads and just fills the area under cover slip. The aim is to get a good separation between individual grains but not get the residue so thinned that it takes much searching to locate a grain. This is something that can only be judged by experience. Ideally, the thickness of the layer of oil on the slide should be slightly greater than the grains, so that they are all approximately in the same plane and can roll. Both thick and thin slides (that is, the distance between the cover slip and the slide surface) have problems. In thick slides, the pollen grains can overlap and be obscured or it can be difficult to get the grains in focus where they ''float'' to different depths in the oil. Moreover, if too much suspension is used, it will squeeze out under the edge of the cover slip and spread across the slide. Such slides are virtually useless, in part because the oil film prevents proper adhesion of the seal (see below). Most common laboratory solvents (e.g., ethanol) are ineffective for removing excess oil from the slide.

For thin slides, when pollen was mounted in glycerine jelly, Cushing (1961) found that the cover slip's weight can squash the grains, causing distortion or compression in their size. This is clearly undesirable because, as noted earlier, size is an important identification criterion. The problem was less acute with silicone oil suspensions. He suggested adding a few grains of fine sand to the mount to support the cover glass (Cushing 1961). Moore et al. (1991) suggest that cover slip supports (small pieces of clay) can be used to prevent grain compression. I have not found such supports necessary, because the mounting techniques for reference and subfossil samples are similar. I am not aware of any pollen collection where such supports are regularly used.

Slides and cover slips should be clean and dust- and grease-free; it may be necessary to clean them with ethanol before use (Wood et al. 1996). Slides should be labelled before the residue is placed on them. It is good practice to have only one vial opened at any time, to prevent accidentally mixing up samples or cross-contaminating them. I generally use standard 3 inch × 1 inch (75 mm × 25 mm) glass slides, which have a thickness of about 1 mm. If frosted-end slides are available, labels can be written directly on the slide using indelible or India ink. Otherwise, information can be printed or written on labels and affixed to the slides. In recent years, I have been using Avery brand white multipurpose 1 inch × 0.5 inch (2.54 cm × 1.27 cm) labels and found them satisfactory, even under repeated handling.

I use round cover slips (22 mm diameter, No. 1 thickness) for reference pollen samples (Fig. 2c), to help distinguish them from the subfossil sample slides, which are prepared with square or rectangular cover slips. Cover slips of this thickness (0.13–0.17 mm) are robust enough to withstand repeated slide handling and are optimal for most microscope objectives (see Wood et al. 1996).

It is common practice to seal slides. There are three main reasons for this. First, it is easy to bump the cover slip and damage the slide beyond further usefulness as it is moved onto and off the stage. Reference pollen slides, which are viewed many times, are especially vulnerable to such damage. Second, when examining the slide, pollen analysts usually compress the cover slip slightly with a dissecting needle to move or rotate the pollen grains. In unsealed slides, this causes the oil to squeeze out from under the edge of the cover slip and, often, air bubbles then intrude under the slip. Third, it is often necessary to examine pollen morphology using oil immersion. It is nearly impossible to clean immersion oil from unsealed slides.

For silicone oil preparations, clear nail polish is the generally recommended sealant (see Anderson 1965). Using the applicator or a fine brush, a thin bead of nail polish is applied around the edge of the cover slip. The nail polish seal should just overlap the edge of the cover slip but not extend far across it. I usually leave the slides overnight to allow the nail polish to harden thoroughly and cure before inspecting them. The formulation of commercial brand-name nail polishes varies (Draelos 2000). I have found Sally Hansen® brand "Hard-as-Nails"® clear polish the most satisfactory for sealing slides (www.sallyhansen.com).

Even sealed slides are vulnerable to some types of damage. Anderson (1965) reports that nail polish can be attacked by anisole, which is sometimes used as immersion oil. I use Cargille Type A immersion oil (www.cargille.com/immeroil.shtml), which does not appear to affect the seal. More serious is an apparent interaction between the nail polish and the silicone oil, leading to deterioration of pollen grains, a phenomenon known as "pollen pox" after Cushing (1993). He suggests that this might be due to dibutyl phthalate, a plasticizer commonly used in nail polish, diffusing through the oil to the

pollen. He reports that this compound deteriorates pollen exines experimentally. However, due to its known health effects, the use of dibutyl phthalate in nail polish is now being phased out (De Orsi et al. 2006) in many jurisdictions, including Europe (see directive from the European Commission 2004) and California (see chemical list from the State of California 2010), although it apparently is not banned for cosmetic use in Canada (Health Canada 1994). It now is possible to purchase phthalate-free nail polish (see list at www.ewg.org/node/21288). This suggests that pollen pox from this source should diminish as a problem. Some recent discussions on the POLPAL-L discussion list (January 2010 and Grimm pers. comm. 2010) suggest that incomplete evaporation of TBA also might play a role. A more thorough examination of this problem is awaited. The severity and occurrence of this phenomenon seems to vary widely between different collections. I have not noticed this being a significant problem in slides in the PRC at our Museum.

If handled carefully, by their edges, these pollen reference slides will last for decades, even with regular use. However, remaining residue always should be retained so that additional slides can be prepared as needed or if slides deteriorate beyond usefulness. Moreover, palynologists regularly swap or trade reference pollen samples and an adequate supply of residue is also useful to provide slides for such exchanges.

After preparing slides, they should be inspected for pollen concentration and quality of the preparation from processing. At this stage, if the pollen is sparse or poorly preserved, it might be advisable to repeat the processing with more of the plant material—another good reason to collect plenty of material in the field! The quality of the preparation (''pollen sparse'' or ''pollen abundant and well-preserved'') should be included in the sample record.

Because the pollen is suspended in oil, there is a tendency for it to drift and accumulate along one edge of the slide if the slide is stored upright. Hence pollen slides always should be stored flat in trays or slide boxes (Fig. 2d). A slide cabinet with trays is the most practical means of storing reference slides. Pollen types within genera and, often, families usually have similar morphologies. Therefore it is most useful to store slides in trays by family, arranged alphabetically by genera within the family. This facilitates use of the collection because a family tray can be removed and taken over to the microscope so that several taxa can be rapidly examined and studied to find a match for a grain in a subfossil preparation. For this purpose, I generally have a second compound (biological) microscope set up, so that comparisons can be made without removing the target grain from the counting scope. A subfossil sample might contain 50 or more taxa, necessitating frequent consultation of the reference collection.

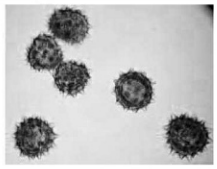
Record-Keeping and Databases

The Pollen Reference Collection database at the Royal Alberta Museum is currently built in FileMaker® Pro 11 software (www.filemaker.com). The database has a flat-file format, although it would lend itself to a relational structure (Fig. 3). Database records should contain standard information (e.g., habitat, place of collection, collector, date of collection) as well as details of the processing (e.g., processed by, date of processing) and any relevant collections management information (such as tray number). However, besides these purely administrative details, it is extremely useful to include basic descriptive and metric data about the taxon, such as morphotype (e.g., triporate, tricolporate, periporate), surface sculpturing and ornamentation (e.g., striate, verrucate, echinate), and overall shape (e.g., prolate, oblate, subtriangular outline). Measurements

Royal Alberta Museum
POLLEN REFERENCE COLLECTION

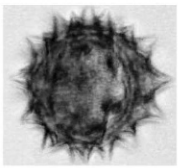
FAMILY **Compositae** GENUS Achillea SPECIES millefolium
VARIETY / SUBSPECIES
REFERENCE NUMBER R00804 AUTHORITY L.
SOURCE NUMBER Field number 4 ALT PLANT FAMILY Asteraceae
SOURCE SCAPE Project COMMON NAME Common Yarrow

FIELD COLLECTION DETAILS DATE OF FIELD COLLECTION 13/07/2000
PLACE OF COLLECTION Cypress Hills: in immediate vicinity of Stampede Site
PROVINCE OR STATE Alberta ELEV ca. 4000 DEC_LAT 49.668056
COUNTRY Canada DEC_LONG 110.252778
HABITAT AT COLLECTION SITE Wooded area, mainly aspen



HABITAT Moist meadows, woods and clearings; Prairies, Parkland, Boreal forest and Rocky Mountains.
IN HERBARIUM? N HERBARIUM COLLECTED BY A. B. Beaudoin

PROCESSING DETAILS
PROCESSED NaOH wash, acetolysis, staining, silicone oil
DATE PROCESSED 3/10/2002
PROCESSED BY D. Keller
ADDITIONAL MATERIAL AVAILABLE Y COMMENTS
SLIDE Y VIAL Y
SLIDE QUALITY Good
COMMENTS ON SLIDE Abundant grains, clearly visible. Very little debris present



POLLEN DESCRIPTION
MORPHOLOGICAL CATEGORY Tricolporate
POLAR VIEW Circular
EQUATORIAL VIEW Circular
POLAR DIMENSION 26
EQUATORIAL DIMENSION 26
POLAR VIEW DESCRIPTION
EQUATORIAL VIEW DESCRIPTION
POLAR AREA Small
PE CATEGORY Spheroidal
PE INDEX 1
SCULPTURING Echinate
OTHER DESCRIPTION Colpus long and wide. Tectate. Exine thick-walled. Spines short and thick.

REFERENCES DATE ADDED TO REFERENCE COLLECTION 06/11/2008
REFERENCE
LITERATURE 1 Kapp (1969: 153-154) - general key to Compositae pollen
LITERATURE 2 Moss (1983: 526) - distribution map, p. 657
LITERATURE 3
NOTES SCAPE Project Tray 3

DATABASE MANAGER Alwynne B. Beaudoin **DATE GENERATED** 12/1/2010

Figure 3. Record from the Pollen Reference Collection database, showing typical information recorded for the preparation quality.

of polar and equatorial dimensions are also valuable. Measurements should be done with an eyepiece micrometer, calibrated against a stage micrometer. For statistical reasons, measurements should be made on a minimum of 30 well-preserved grains, and the means and standard deviations computed and included in the record. In subfossil preparations, pollen grains often do not present in the most diagnostic orientation. Having several descriptive fields and measurements in the database allows the user to search and narrow

down the field of possibilities using a subset of a complete description (e.g., prolate tricolporate grain, about 32 μm in polar length).

