Integrated Pest Management (IPM) for Cultural Heritage

Proceedings from the 4th International Conference in Stockholm, Sweden, 21–23 May 2019
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Foreword

Threats by pests to cultural heritage are now more than ever on the agenda for museums, archives, libraries and historic houses. It is therefore important that professionals within the sector, such as scientists, conservators, curators, archivists, librarians, collection managers and others, meet and discuss methods of dealing with the challenges posed by pests. Following the successful IPM conferences in Piacenza in 2011, Vienna in 2013 and Paris in 2016, the 4th international conference on Integrated Pest Management, IPM 2019, Integrated Pest Management for Cultural Heritage, was held in Stockholm 21–23 May 2019. In all, 160 delegates from 23 countries participated.

Since the conference sold out long before the deadline, it was decided to live stream the whole conference. There were more than 700 individual logins each day, and subsequent e-mails have confirmed the appreciation from viewers who had not been able attend the conference in person.

The overall purpose of the conference was to disseminate knowledge and increase interest in the subject, nationally and internationally, by sharing experiences and relevant research. A specific goal was also to promote and implement the standard on integrated pest management (EN 16790).

To further disseminate this knowledge the conference proceedings are published online, free for all. Articles focus on different aspects of IPM – treatments, detection, new threats and not least communication and training – if the IPM message does not reach out where it is needed, a lot of the hard work might be in vain. We are greatly indebted to the 69 dedicated authors who presented their papers at the conference. The editors, Lisa Nilsen and Maria Rossipal, are especially grateful to the work by the peer-reviewers, who, by their diligence and accuracy helped both authors and editors to improve the result. A special mention should also be made to the 16 posters that added an extra quality to the conference. Posters can be found at the conference website: www.raa.se/ipm2019.

With so many experts present, the conference gave an opportunity to address the European restriction of using nitrogen in anoxic pest treatment. An open discussion was held on the second day of the conference which hopefully will contribute to the ongoing work by museum organisations in taking this issue forward.

Finally I would like to take this opportunity to acknowledge the contributions of our organising partners Nationalmuseum, Swedish National Archives, Swedish Museum of Natural History and PRE-MAL.

Stockholm, September 2019
Lars Amréus, Director General of the Swedish National Heritage Board
This conference could not have been arranged without the financial and professional support from the Swedish National Heritage Board. The organizing committee would like to thank the Swedish National Heritage Board for making the conference happen.

Organising Committee and Partners
The conference was organised in collaboration with the following partners:
Maria Rossipal, Project Manager & Lisa Nilsen, Publication Co-ordinator, Swedish National Heritage Board
Carola Häggström & Ingela Chef Holmberg, Swedish National Heritage Board/PRE-MAL
Niklas Apelqvist, Swedish Museum of Natural History
Anne-Grethe Slettemoen & Charlotte Bylund Melin, Nationalmuseum
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Peer reviewers
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Receptions and excursions
We would also like to express our thanks to the City of Stockholm for hosting a much appreciated reception at the City Hall on the first evening of the event.

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We also want to thank the Vasa Museum, the Swedish National Archives, the Swedish Museum of Natural History, the National Library of Sweden, the Hallwyl Museum, the Nordic Museum and the Royal Palace and The Royal Collections Department, who all contributed with the guided tours at the excursions on the last day of the conference.
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Catherine Stephens is a Preventive Conservation Scientist in the Metropolitan Museum of Art’s Department of Scientific Research, where she is focusing on evaluating environmental conditions and identifying potentially hazardous chemical compounds found in materials proposed for use in display and storage. Before joining The Met in 2016, her specialty was studying the degradation mechanisms and structure-property relationships of polymers found in museums.

Tom Strang is a Senior Conservation Scientist with the Canadian Conservation Institute, Department of Canadian Heritage. He has worked on integrated pest management issues for cultural property for three decades in research, advisory and training capacities.

Julia Sybalsky is Senior Associate Conservator at the American Museum of Natural History, New York. Julia received her MA with an Advanced Certificate in Conservation from The Conservation Center, Institute of Fine Arts, New York University. At the AMNH, Julia was an important contributor in the recent projects concerning dioramas in the Hall of Biodiversity, the Hall of North American Mammals, and the Theodore Roosevelt Memorial Hall, and conducts ongoing research into materials and techniques for the conservation of natural science collections. Previous to her time at AMNH, Julia worked at the Archaeological Exploration of Sardis in Turkey, the National Gallery of Art in Washington DC, and interned at the New Bedford Whaling Museum in New Bedford, MA.