In recent years, I have been adding digital images to the database records (Fig. 3). Each taxon record usually includes two images, either of a single grain in polar and equatorial view, or a single grain (generally at 400× magnification) and a group of grains (generally at 250× magnification). Our compound microscope does not have the capability of accommodating a trinocular head. However, I have had good success at imagery using a low-tech approach, consisting of a digital camera (Nikon Coolpix 995 or Canon PowerShot G7) mounted on a tripod and shooting down one of the eyepieces. Camera mounts or adapters (e.g., from Martin Microscope, www.martinmicroscope.com), which allow the digital camera to be affixed to the eyepiece tube, produce images of comparable quality to those from trinocular tubes (Hastings pers. comm. 2010; Jarzen pers. comm. 2010). Although verbal or written descriptions of pollen grains are useful, the images are far more helpful as a first cut when trying to identify mystery grains. Digital images are captured at the highest resolution. However, these images are too large, both in pixel width and file size, for incorporation in the database. Hence all images are cropped, reduced to thumbnails, and saved in lossy (.jpg) format. This produces a compact image that can readily be incorporated in the database without greatly inflating the file size. The PRC database currently occupies 1.41 gigabytes of storage; the thumbnail images occupy about 183 megabytes.

Although each slide should contain the pollen of only one taxon, it is very common to find a variety of pollen types on the slide. This is especially the case with entomophilous taxa where insects can leave pollen from other plants they have visited. Occasionally, the residue can be almost entirely devoid of the target pollen type and only consist of such extraneous pollen types. In our region, for example, it is very common to find large quantities of birch grains in reference pollen samples. This can be very confusing for novice palynologists who are trying to use the reference samples to identify unknowns. Hence, it is useful to take pictures of the target pollen type for inclusion in the database so that users can be sure they have found the right taxon on the slide. Such problems could be minimized, but not eliminated, by selecting and processing only individual anthers, rather than whole flowers.

The inclusion of geospatial information (decimal latitude and longitude values) allows the sample data to be used in GIS (geographic information systems) presentations. In this way, a mapped summary of the collection could be generated and tied to other information, such as plant distributions or subfossil pollen collecting sites. This has advantages for visualization and also can help to identify gaps within the coverage of the collection.

Acknowledgments

In recent years, several summer students have worked on the pollen reference collection database, focusing especially on capturing and processing digital images. It is, therefore, my pleasure to acknowledge the help of Brendan Seale, Pauline Bodevin, and Keri Fisher. I also thank Margot Brunn, Conservator at the Royal Alberta Museum, and Roxy Hastings, Curator of Botany at the Royal Alberta Museum, for useful comments on earlier drafts of this paper. Helpful feedback from the journal's reviewers, D.M. Jarzen and M.C. Peñalba, also significantly improved the paper.

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THE INSTITUT QUÉBÉCOIS DE LA BIODIVERSITÉ (IQBIO) AND NATURAL HISTORY COLLECTIONS IN QUEBEC

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Abstract.—Two Canadian provinces lack a state museum of natural history, Quebec and Prince Edward Island. In Quebec, this governmental negligence in a province with such a large continental territory adjacent to extensive marine areas prompted a group of concerned scientists in 2004 to incorporate the Institut québécois de la biodiversité (IQBIO), a nonprofit organization dedicated to the knowledge and preservation of Quebec's biodiversity. In 2003, the group had received a grant from the Quebec Government in order to survey, through visiting committees, the numerous natural history collections scattered in Quebec and create a first register. The register now lists 242 collections, defined by major taxonomic and ecological criteria, held by 126 owners, 72 (57%) of which are private scientists and amateurs without any governmental or institutional mandates and attendant resources, 23 (18%) are universities or colleges, and only 14 (11%) are governmental agencies. Most collections (216) are based on taxonomic samples, and only 26 contain ecological samples. Taxonomic collections mostly are devoted to insects (27%) and vascular plants (14%), followed by fungi (7%) and birds (6%). A few major collections will be preserved with high standards in the new Montreal Biodiversity Centre (now under construction), but without a complementary major infrastructure, many important collections, especially of vertebrates and aquatic invertebrates, will remain dispersed, underfunded, and at risk in the near future.

Introduction

Most scientists know that much of the knowledge on biodiversity is acquired through natural history collections accurately documented and preserved over long periods of time, because most of natural biodiversity consists of very small individuals of species which cannot be identified nor counted and measured in the field. These samples require microscopic examination of tiny morphological characters. This scientific activity has been extremely time-consuming until now and will probably remain so for some time. Molecular genetic tools such as the "barcode of life" (DNA) now are under scrutiny with the hope of accelerating the essential task of species identification in collections, thereby assisting conservation efforts. The samples in collections nevertheless will retain their great importance in such endeavours.

Two Canadian provinces, Prince Edward Island and Quebec, lack a governmental museum of natural history with a mandate and attendant recurrent resources to improve fundamental knowledge on the biodiversity of their territory. Although Quebec's territory (1,542,056 km^2 in area) ranks second in Canada (15.4%), next to the northern Nunavut Territory (21.0%), it is surprising that the Quebec Government has neglected in recent years to establish such a public museum.

Moreover, Quebec's marine coastlines are extensive: 13,323 km in the Estuary and Gulf of St. Lawrence, Hudson Strait, and Hudson and James Bay. By contrast, the smallest province in Canada, Prince Edward Island, has a mere 5,660 km^2 of territory (0.1% of Canada) and only about 1,260 km of marine coastline in the Gulf of St. Lawrence. The absence of a PEI natural history museum thus is easier to justify.

Historical Overview

Natural history collections in Quebec have been developed mostly in two distinct traditions by the so-called ''two solitudes,'' that of the English-speaking community and that of the French Canadians. In the 19th century, collections were gathered by the Natural History Society of Montreal (NHSM 1828–1926) and by the Geological Survey of Canada (created in 1844). The latter was the owner of a museum in Montreal prior to its move to Ottawa in 1881 and ultimately became the present Canadian Museum of Nature. Sir William Dawson, Principal of McGill University from 1855 to 1893, also assembled paleontological and marine zoological collections which were stored in his Redpath Museum, built on campus in 1882. It received the collections of the NHSM when the latter closed in 1926. Specimens of comparable historical value also were stored in the Lyman Entomological Museum and the Herbarium of McGill University in its Sainte-Anne-de-Bellevue campus on western Montreal Island.

French Canadian Catholic priests and other clerics long have played a significant role in natural sciences and the development of natural history collections in Quebec. One such pioneer was Abbé Léon Provancher (1820–1892), a parish priest from the Quebec City region who described many species of insects, especially Hymenoptera, and built important private collections of insects, plants, and molluscs. He also single-handedly founded and published the first natural history journal in Canada, *Le Naturaliste canadien,* as well as taxonomic monographs on Quebec insects, vascular plants (*Flore canadienne*), and molluscs. After his death, the largest portion of his historical collections was transferred to a governmental museum founded in 1880 in Quebec City. After having added other natural history collections but gradually changing to emphasize art collections, this public museum chose in 1962 to part with all of its long-neglected natural history collections. These were either dispersed, destroyed or, happily for the Provancher collections, given to Université Laval in Quebec City.

Another eminent clerical naturalist, Brother Marie-Victorin (1885–1944) (see Lloyd and Brunel 1944), began studying and collecting Quebec vascular plants around 1903, published extensively in *Le Naturaliste canadien,* became Professor at the Université de Montréal in 1921, and Director of its Botanical Institute. In 1935 he published the *Flore laurentienne,* a monograph on vascular plants of southern Quebec. Through his competence and charisma he became a prominent public figure in Quebec society and managed to convince the Quebec Government to start building the Montreal Botanical Garden during the Great Depression. The Marie-Victorin Herbarium, owned by the Université de Montréal, now is the largest in Quebec and one of the three largest in Canada. Marie-Victorin also was a key figure in the multiplication of the Cercles des Jeunes Naturalistes (see Préfontaine, 1940) in the 1930s. Through these clubs for youngsters, many clerical teachers promoted the study of nature and the gathering of natural history collections in private and public schools and colleges throughout the province. It is my personal hypothesis, however, that many of them may have been inspired by Marie-Victorin on account of his religion more than by his scientific expertise. Despite their obvious good will and dedication, these teachers might not have projected on their pupils and students an image of scientific competence.

Some of their static collections might have been viewed as ''dusty useless accumulations'' of objects by those good students who later became decision-makers in Quebec. Like Marie-Victorin, several clerics nonetheless managed to become taxonomic experts, holding private collections later bequeathed mostly to universities and now bearing their names.

Recent Revivals

In 1993, a small group of Quebec scientists became worried by the lack of success of some committees who had recommended the creation by the Quebec Government of a public natural history museum with a clear mandate for biodiversity research based on good collections. The group started to meet formally (e.g., Prescott 1994) and informally, hoping to make progress in the digitalization of data from natural history collections. However, much time was devoted to computer technology, which had not yet become very powerful and user-friendly, at the expense of collection care and biological data acquisition. After some dormancy, the group managed to revive in 2003 and took advantage of a new Quebec program designed primarily to survey private natural history collections in Quebec. To be eligible for funding, the informal group had to delegate management of its grant to an entomological non-profit organization, the Entomofaune du Québec, founded in 1982 to serve entomology, by ant taxonomist André Francoeur, a pioneer member of IQBIO. The grant provided funds for a technical assistant, for traveling expenses of visiting committees of experts to gather detailed metadata on the small, medium-size and large collections dispersed across the Quebec territory, and for the report (Brunel 2004) on a first register of these collections.

An expanded group of concerned scientists finally asked for incorporation on its own, leading to the creation of the Institut québécois de la biodiversité (IQBIO) in February 2004. The first Annual Meeting gathered 25 "founding members" on 4 April 2004 (Fig. 1). They defined the basic objectives of this new network, which are to: (1) increase fundamental knowledge on Quebec's biodiversity, especially through research collections; (2) build and update a register of metadata on all natural history research collections known to occur in Quebec; (3) offer services to its members, especially through exchanges of relevant information among them; (4) disseminate knowledge on Quebec biodiversity; and (5) lobby for greater resources for collections. For instance, along with early initiatives for newsletters and a Web site (www.iqbio.qc.ca), decisions recently were made to launch an online series of refereed *Bulletins scientifiques de l'IQBIO* and to maintain a library of relevant literature on the taxonomic and ecological biodiversity of Quebec's territory and adjacent seas and biogeographic zones. Another more recent and independent sign of some revival of interest for Quebec's collections, the Montreal Biodiversity Centre, is discussed below.

The IQBIO Register of Collections

The final report to the Quebec government on the collection survey was filed in March 2004 (Brunel 2004), but the granting program was apparently discontinued and IQBIO could not apply for further support. But the register of Quebec collections was started, and some progress is documented below. Given the expected magnitude of the survey, it was agreed to focus on dead collections with sufficient documentation to consider them as having research potential, and to exclude for the time being all paleontological collections as well as collections of living specimens. Specimens stored for teaching or exhibition purposes without adequate data thus were not considered, unless they had exceptional historical value, such as many of those preserved by Abbé Léon Provancher during the 19th century.

Collections then were defined using both scientific and ownership criteria. **Scientific criteria** were those of major taxonomic levels of classification (kingdoms, phyla, and classes), and major ecosystems (terrestrial, fresh-water, and marine). Additional scientific criteria distinguished between collections of **taxonomic biodiversity**, i.e., sorted samples

Figure 1. Seventeen of the 25 founding members of Institut Québécois de la Biodiversité (IQBIO) at the first Annual Meeting held at the Université de Montréal on 4 April 2004. Left to right, front row: Peterjürgen Neumann (Biology, Université de Montréal), Jean Dubé (Quebec Ministry of Natural Resources and Wildlife), Jacques Prescott (Quebec Ministry of the Environment); middle row: André Francoeur (Entomofaune du Québec, Université du Québec à Chicoutimi), Pierre Brunel (Biology, Université de Montréal), Huguette Massé (Quebec Ministry of Natural Resources and Wildlife), Isabelle Picard (Private Consultant), Christiane Hudon (Environment Canada), Laurent LeSage (Agriculture and Agri-Food Canada), Geoffrey Hall (private consultant); back row: Claude Chantal (President, Association des Entomologistes amateurs du Québec), Serge Parent (Biodôme de Montréal, City of Montréal), Pierre Richard, (Geography, Université de Montréal), Jean-François Desroches (private consultant), Guy Baillargeon (Agriculture and Agri-Food Canada and Global Biodiversity Information Facility), Yves de Lafontaine (Environment Canada), and Cyrille Barrette (Biology, Université Laval).

identified to various levels below that of the three highest taxa, and those of **ecological biodiversity**, which are unsorted or partly sorted samples of whole ecological communities, mostly aquatic. For example, the register contains metadata on taxonomic collections of terrestrial molluscs, freshwater molluscs, and marine molluscs. It also lists collections such as freshwater or marine zooplankton, freshwater or marine zoobenthos or phytobenthos, land soil collections, and freshwater or marine parasites. To avoid excessive splitting of taxonomic collections, only those collections of the different classes of arthropods and of the phylum Mollusca were distinguished, because these two phyla contain the largest number of described species. All other smaller phyla of invertebrates simply were labelled ''Collections of marine invertebrates.'' No attempt was made to use an up-to-date classification of the numerous groups of ''algae,'' now variously pigeonholed in the kingdoms Plantae, Protoctista, and sometimes newer ones.

Ownership criteria distinguished between collections belonging either to governments, universities and colleges, private institutions, or private individuals. In order to retain the

traditional usage of the word ''herbarium,'' this uncapitalized word refers only to a collection of vascular plants (Tracheophytes), whereas the word ''Herbarium'' refers to the ownership of different collections that are not even plants any more, such as Fungi or lower algae, or of nonvascular plants such as mosses (Bryophytes). Another arbitrary choice was to exclude the numerous Canada-wide collections stored in the Natural Heritage building of the Canadian Museum of Nature, which has been built in Gatineau, Quebec, a federal institution with headquarters in Ottawa, Ontario.

The IQBIO register first was based on previous knowledge about the existence of major collections present within Quebec (Brunel 1994). With a log sheet of abundant metadata to be manually recorded on site at first, visits started on 10 January 2003, always led by the author accompanied by at least one expert on the taxonomic nature of the collection to be examined. In addition to the basic metadata on site, ownership, names of responsible persons, and a checklist of collections still extant, the visiting committee members noted metadata on the size, history, staff, and financial resources of the collection, as well as its essential taxonomic and biogeographic contents. Repeated visits to a single collection sometimes were required. A statistical summary of the visits achieved prior to 31 December 2003, given in Brunel (2004) and partitioned according to the type of ownership, is presented in Table 1. It records only the number of existing collections at that time, and completely ignores information on their size.

Of the 195 collections then listed in the register, the largest proportion (36.4%) of research collections are owned by institutions with teaching and research mandates, mostly universities without any mandate for conservation of collections. Next in importance are private amateur and professional individuals (23.1%), also deprived of any conservation mandate. Governmental agencies having such mandates hold a mere 17% of research collections, all of which are designed primarily to serve economic lobbies such as agricultural, forestry, commercial fishery, sport hunting, and fishing interests, bent on knowing all about useful or harmful species. In general, individual scientists who maintain collections for their research activities in universities (16.9%) and in governmental agencies (2.0%) might be added to those having collections at home (23.1%), which means that 42% of all research collections in Quebec are preserved without any governmental mandate and attendant resources to do so.

The IQBIO register has been updated more slowly after 2003, relying on resources from its faithful institutional and individual members and a small governmental contract for collection-based data on invasive species, and much free time provided by its voluntary leaders. A list updated to 31 May 2010 shows progress since 2003. The absolute number of collections has increased (242) but few significant changes in the percentages have occurred. Several collections have disappeared from the register, whereas others with comparable ownership have been identified.

For instance, the Rolland-Germain Herbarium, which was the third largest in Quebec and was held in poor storage conditions by the Université de Sherbrooke, was offered by that university to the two largest in the province, the Marie Victorin Herbarium (Université de Montréal) and the Louis-Marie Herbarium (Université Laval). An agreement was made to allocate specific samples to either receiving institution. In 2008 the private home of a professional biologist burned down, destroying his four collections. On the other hand, looking for data on invasive insects, IQBIO recorded in 2007 possibly significant new amateur collections that were added to the register, but funds and time

Table 1. Progress of visits and documentation of metadata on Quebec's natural history collections prior to 31 December 2003 and between 31 December 2003 and 31 May 2010.

Number of collections with different types of ownership	2003									2010								
	V1	V2	V3	V4	V5	All *n*	%	All *N*	%	V1	V2	V3	V4	V5	All *n*	%	All *N*	%
Governments[a]	1	15	1	16	0	33	16.9	104	53.3	9	11	8	15	2	45	18.6	108	44.6
Teaching[b]	14	22	17	18	0	71	36.4			17	21	9	14	2	63	26.0		
Private, stored in institution																		
Government	0	0	1	3	0	4	2.0		0	2	3	7	0	12		5.0		
Teaching	2	4	11	16	0	33	16.9	46	23.6	6	10	5	13	1	35	14.5	71	29.3
Private	7	2	0	0	0	9	4.6		6	6	4	5	3	24		9.9		
Private home																		
Amateurs	16	4	2	22	1	45[c]	23.1	45[c]	23.1	13	3	1	31	1	49[c]	20.2	63[c]	26.1
Professionals										3	6	0	4	1	14	5.8		
Total	40	47	32	75	1	195		195		54	59	30	89	10	242		242	
%	20.5	24.1	16.4	38.5	0.5		100.0		100.0	22.3	24.4	12.4	36.8	4.1		100.0		100.0

V1 = Collection visited and completely documented on paper form.
V2 = Collection visited but still incompletely documented on paper form.
V3 = Collection visited but not yet documented.
V4 = Owner or witness personally contacted, collection existence confirmed.
V5 = Past existence of collection known but not yet confirmed.
[a] Municipal, regional counties, provincial, and federal.
[b] State-supported universities and colleges.
[c] Choice among collections is based upon expert advice until scientific value is documented through visit.

Table 2. Types of taxonomic biodiversity collections listed in the Institut Québécois de la Biodiversité (IQBIO) register of Quebec's natural history research collections as of 31 May 2010.

Taxon	*n*	%
Insects	59	27.3
Tracheophytes (= herbaria)	31	14.3
Fungi	15	6.9
Birds	13	6.0
Mammals	10	4.6
Mosses	10	4.6
Marine invertebrates[a]	8	3.7
Freshwater fishes	8	3.7
Marine fishes	7	3.2
Arachnids	7	3.2
Freshwater algae	7	3.2
Freshwater invertebrates[a]	6	2.8
Amphibians and reptiles	6	2.8
Freshwater molluscs	5	2.3
Marine algae	5	2.3
Marine molluscs	4	1.8
Myriapods	3	1.4
Plant morphological parts (e.g., pollen grains)	2	0.9
Terrestrial molluscs	2	0.9
Freshwater parasites[a]	2	0.9
Marine parasites[a]	2	0.9
Terrestrial parasites[a]	2	0.9
Terrestrial invertebrates[b]	1	0.5
Histological sections of vertebrate brains[c]	1	0.5
Subtotal	216	100

[a] Miscellaneous phyla and classes other than arthropods and molluscs.
[b] Tardigrades.
[c] Mostly mammals.

did not allow for the required visits. The IQBIO register of collections is still far from complete, and is not yet stored in a state-of-the-art computerized database.

Metadata on the **taxonomic biodiversity** of Quebec's collections (Table 2) show a distinct dominance of insects, followed by vascular plants. Apart from the documented natural dominance of those major taxa, this might well reflect the past taxonomic specializations of Quebec biologists and their decisions to preserve their collection or not. The relative ease of collecting the natural abundance of insects and plants in one's backyard, as opposed to the costs of dredging marine invertebrates or trawling fishes, for instance, most probably is an important factor in such taxonomic dominance. It also might be observed that taxa without obvious commercial value such as terrestrial and aquatic invertebrates other than insects are poorly represented in the register.

Collections of **ecological biodiversity** (Table 3), which are not part of the long taxonomic tradition of natural history museums, are few in number and largely restricted to aquatic communities. These usually are sampled with plankton nets, bottom trawls, dredges, and grabs. Benthic samples often even include the sediments from which the animals must be sorted. Analogous ecological samples of terrestrial soils and marine benthic vegetation (plants and algae) have not been found yet. The register is useful in pointing out such omissions and stimulating more active searching.

Table 3. Numbers and types of ecological biodiversity collections listed in the Institut Québécois de la Biodiversité (IQBIO) register of Quebec's natural history research collections as of 31 May 2010.

Collection	*n*
Marine phytoplankton	4
Marine zooplankton	4
Marine zoobenthos	7
Estuarine zooplankton[a]	1
Freshwater phytoplankton	3
Freshwater phytobenthos	2
Freshwater zooplankton	3
Freshwater zoobenthos	1
Terrestrial plant diseases	1
Subtotal for ecological collections	26
Subtotal for taxonomic collections	216[b]
Grand total for all research collections	242

[a] Restricted to the very large St. Lawrence Estuary ecosystem; other smaller estuaries are combined with marine ecosystems.
[b] From Table 2.