David Thickett joined English Heritage in 2003 as senior conservation scientist, mainly researching preventive conservation. Recent projects have focussed on historic house environments, collections’ epidemiology, non destructive testing, microclimate frames and optical coherence tomography. He is an assistant co-ordinator of the ICOM-CC Metals Working Group, and an ex co-ordinator of the Preventive Conservation Working Group. He sits as UK expert to the European Standards CEN TC 346 (conservation standards) and a directory board member of the Infra-red and Raman Users Group.

Magnus Wessberg has an MSc in Mechanical Engineering, is a PhD candidate in Control Engineering at Czech Technical University in Prague and works as a teacher in Building Physics and Building Materials at Uppsala University. Magnus’s PhD thesis is focused on climate control in massive historic buildings.

Amber Xavier-Rowe ACR FIIC is the Head of Collections Conservation at English Heritage where she has worked for 24 years developing her expertise in IPM and preventive conservation. Previously she worked for Leather Conservation Centre in England and Artlab Australia. She is a graduate of the Conservation of Cultural Materials (BSc) course, Canberra University.

Maruchi Yoshida is a graduate conservator and safety engineer running her office YCONS since 2010. She is a consultant for museums, archives and public authorities, specialized on participatory planning processes. In 2013 she founded kurecon, offering climatized containers and services to safeguard cultural assets in complex contexts like acute contamination and emergency cases. She has projects in Iran and in the Autonomous Region Kurdistan in Norther Iraq, connecting social development and cultural heritage preservation in rural and post-conflict contexts.
Day I:
Communicating IPM
I was very pleased and honoured to be asked by the organisers of IPM 2019 to give the introductory presentation. This gives me the opportunity to give a personal view of my pest management journey through museums, galleries, libraries, archives and historic houses across the world.

The starting point

My first encounter with pests in museums was the day I received a phone call telling me that a quagga was being eaten by insect pests and lumps of hair were falling out. A visit to Tring Museum (an outstation of the Natural History Museum in London) revealed that the quagga was an extinct type of zebra and the hair on this irreplaceable specimen was being damaged by larvae of *Anthrenus verbasci*, the varied carpet beetle. A survey of the collection showed that there was an extensive infestation in the building of both *A. verbasci* and *Attagenus pellio*. The solution in 1977 was to seal up the building and fumigate the whole museum with methyl bromide gas. Although the treatment was totally successful, the museum wanted to ensure that the collection was not re-infested and I was tasked with providing advice on preventing further problems.

At this time I was working at the Pest Infestation Control Laboratory in Slough, which was part of the Ministry of Agriculture, Fisheries and Food. My main area of research was with insect pests in the food storage and processing industry and we had just started to explore the then new concept of Integrated Pest Management (IPM). Instead of the previous regimes of regular treatment with insecticides and fumigants, we devised programmes using traps to find out where the pests were, targeted cleaning where the pests were living and then treatment only where and when it was deemed appropriate (Mueller 1998). This sounds very familiar now, nearly 50 years later, but was a very new approach for flour mills and food factories. If such a programme could be successful in a food storage environment, then why not in a museum, such as the Natural History Museum? I then met Jim Black, who runs Archetype Press and International Academic Projects in London. He asked me to contribute to conservation courses at the Institute of Archaeology in London. Another lecturer on these courses who was working with museum pests was Bob Child then a conservator at the National Museum of Wales and also runs his own company called Historyomics, which supplies pest traps and insecticides specifically for use in the heritage world.
Publications and PRE-MAL

My first slim volume “Insect pests in Museums”, published in 1989, was the result of Jim Black persuading me to write a book instead of giving out sheets of loose handouts on the courses. This book was extensively revised and updated in 1994 with illustrations based on those by a Danish entomologist Ebbe Sunesen. Running pest workshops with Jim Black and Bob Child gave me the opportunity to meet and work with people from many countries who were also interested in developing better methods to implement IPM. A participant in one of the first workshops in London in 1987 was Monika Åkerlund from the Swedish Natural History Museum. She introduced me to PRE-MAL, probably the first national IPM organisation, with members from Sweden and other Nordic countries. I attended a number of PRE-MAL meetings and conferences in Sweden, which then led to other collaborations. I first encountered *Trogoderma angustum* in the Swedish Natural History Museum and as it did not have a common name, I christened it the “Stockholm beetle” which did not please Monika. However, since then it has been adopted by the Germans as the “Berlin beetle” which will appear again later in the history.

Monika Åkerlund’s book “Ängrar – finns dom” published in 1991, was a pioneering work on pests found in museums and with its wide range of coloured images of pests, it is still a useful reference work today. Together with the late Jan-Erik Bergh, Monika carried out a number of investigations into freezing and anoxic treatments which culminated in a multi-national EEC funded project to evaluate nitrogen generators (Åkerlund and Bergh, 2001).