The various **types of ownership** of natural history collections in Quebec (Table 4) reveal that the number of owners (126) is about half that of collections, which means that each owner holds an average of two distinct collections. More interestingly, a very large number (72) and proportion (57%) of collections are owned by private individuals, and a very small number (14) and proportion (11%) of collections belong to governmental agencies. Finally, among institutions, universities and colleges hold more collections (23) than governmental agencies (14). This difference might be acceptable if universities, which have a mandate to develop knowledge, had received adequate funding from governments to house the major research equipment, staff it properly, and improve it with time through thorough exploration of biodiversity on Quebec territory and adjacent seas. This long-term responsibility, which generally is that of governments elsewhere, unfortunately has been largely neglected in Quebec.

The majority of individuals holding collections are amateur entomologists, mostly members of the Association des entomologistes amateurs du Québec. The president of that association confirms that this trend is distinctive of Quebec, at least among Canadian provinces. Many visits remain to be programmed in order to distinguish those collections that have real scientific value from those that are less valuable. Professional entomologists in universities and governments admit that much of taxonomic expertise in Quebec now relies on the enduring efforts of such amateurs preserving their private collections. For insects, large entomological collections are held by universities, where those smaller private collections are often ultimately deposited when their owner is no longer able or willing to keep them. To a lesser extent, the same can be said for herbaria, despite the insufficient resources allocated to universities for their care and conservation. But there is a great void for collections of aquatic invertebrates other than insects and for collections of vertebrates, all of which require significantly larger storage space. This illustrates how the lack of a public natural history museum endangers some important collections.

The catalogue of a collection obviously is a prime tool to summarize its metadata. Collection owners were thus queried as to the **availability of a catalogue**, especially in computerized format. Results of these metadata summarized as of 31 December 2003

Table 4. Numbers (N) and proportions (%) of types of collection owners in the Institut Québécois de la Biodiversité (IQBIO) register of Quebec's natural history research collections as of 31 May 2010.

Type of owner	*n*	%
Self-taught private taxonomic experts	38	30.2
State-supported universities or colleges	23	18.3
Professional university or college scientists hosted in their institution[a]	18	14.3
Professional governmental scientists hosted in their institution[a]	16	12.7
Governmental agencies[b]	14	11.1
Private museums (nonprofit institutions)	9	7.1
Professional consultants	6	4.8
Commercial enterprises	2	1.6
Total	126	100
Nonprofit individual owners (38 + 18 + 16)	72	57.1
University or college institutional owners	23	18.3
Governmental institutional owners	14	11.1
Nonprofit institutional owners	9	7.1
Professional consultants and commercial enterprises (6 + 2)	8	6.3
Total	126	100

[a] Scientists having collections for their research needs without any long-term conservation commitment from their institution or from granting agencies.
[b] Municipal, regional county, provincial, and federal agencies.

(Table 5) showed that a small proportion (33.4%) of collections had some form of catalogue, whereas 57.9% did not have any. An even smaller proportion (12.8%) of collections was completely digitized. These mostly are small ones, including some very well-curated private individual collections. Despite the lack of follow-up since 2003, to our knowledge, a single governmental collection has been completely computerized, that of freshwater fish owned by the Quebec Ministry of Natural Resources and Wildlife in Longueuil (south of Montreal). Digitization of the marine biodiversity collections of the Maurice Lamontagne Institute (Fisheries and Oceans Canada in Mont-Joli) had been put on an Access database, but was almost stopped when its curator was transferred to other responsibilities. This is symptomatic of the Quebec situation in which an equal number (11) of collections have been completely (C1) or incompletely (C2) computerized by governmental agencies and by private individuals at home, with more of the latter being able to keep theirs up to date.

The Montreal Biodiversity Centre

The Quebec predicament over its natural history collections has improved recently. The Université de Montréal and the City of Montreal, which have been closely associated under the roof of the Montreal Botanical Garden since the latter was founded by Marie-Victorin, have moved one step further by developing a partnership to launch the Montreal Biodiversity Centre (MBC). Major grants from the Canadian Foundation for Innovation and the Quebec Government, and a campaign to collect private funds by the municipal Muséums Nature de Montréal led to the construction of the MBC, due for opening in early 2011. This centre will house, with state-of-the-art conservation conditions, all samples of the Marie-Victorin Herbarium and the Ouellet-Robert Entomological Collection, both owned by the Université de Montréal, those of the Firmin-Laliberté Entomological Collection, owned by the Montreal Insectarium, and those of the Fungarium, owned by the Cercle des mycologues de Montréal, the largest

Table 5. Progress of data cataloguing in Quebec's natural history research collections as of 19 December 2003.

	Number of collections with different types of ownership							
			Private, stored in institution			Private home	Total	
Code	Governments[a]	Teaching[b]	Government	Teaching	Private	Amateurs + Professionals	*n*	%
C1	1	11	0	2	2	9	25	12.8
C2	9	12	0	3	2	2	28	14.4
C3	0	4	0	8	0	0	12	6.2
C4	4	6	1	4	0	2	17	8.7
C5	19	38	3	16	5	32	113	57.9
Total	33	71	4	33	9	45[c]	195	
%	16.9	36.4	2.1	16.9	4.6	23.1		100.0

C1 = Data completely computerized.
C2 = Data incompletely computerized.
C3 = Complete manuscript catalogue available.
C4 = Incomplete manuscript catalogue available.
C5 = No known catalogue at this date.
[a] Municipal, regional county, provincial, and federal administrations.
[b] State-supported universities and colleges.
[c] Choice among collections is based on advices until scientific value is documented through visit.

North American association of mushroom amateurs. The MBC also will house the headquarters of Canadensys (www.canadensys.net), a consortium of major Canadian natural history collections in 11 universities, five botanical gardens, and two museums, funded mainly to digitize those collections, which include the Marie-Victorin Herbarium and the Ouellet-Robert Collection. This digitization already is underway.

The MBC was designed to house only the botanical, entomological, and mycological collections owned by the institutions named above. Although not numerous, they are very large collections adequately representative of Quebec's biodiversity in those taxonomic groups. And the mere existence of the Centre is likely to incite private owners to bequeath their collections of these taxa therein. One can cite the example of other major collections of insects and plants held by McGill University in Montreal and Université Laval in Quebec City; they already have attracted similar donations. Indeed, the MBC partnership between a university and a government, similar to that formerly in place between the University of Toronto and the Ontario Provincial Government to strengthen the Royal Ontario Museum, might well serve as a model for consolidating under Quebec jurisdiction the future conservation of collections and the development of fundamental biodiversity knowledge. Because Quebec universities have invested much in their collections without any significant help from the Quebec Government, they are not likely to let go easily of the research expertise and recognition acquired in the past.

Future Prospects

A **public infrastructure complementary** to that of the Montreal Biodiversity Centre is clearly needed for the permanent storage and study of valuable but dispersed and orphaned collections of vertebrates, aquatic invertebrates other than insects, parasites, and the like. Those taxa, as well as collections of ecological biodiversity, are ignored by the MBC, and they do not benefit from resources comparable to those devoted to vascular plants and insects in the province.

The importance of an additional and permanent infrastructure and **additional resources** for a more complete knowledge of Quebec's biodiversity will increase with time. Queries for solid collection-based data are bound to be addressed to those few biologists employed by the underfunded environmental and fish and wildlife services of the Quebec Government. Such pressures will arrive not only from militant environmental associations, but also from researchers in universities and other governmental services, from the media, from museums designing exhibits, from genuinely green corporations, and others.

At the moment, there is a need for an expansion of IQBIO's scientific network and services, especially for hiring staff to pursue the assessment of existing collections and to complete and computerize the register of metadata on the collections. Some relief for its voluntary administrators will then be welcome. Good governmental programs exist to fund biodiversity research, like that which recently funded the McGill University Centre for Biodiversity Research. None or only ephemeral ones exist to fund **research services**, including the time-consuming services rendered by research collections. Funding programs do support scientific journals, which are research services also. Very numerous public and private funding programs also can support field work at local or regional scales. Managers of these programs should realize that research collections are merely the most time-consuming part of a field survey in which the tiny species could not be identified nor measured outdoors and must be examined indoors! For that reason, they deserve adequate funding.

A **longer-term vision** evidently is required from politicians and public managers. A metaphor of mine has once proved convincing to a curator: ''One does not tear off from a dictionary all those pages that have not been consulted in the last budgetary year.'' Given that biodiversity ignores political frontiers, convincing political neighbours that in-house knowledge of Quebec's biodiversity is bound to help them should be sound cooperative politics. Political will obviously is essential, too. For example, former Quebec Premier Lucien Bouchard who likes reading and books strongly supported the proposal that Montreal should get the public Grande Bibliothèque, a dream which became a tremendous success after only 5 years. There is clearly a need for a quebec premier who likes animals, plants and mushrooms, but not just for fishing, hunting, or eating!

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Postscript: The institution known since its inception as the *Centre sur la biodiversité de Montréal (CBM)* [Montreal Biodiversity Center (MBC)] was inaugurated on 10 March 2011 under the new name *Centre sur la biodiversité de l'Université de Montréal (CBUdeM)* [Université de Montréal Biodiversity Center (UdeMBC)], according to the invitation that I received on 18 February 2011, too late to correct the section on that center in my paper.—P.B.

MICROFADE TESTING TO SUPPORT EXHIBIT DECISIONS: THE CATHARINE PARR TRAILL SCRAPBOOKS

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Abstract.—The Catharine Parr Traill Herbaria Collection consists of 25 scrapbooks compiled between 1866 and 1898, and is the largest known collection of her plant pressings collected in southern Ontario. This unique collection is relevant for research on species conservation and environmental change. Eleven of these scrapbooks were chosen for public presentation as a supplemental element in the exihibition "Barbara Gamble: Natural Affinities." Due to the known light sensitivity of many herbarium specimens, the pristine condition, and the value of the collection, it was necessary to determine the expected fading during exhibition. Light sensitivity of various elements of the scrapbooks were determined using the Oriel Microfade Tester. These elements include flower petals, algae, leaves, insects, inks, and crayons. Of the 89 locations tested, approximately 65% were categorized as having high sensitivity to light, and the remainder have medium sensitivity. Among the most sensitive are the orange moth, inscription inks, and pink and blue flower petals. Based on these results, six pages of the scrapbook that do not contain highly light-sensitive elements were chosen for the exhibit.

Introduction

Catharine Parr Traill and her Scrapbooks

Catharine Parr Traill and her husband Thomas arrived in the wilderness of Upper Canada in 1832 from Britain with dreams of a new life. Even though pioneer life in Canada turned out to be very difficult, Catharine Parr Traill was inspired by the natural beauty of her surroundings. She collected from and documented the natural world she experienced and noted the impact of development on the wildlife.

Catharine and her sister Susanna Moody became well-known pioneer icons. They wrote celebrated accounts of pioneer life in upper Canada including *Backwoods of Canada* (1836) and *Roughing it in the Bush* (1868). Catharine kept detailed journals documenting her new home. She also diligently documented the new landscape, climate, and distinctive flora. She collected and identified hundreds of plant specimens in scrapbooks and consulted widely with scientists. Her journals and herbarium scrapbooks were the foundation for a wide range of publications, most famously *Backwoods of Canada* and *Canadian Wildflower*. These accounts of the lives of early pioneers and their love of nature have the power to reach across time, and continue to inform and inspire people at the beginning of this new century.

The Catharine Parr Traill Herbaria Collection at the Canadian Museum of Nature consists of 25 scrapbooks compiled by Catharine and other family members between 1866 and 1899, and is the largest collection of her plant pressings. They consist mainly of plants species present in southern Ontario during the 1800s. The majority of the plants are mounted directly on scrapbook pages, but others are mounted on unbound sheets. Many pages contain hand-written notes of the plants description and their collection

data, often with scientific notes as to the species and location collected. She even included personal reflections. Plants and handwriting often were carefully arranged on pages to create aesthetic effect. Composite arrangements in the books consisted of various types of plants, flowers, insects, feathers, and writing. The condition of the scrapbooks varies greatly from better-quality scrapbooks, which are close to their original state, to poor-quality commercial books with inherently unstable bindings and paper.

Because this collection documents plants growing in these regions during the mid-1800s, it has scientific significance because it provides information on historical species distribution that can contribute to knowledge about nature conservation and environmental change. The scrapbooks are also culturally significant in that they demonstrate and document an approach to amateur botany that is characteristic of the time.

Exhibition of Catharine Parr Traill Scrapbooks

In 2008, the Canadian Museum of Nature was asked by Ottawa artist Barbara Gamble to exhibit some of the Parr Trail's scrapbooks as part of her restrospective exhibition "Barbara Gamble: Natural Affinities" because her naturalist paitings were greatly inspired by the famous pioneer. Both women shared a passion for nature, in particular plants, and both have devoted efforts into learning about and preserving the nature around them. Barbara Gamble chose a selection of pages from eleven scrapbooks as possible candidates to accompany her exhibit. Great care was taken in exhibiting the scrapbooks due to their inherent value and fragility, but particular care was given to address the issue of potential fading. The duration of the exhibit was planned for 90 days, 10 hours per day, 7 days per week, with no flash photography. At 50 lx, the total light exposure (ultraviolet [UV]-free) for the planned exhibit would be 45 klx-hr.

It is well known that most plant materials are very light-sensitive, resulting in color change and/or fading (Giles and MacKay 1963; Padfield and Landi 1966; Duff et al. 1977; Michalski 2010). This collection never had been exhibited and the colors are in pristine condition. Because of its significance, there is a high risk of loss in aesthetic, historic, and study values as a result of light exposure during exhibition. In order to assess expected color change and to establish an acceptable level of light exposure for the exhibition, items that were proposed for exhibition were tested for light sensitivity using microfade testing.

Microfade Testing

It is very difficult to obtain accurate light sensitivity data using conventional methods. Typically, this requires identification of the color components of an object and estimating their light sensitivity based on model samples of the same composition. This has enormous challenges because it requires destructive sampling, which often is not possible; identification of colorants, which is laborious and difficult, especially with organic dyes; and replicating matrices and exposure histories in model samples, which is difficult if not impossible. Alternatively, color monitoring programs have been used in an attempt to identify colorants that have high light sensitivity by detecting small changes in color over time. However, this approach requires consistent and meticulous execution, and equipment maintenance over time, and the biggest limitation is that it only can measure light damage after the fact, without the ability to predict future behaviour of the colorant.

Microfade testing (MFT) is a technique that overcomes these challenges and is uniquely able to predict light sensitivities of colorants, in their current matrix and state of preservation, through *in situ* measurements. This microdestructive technique was

developed by Paul Whitmore for identifying light-sensitive materials in museum and gallery collections (Whitmore et al. 1999, 2000; Whitmore 2002). The test involves directing a high-intensity, UV-free (~5–7 Mlx) light spot (0.25–0.4 mm diameter) directly on an object for the duration of the test, typically 10 minutes, then recording its visible spectra at set time intervals; this effectively records any color change that occur during light exposure. The technique is most useful for identifying colorants that have high light sensitivities (ISO Blue Wool 1–3). It complements color monitoring programs by identifying the areas that require long-term color monitoring—areas that are light sensitive.

Direct extrapolation of the light dose from the MFT (5–7Mlx) to museum light levels (50–150 lx) cannot be done accurately because of a very different dose-response relationship due to the magnitude of difference in light intensities (Tse unpubl. data 2008). In order to make use of the results from this technique, fading rates of test objects are compared to fading rates of well-characterized ISO Blue Wools standards, and the results are expressed as ''Blue Wool range'' or ''Blue Wool equivalence.'' The light dose for safe exhibition is estimated based on the equivalent Blue Wool (BW) standards.

Since 2008, the microfade tester has been used at the Canadian Conservation Institute to test various materials, including some of Queen Victoria's handwriting in iron gall ink; 19th century photographs; wool yarns with natural dyes and mordants; treatment materials such as digitally printed textiles and paper; oil and acrylic paintings; and herbarium specimens in the Catharine Parr Traill scrapbooks.

Experimental

Microfade testing was carried out using the Oriel Microfade Tester shown in Figure 1. Details of the construction and operation of the tester previously were described by Whitmore et al. (1999), and recent modifications of various systems have been summarized by Druzik and Pesme (2010). The light source is a 75 W xenon arc lamp. The light beam passes through a water filter, infrared filter and ultraviolet filter before entering the illuminating optical fibre. The illuminating and collector beams are focused using two sets of doublet achromatic lenses. The diameter of the light spot was estimated to be 0.3 mm using image analysis of the effective faded spot (Young 2008). An endoscope pencamera was used to locate and document the light spot on the test areas (Fig. 1).

Testing was carried out for 10-minute intervals, and spectral data were collected every 30 seconds using a spectrophotometer from Control Development, with Spec32 software. Color differences (Commission internationale de l'éclairage (CIE)) with time; and chromaticity co-ordinates L* (lightness), a* (red–green), and b* (yellow–blue) were calculated from the spectral data by the software. Further data processing was done using the Getty Spectralviewer (2006; software developed by L. Keene, made available by J. Druzik, senior scientist at the Getty Conservation Institute).

The pages and locations subjected to the MFT are given in Figure 2. During the test, the rest of the page was protected from exposure to room light by covering with four layers of acid-free tissues. The changes in appearance as a result of light exposure, or fading rates, are documented as changes in color (dE'94, dL*, da*, and db*) as a function of time. Along with the samples, the fading rates of standard ISO Blue Wools (BW 1–4) were measured each day as calibrating standards.

The light sensitivity for each test area was determined by comparing the rate of total color change during a 10-minutes exposure, to that of the BW standards. The results are

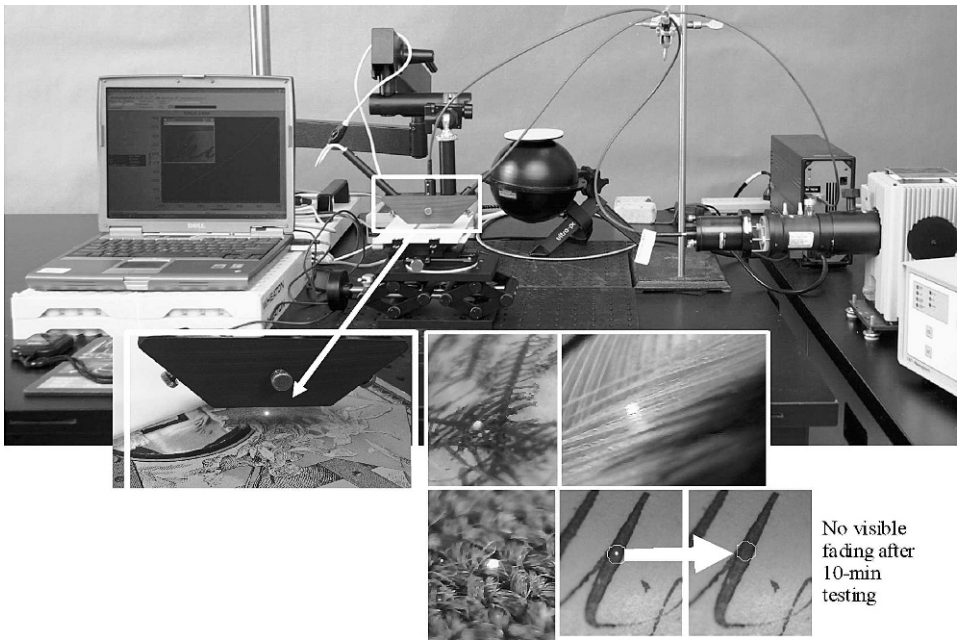

Figure 1. Oriel Microfade Tester, and light spot on test area viewed with the pencamera with the neutral density filter in place.

expressed as ''Blue Wool range.'' Based on the BW range, the light sensitivity categories can be determined: BW 1–3 have high light sensitivity; BW 4–6 have medium sensitivity and BW 7–8 have low sensitivity (Feller 1975; Michalski 2010). Estimated light dose to ''just noticeable fade'' (JNF) was calculated using guidelines by Michalski (1987, 2010). JNF is defined as Grey Scale 4 (GS4), the first step of fading used in the ISO lightfastness testing. It is important to note that the light dose to JNF are estimates based on averaged values obtained through an extensive literature review. The uncertainty in each dose to JNF estimate ranges approximately to the value for the adjacent Blue Wool (Michalski 2010). For example, the uncertainty range for dose to JNF for BW 1 with UV is between 0.09 and 0.6 Mlx-hr, the average is 0.22 Mlx-hr; without UV, the dose to JNF would be between 0.1 and 1 Mlx-hr, with an average of 0.3 Mlx-hr. Based on the average light dose to JNF, a calculation of years to JNF is estimated for three lighting scenarios (50 lx, 150 lx, 500 lx) assuming no prior fade, no UV, 10 hours light exposure per day, and 365 days per year.

Results

In total, 103 tests were carried out in 89 separate locations (Fig. 2). The spectral changes and the rate of change in L*, a*, b*, and dE'94 is illustrated in Figure 3, showing the fading of a blue flower, larkspur (genus *Delphinium*), on the ''Moth'' page. Test results for all locations after 10-minute tests, and the ''years to JNF'' for the three lighting scenarios are summarized in Tables 1–3 and Figure 4.

The results showed that 58 (65%) of the test locations belong to the high-sensitivity category, BW 1–3. The remaining 31 (35%) of the test locations are in the medium-sensitivity category, BW 3–4. The most light-sensitive element is the orange pigment in

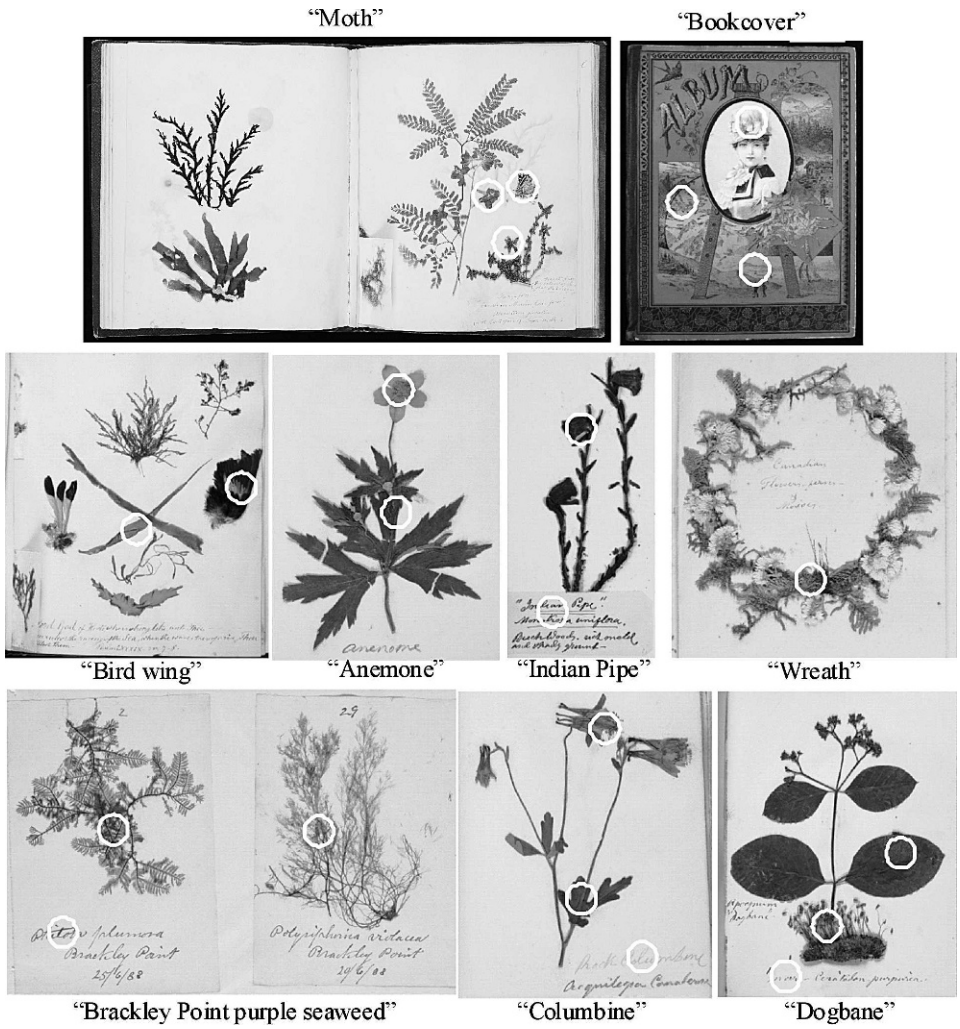

Figure 2. Pages and locations subjected to microfade testing.

the moth wing, *Apantesis virgo* Linnaeus (Lepidoptera: Arctiidae), falling between BW 1 and 2. Figure 5 shows the spectral changes of the orange moth wing, the rate of total color change (dE'94), and the change in color co-ordinates. Exposure to light resulted in an overall lightening of the orange pigment, with the loss in the red and yellow range of the optical spectrum. The shape of the fading curve (dE'94 vs. time), almost linear with time, suggests that these biopigments are present as large aggregates in the moth wing (Cox Crews 1987). In moths, the orange pigment granules can be sufficiently large to occupy a single wing scale (Scoble 1995). The current estimate is that in conditions of 50 lx, 10 hours per day, and year-round display, JNF could be observable in less than 2 years. With higher light levels, noticeable change would occur in less time.

Another group of highly light-sensitive (BW 1–2) elements are the inks, such as the dark inks on the ''Indian Pipe'' page, and the ink on the ''Brackley Point Purple

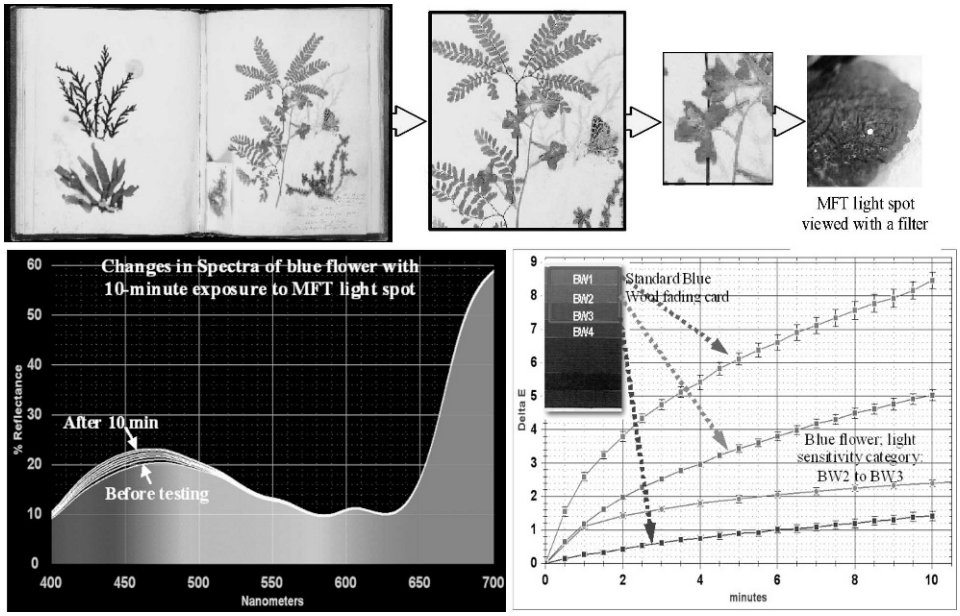

Figure 3. Example of microfade testing (MFT) test results: spectral changes and fading rates of larkspur (*Delphinium*).

Seaweed'' page. Other inks belong to the medium–high sensitivity group (BW 2–3). Most of these are believed to be iron gall inks; these inks are known to contain light-sensitive components (Tse et al. 2010), and their light sensitivity is affected by their composition (Reissland and Cowan 2002). Some of the inscription inks in this collection are very light in color. Because this collection has never been exhibited, we believed that the light ink colors are not a result of previous light exposure. The microfade test results showed that there is high expectation of further fading with light exposure, eventually resulting in loss of legibility. During testing, all the inks resulted in substantial increase in L*, or becoming lighter in color. Some inks, such as those on the ''Anemone'' page decreased slightly in a* (becoming less red), and others, such as those in the Indian Pipe page, increased in a* (becoming more red). All the inks increased in b*, becoming more yellow or less blue in color. At 50 lx, 10 hours per day, and on year-round display, noticeable fading could occur in less than 2 years, or sooner at higher light levels.

The flowers and the purple and green algae all have similar light sensitivities, in the medium–high category, the fading rates are between BW 2 and BW 3. This means that at 50 lx, 10 hours per day, and on year-round display, noticeable fading.could occur within 6–17 years, or sooner at higher light levels. The blue flowers on the Moth page (larkspur *Delphinium*), showed an increase in lightness, and a small decrease in green, but most of the color change is a result of decrease in yellow or an increase in blue. This loss of yellow could be fading of a yellow component of the flower petal. With the pink flowers on the ''Columbine'' page, *Aquilegia canadensis*, and the purple seaweed on the ''Birdwing'' page, there is an overall fading, increase in lightness, and decrease in red and yellow, of the pink in the petals. With the green algae and mosses, in most cases there is an increase in red or loss of green (a*), and loss of yellow (b*).

Table 1. Microfade test results for areas with high light sensitivity Blue Wools (BW 1–3) in descending order.

ID	Sample description (Page, location)	dL* at 10 min	da* at 10 min	db* at 10 min	dE'94 at 10 min	SD	BW range dE'94	BW equiv. dE'94	Estimated years to JNF 50 lx	150 lx	500 lx
	BW 1 (4×)				8.5	0.2	1	1	2	0.5	0.2
	BW 2 (slow; 4×)				5.0	0.2	2	2	6	2.0	0.5
	BW 3 (7×)				1.4	0.1	3	3	17	6	2
	BW 4 (1×)				0.6	0.03	4	4	55	17	6
10	Moth (CAN 588169), *Apantesis virgo* L. wing, orange	7.59	−11.01	−4.76	9.5		<1	0.7	<2	<0.5	<0.2
75	Indian Pipe (CAN Catherine Parr Traill CPT #26), dark ink (2×)	4.97	0.78	5.3	9.0	0.3	<1	0.8	<2	<0.5	<0.2
35	Brackley Point (CAN CPT #26), ink	3.63	−0.54	5.95	8.5		1	1.0	2	0.5	0.2
34	Brackley Point, ink	3.68	−0.25	5.82	8.0		1–2	1.1	2–6	0.7–2	0.2–0.5
9	Moth (CAN 588169), *Apantesis virgo* L. wing orange	5.95	−8.51	−1.79	7.8		1–2	1.2	2–6	0.7–2	0.2–0.5
76	Indian Pipe (CAN CPT #26), ink (medium)	0.73	0.1	2.55	4.7	0.2	2–3	2.1	6–17	2–6	0.5–2
65	Wreath (CAN 588165B), ink (dark)	1.82	−0.52	−1.39	3.2		2–3	2.5	6–17	2–6	0.5–2
89	Columbine (CAN 588166), purple crayon (2×)	2.52	−1.27	1.51	3.0	0.1	2–3	2.6	6–17	2–6	0.5–2
64	Wreath (CAN 588165B), ink (medium)	1.53	−0.02	−1.18	2.6		2–3	2.7	6–17	2–6	0.5–2
12	Moth (CAN 588169), larkspur (*Delphinium*) 1&4 (2×)	0.51	0.8	−3.99	2.4	0.2	2–3	2.7	6–17	2–6	0.5–2
13	Moth, larkspur (*Delphinium*)	−0.40	0.13	−2.27	2.4		2–3	2.7	6–17	2–6	0.5–2
77	Indian Pipe (CAN CPT #26), ink (light)	1.42	0.15	0.72	2.1		2–3	2.8	6–17	2–6	0.5–2
63	Wreath (CAN 588165B), ink (light)	0.21	0	−1.41	1.9		2–3	2.8	6–17	2–6	0.5–2
86	Columbine (CAN 588166) *Aquilegia canadensis* (3×)	1.15	−0.91	−1.13	1.9	0.1	2–3	2.9	6–17	2–6	0.5–2
28	Birdwing (CAN 588169), purple algae	0.99	−1.91	−2.23	1.9		2–3	2.9	6–17	2–6	0.5–2
22	Birdwing, purple algae	1.52	−0.67	−0.57	1.8		2–3	2.9	6–17	2–6	0.5–2
21	Birdwing, green algae (4×)	1.00	0.35	−3.06	1.7	0.1	2–3	2.9	6–17	2–6	0.5–2
33	Brackley Point (CAN CPT #26), algae (*Ptilota plumose*)	0.88	−2.49	−0.9	1.7		2–3	2.9	6–17	2–6	0.5–2
84	Anemone (CAN 588166), pink petal	1.57	−1.95	−0.76	1.7		2–3	2.9	6–17	2–6	0.5–2
61	Wreath (CAN 588165B), green moss (2×)	0.75	0.29	−2.36	1.7	0.2	2–3	2.9	6–17	2–6	0.5–2
78	Anemone (CAN 588166), paper (5×)	0.40	0.07	−1.74	1.6	0.1	2–3	2.9	6–17	2–6	0.5–2
36	Brackley Point (CAN CPT #26), algae (*Polysiphonia violacea*)	1.24	−1.38	−0.74	1.6		2–3	2.9	6–17	2–6	0.5–2

Table 1. Continued.

ID	Sample description (Page, location)	dL* at 10 min	da* at 10 min	db* at 10 min	dE'94 at 10 min	SD	BW range dE'94	BW equiv. dE'94	Estimated years to JNF 50 lx	150 lx	500 lx
14	Moth (CAN 588169), larkspur (*Delphinium*)	0.58	0.34	−1.88	1.6		2–3	2.9	6–17	2–6	0.5–2
80	Anemone (CAN 588166), leaf	0.45	−0.2	−2.38	1.6		2–3	2.9	6–17	2–6	0.5–2
87	Columbine, green leaf (2×)	0.79	−0.4	−1.15	1.5	0.01	3	3.0	17	6	2
31	Brackley Point (CAN CPT #26), Algae-*Ptilota plumosa*	−0.17	−2.57	−0.27	1.5		3	3.0	17	6	2
32	Brackley Point (CAN CPT #26), Algae-*Ptilota plumosa*	0.80	−2.05	−1.18	1.5		3	3.0	17	6	2
25	Birdwing (CAN 588169), purple algae	0.80	−1.46	−0.9	1.5		3	3.0	17	6	2
23	Birdwing (CAN 588169), purple algae	0.10	−1.88	−1.78	1.5		3	3.0	17	6	2
74	Indian Pipe (CAN CPT #26), purple flower	0.20	−0.45	−1.23	1.4		3	3.0	17	6	2
82	Anemone (CAN 588166), pink petal	0.67	−1.5	−1.78	1.4		3	3.0	17	6	2
72	Dogbane (CAN 588166), ink (2×)	0.92	−0.02	−0.1	1.4	0.1	3	3.0	17	6	2
83	Anemone (CAN 588166), pink petal	1.06	−1.44	−0.71	1.4		3	3.0	17	6	2

[a] No prior fade; no ultraviolet (UV); 10 hr/day; 7 days/week; 52 weeks/year.
BW = Blue Wool.
da* = Change in red–green.
db* = Change in yellow–blue.
dE'94 = Change in color.
dL* = Change in lightness
JFN = Just noticeable fade.
SD = Standard deviation.
x = Number of replicates.
'CAN' & 'CPT' are museum catalogue numbers.

Table 2. Microfade test results for areas with medium light sensitivity Blue Wools (BW 3–4) in descending order.

ID	Sample description (Page, location)	dL* at 10 min	da* at 10 min	db* at 10 min	dE'94 at 10 min	SD	BW range dE'94	BW equiv. dE'94	Estimated years to JNF[a]		
									50 lx	150 lx	500 lx
71	Dogbane (CAN 588166), flower (2×)	1.02	−0.42	0.27	1.2	0	3–4	3.3	17–55	6–17	2–6
88	Columbine (CAN 588166), green leaf	0.84	−0.42	−0.5	1.2		3–4	3.3	17–55	6–17	2–6
15	Moth (CAN 588169), pink flower	0.06	−1.09	−1.11	1.0		3–4	3.4	17–55	6–17	2–6
62	Wreath (CAN 588165B), green moss	0.57	−0.26	25	1.0		3–4	3.5	17–55	6–17	2–6
85	Columbine (CAN 588166), *Aquilegia canadensis* petal	0.75	−0.47	−0.35	1.0		3–4	3.5	17–55	6–17	2–6
11	Moth (CAN 588169) *Apantesis virgo* L., wing, black	1.04	−0.17	0.13	1.0		3–4	3.5	17–55	6–17	2–6
79	Anemone (CAN 588166), blue crayon (3×)	0.36	0.26	−1.12	1.0	0.04	3–4	3.6	17–55	6–17	2–6
68	Dogbane (CAN 588166), dark flower on moss	0.69	−0.52	−0.22	0.9		3–4	3.6	17–55	6–17	2–6
17	Birdwing (CAN 588169), orange feather	−0.94	−0.15	−0.82	0.9		3–4	3.6	17–55	6–17	2–6
18	Birdwing (CAN 588169), orange feather	0.28	−0.14	−0.81	0.9		3–4	3.6	17–55	6–17	2–6
27	Birdwing (CAN 588169), purple algae	0.41	−0.8	−0.63	0.9		3–4	3.7	17–55	6–17	2–6
24	Birdwing (CAN 588169), purple algae	0.05	−1.03	−0.97	0.9		3–4	3.7	17–55	6–17	2–6
70	Dogbane (CAN 588166), pink flower	0.88	−0.52	−0.36	0.8		3–4	3.7	17–55	6–17	2–6
19	Birdwing (CAN 588169), black feather	0.42	−0.1	−0.45	0.8		3–4	3.7	17–55	6–17	2–6
67	Dogbane (CAN 588166), flower on moss (2×)	0.5	−0.52	−0.18	0.7	0.1	3–4	3.8	17–55	6–17	2–6
73	Indian Pipe (CAN CPT #26), purple flower (2×)	0.27	−0.35	−0.51	0.7	0.01	3–4	3.8	17–55	6–17	2–6
69	Dogbane (CAN 588166), brown flower (2×)	0.66	−0.1	0.12	0.7	0.2	3–4	3.9	17–55	6–17	2–6
26	Birdwing (CAN 588169), purple algae (6×)	0.24	−0.77	−0.41	0.6		3–4	3.9	17–55	6–17	2–6
66	Dogbane (CAN 588166), green moss (3×)	0.16	0.11	−0.58	0.6	0.03	4	4.0	17–55	6–17	2–6
81	Anemone (CAN 588166), leaf (3×)	0.26	−0.23	−0.6	0.6	0.1	4	4.0	17–55	6–17	2–6

[a] No prior fade; no ultraviolet (UV); 10 hr/day; 7 days/week; 52 weeks/year.
BW = Blue Wool.
da* = Change in red–green.
db* = Change in yellow–blue.
dE'94 = Change in color.
dL* = Change in lightness
JFN = Just noticeable fade.
SD = Standard deviation.
x = Number of replicates.
'CAN' & 'CPT' = Are catalogue numbers & identifiers by the museum.

Table 3. Microfade test results for colors on the "Bookcover" (CAN 588167) with light sensitivity in descending order.

ID	Sample description (Page, location)	dL* at 10 min	da* at 10 min	db* at 10 min	dE'94 at 10 min	SD	BW range dE'94	BW equiv. dE'94	Estimated years to JNF 50 lx	150 lx	500 lx
42	Bookcover, pink ribbon (3×)	2.01	−3.42	−0.46	2.9	0.1	2–3	2.6	6–17	2–6	0.5–2
45	Bookcover, pink lips (3×)	1.5	−2.62	−1.08	2.3	0.2	2–3	2.7	6–17	2–6	0.5–2
54	Bookcover, blue green	0.83	0.27	−2.18	2.3		2–3	2.8	6–17	2–6	0.5–2
52	Bookcover, light blue ribbon (2×)	0.58	0.49	−1.99	2.1	0.1	2–3	2.8	6–17	2–6	0.5–2
37	Bookcover, red	1.48	−2.86	0.15	2.1		2–3	2.8	6–17	2–6	0.5–2
55	Bookcover, blue green (background)	0.66	0.3	−1.88	2.9		2–3	2.8	6–17	2–6	0.5–2
51	Bookcover, light blue	0.61	0.3	−1.96	1.8		2–3	2.9	6–17	2–6	0.5–2
38	Bookcover, red (3×)	1.19	−2.26	0	1.6	0.01	3	3.0	6–17	2–6	0.5–2
56	Bookcover, green	1.02	0.6	−1.33	1.4		3	3.0	17	6	2
49	Bookcover, blue (3×)	0.99	−0.31	−0.99	1.4	0.1	3	3.0	17	6	2
59	Bookcover, brown (2×)	0.77	−1.32	−1.3	1.2	0.03	3–4	3.2	17–55	6–17	2–6
39	Bookcover, red	0.74	−0.86	−0.17	0.9		3–4	3.6	17–55	6–17	2–6
48	Bookcover, blue	0.28	0.25	−0.96	0.8		3–4	3.8	17–55	6–17	2–6
57	Bookcover, green (2×)	0.1	0.23	−0.57	0.5	0.1	3–4	4.1	17–55	6–17	2–6

[a] No prior fade; no ultraviolet (UV); 10 hr/day; 7 days/week; 52 weeks/year.
BW = Blue Wool.
da* = Change in red–green.
db* = Change in yellow–blue.
dE'94 = Change in color.
dL* = Change in lightness
JFN = Just noticeable fade.
SD = Standard deviation.
x = Number of replicates.

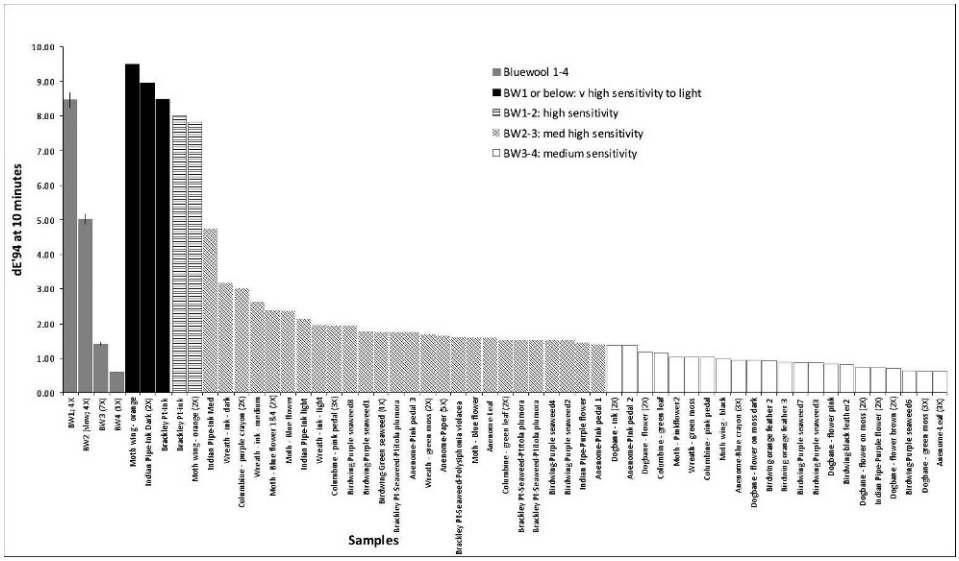

Figure 4. Total color change (dE'94) after 10-minute microfade testing—from most light-sensitive to least sensitive (excluding results from ''Bookcover'').

Exhibition Decision

The exhibition posed a siginificant risk of light damage to the Parr Traill scrapbooks, because many of the components that had not been previously exhibited and were in pristine condition, were found to be sensitive to light fading. Considering the value of this collection, and the expected loss of value from this exhibit, we decided to keep the most vulnerable pages for those exhibits where the collection was the main focus, and not a supporting element, as it is in this case. A conservative approach was taken because it was anticipated that there would be many future requests for exhibition of this important material and we need to balance the ''cost'' of fading from each exhibit with the benefit to many people in future generations (Brokerhof 2008). Therefore, it was decided that only items with light sensitivity close to BW 3 or higher (e.g., BW 4) would be included in the 90-day exhibition at 50 lx, a standard light level for museums (Table 4). The exhibition of the specimens at 50 lx worked well within the context of the art exhibit.

The challenge was to find an informed way to meet this standard. Microfade test results provided reliable light sensitivity data for the main components of these pages, and this allowed forconcrete decisions to be made. Pages were chosen that could illustrate the uniqueness of the whole collection; e.g., Catharine Parr Traill's elaborate compositions, the Moth and Birdwing pages have similar attributes. The high light sensitivity for the orange moth (BW 1) on the Moth page, meant that the page needed to be eliminated from the exhibition, whereas the Birdwing page—with all the colors close to BW 3 or higher—was used instead. Figure 6 shows the final layout of pages for the Barbara Gamble exhibit.

Recent research in light fading of natural history specimens, similar to those found the Parr Traill scrapbook collection, showed that the fading rates of many of these organic dyes and pigments can be reduced greatly when stored in an oxygen-free (anoxic)

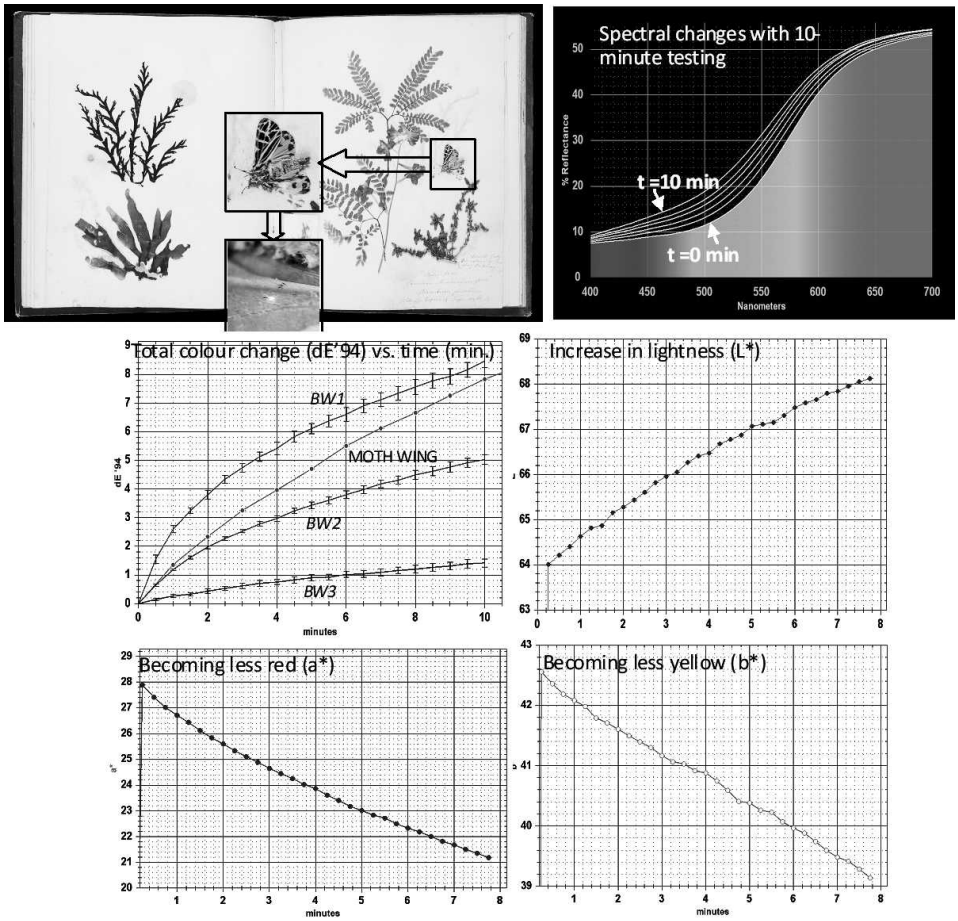

Figure 5. Microfade testing of the orange moth, *Apantesis virgo* Linnaeus (Lepidoptera: Arctiidae). Spectral change, total color change (dE'94), change in lightness (L*), red–green (a*), and yellow–blue (b*) with 10-minute testing.

environment (Beltran et al. 2008). Creation of display cases with an anoxic enviroment would be a solution for future exhibition of these light-sensitive materials.

Conclusions

As conservators working with botany specimens, we are constantly reminded of how vulnerable many plant and insect specimens are to fading. Therefore the exhibition of valuable botany specimens is problematic. The responsibility of the conservator is to determine how to exhibit this valuable collection safely. Until now, our decisions were based on interpretation of broad lighting guidelines. With the microfade tester, we were able to make infomed decisions about specific objects. We were able to distinguish between light-sensitive pages that were kept from the exhibit and more colorfast pages that could be safely exhibited.

Additionally, we were able to usethe specific data from the Parr Traill material to build our general knowledge about the lightfastness of plant species and inform us for other display decisions. For example, some of the data from Catharine Parr Traill collection

Table 4. Summary of microfade test results and exhibition decision. Three ferns, CAN 588171.1, .2, and .3 were added to the project later. They were not tested because their brown color suggested they were not prone to fading in this exhibit scenario.

CMN cat. no.	CCI page label	Sample description	CCI sample no.	BW equivalent	Decision
CAN 588167	Cover	Various colors	37,38,39,42,45,48,49, 51,52,54,55,56,57,59	BW 2.5–4.1	Display: 50 lx max
CAN 588165B	Wreath	Ink	63,64, 65	BW 2.5–2.8	Display: 50 lx max
		Green moss	61,62	BW 2.9, BW 3.5	
CAN 588169	Single page, algae, two bird wings	Orange feathers	17,18,19	BW 3–4	Display: Single page over double page
		Green algae	21	BW 2.9	
		Purple algae	22,23,24,25,26,27,28	BW 2.9–3.0, BW 3.7–3.9	
CAN 588169	Double page, algae, moth, flowers	Moth (*Apantesis virgo* L.) wing, orange	9,10	BW 0.70–1.2	Do not display: substitue with a less light-sensitive single page
		Moth wing, black	11	BW 3–4	
		Blue flower (Larkspur, *Delphinium*)	12,13,14	BW 2.7–2.9	
		Pink flower	15	BW 3–4	
CAN 588166	Dogbane	Ink	72	BW 3.0	Display Dogbane instead of Anemone and Columbine
		Moss and flower	66,67,	BW 3–4	
		Pink flower	70,71	BW 3–4	
CAN 588166	Anemone	Paper	78	BW 2.9	Do not display: Use less light-sensitive Dogbane page instead
		Leaf	80,81	BW 2.9, BW 4.0	
		Pink petal	82,83,84	BW 3, BW 2–3	
		Blue crayon	79	BW 3–4	
CAN 588166	Columbine	Purple crayon	89	BW 2.6	Do not display: Use less light-sensitive Dogbane page instead
		Green leaf	87	BW 3	
		Columbine (*Aquilegia canadensis*) petal	85,86	BW 3–4, BW 2–3	
		Green leaf	88	BW 3–4	
CAN CPT #26	Indian Pipe	Ink	75,77	BW 0.8, BW 2.8	Do not display
		Purple flower	73,74	BW 3–4, BW 3	
CAN CPT #26	Brackley Point	Ink	35,34	BW 1.0–1.1	Do not display
		Algae (*Ptilota plumosa*)	31,32,33	BW 2.9–3.0	
		Algae (*Polysiphonia violacea*)	36	BW 2.9	

BW = Blue Wool.
CCI = Canadian Conservation Institute.
CMN = Canadian Museum of Nature.
'CAN' & 'CPT' = Catalogue numbers & museum identifiers.

Figure 6. Final selection and layout of pages for exhibition.

were used to make decisions for herbarium sheets in the recently opened Water Gallery at the Canadian Museum of Nature. From the Parr Traill testing, we knew the seaweed specimens were very light-sensitive and would probably not stand up to permanent exhibition. In anticipation of this problem, special sets of specimens have been prepared specifically for the exhibit and we anticipate they will need to be replaced every 5–7 years at the current light levels. A color monitoring program is being planned for these specimens. This will allow us to compare the predicted fading rate from the microfade tester with actual fading rate from color monitoring.

> *"Man has altered the face of the soil. The mighty giants of the forest are gone, and the lowly shrub, the lovely flower, the ferns and mosses that flourished beneath their shade, have departed with them.…Where now are the lilies of the woods, the lovely and fragrant Pyrolas, the Blood-root, the delicate sweet scented Michella repens? Not on the newly cleared ground, where the forest once stood."* Catharine Parr Traill, 1852 (Ballstadt et al. 1996, p. 74).

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