West Dean and international collaboration

One pivotal point for the international development of IPM was a five-day workshop in 1996 held at West Dean College and organised by the Getty Foundation in California and Peter Winsor from the UK Museums and Galleries Commission. Key sessions were given by Vinod Daniel and Shin Maekawa from the Getty Conservation Institute (GCI), Tom Strang from Canadian Conservation Institute (CCI), Nieves Valentin from Spain and Bob Child and myself from the UK. Participants were from the UK and a number of other countries and many went on to spread the word on IPM in their own institutions. One of the tools to emerge as a result of Amber Xavier-Rowe’s participation in the West Dean workshop was the English Heritage pest poster. First produced in 1998, a second revised version was produced in 2008 with input from Dee Lauder. Over 16,000 copies of these posters have now been distributed in the UK and 20 other countries worldwide. We hope to produce a new and updated version of the poster in the near future.

Tom Strang, the guru of thermal treatments, convinced all of us at the West Dean workshop of the simplicity and efficacy of heat treatment with his hair dryer and aquarium demonstration (Strang, 2001). Vinod Daniel then went from the Getty to the Australian Museum in Sydney to implement anoxia as part of their IPM programme. Tom Strang’s demonstrations of thermal treatments also inspired Vinod Daniel to develop low cost solar heat treatments for developing countries (Daniel and Hanlon, 2001).

We tend to forget that before 1990 museums worldwide relied heavily on toxic gas fumigation with methyl bromide or ethylene oxide to control insect infestations in collections. Because of concern over health issues, chemical residues and undesirable effects on objects there was then a large-scale switch to the use of freezing in Europe and North America. This was also accompanied...
Insect traps and pheromones

Insect behaviour has always fascinated me and led me to thinking about ways to detect insects. In the 1970's I was part of a team carrying out research for better storage of grain and other foodstuffs. We developed effective pitfall traps for bulk grain and then food baited traps for detecting small numbers of beetles in storage buildings. When I became involved with museum pest problems, it was a natural step to modify these traps for use in museums and other buildings with collections (Pinniger, 1990). One of the early international collaborations was with Insects Limited in Indianapolis USA and over the years we have worked on many projects with traps and pheromones. The most notable was the first UK trial in 1996 of the new sex pheromone lure for webbing clothes moth *Tineola bisselliella*. The performance of this lure exceeded all our expectations with baited traps catching over 20 times more moths than unbaited ones (Cox *et al.*, 1996). Since then we have accepted moth pheromones as an invaluable IPM tool for monitoring spread and increase in populations. I have worked with some of the beetle pheromones, which are far less predictable in their performance. Beetle behaviour is less well understood and it seems that some male beetles such as biscuit beetle *Stegobium paniceum* only respond well to the female pheromone when they are flying, often to a light source. Limited trials with the pheromone of *Anthrenus verbasci* and *A. sarnicus* also showed that the lure was attractive when traps were placed on windowsills, but was

by the development of controlled humidity, high temperature treatment, nitrogen anoxia and the use of carbon dioxide as a replacement fumigant. For largely economic reasons this trend was not taken up so quickly in many other countries, but the inclusion of methyl bromide in the Montreal Protocol for reduction of ozone-depleting chemicals meant that it would no longer be permitted as a fumigant. A meeting in Japan “Beyond methyl bromide – meeting the Montreal Protocol” in 2001 was an important turning point and led to more research and development into alternative control methods (Kigawa *et al.*, 2001).

Experiences in other countries have taught me a great deal about the practicalities of implementing IPM in climates very different from Northern Europe. A very clear example was from an IPM workshop that I ran in Singapore for the National Heritage Board in 1999. We carried out a limited survey of the stores and it was quite apparent that the traditional buildings with large eaves and very good natural ventilation usually provided a much better stable environment for the collections than the modern air-conditioned storage block where serious problems of condensation, mould and pests developed rapidly when air handling equipment malfunctioned. I have since seen further examples of this in other countries with the added down side of high energy costs associated with complex air handling equipment.
IPM across a wide and diverse library collection with insufficient resources and lack of acceptance by management of the needs of IPM. This discussion gave rise to the concept of Risk Zones to target IPM where it was most needed and prioritise the programmes of inspection, monitoring and preventive measures to minimise the need for expensive remedial treatments. First implemented in the Imperial War Museum, Natural History Museum and Victoria and Albert Museum in London, the concept of Risk Zones has now been adapted and adopted by other museums (Doyle et al., 2008; Pinniger, 2011). It remains a very useful tool to maximise effect and convince management of the need for IPM when resources are increasingly stretched.

A completely new version of my book, now called “Integrated Pest Management in Museums, Galleries and Archives”, was published by Archetype in 2001 to coincide with the Pest Odyssey conference and later, in 2008, the book was translated into Portuguese by Maria Luisa Cabral as “Controlo de pragas em museus, arquivos e casas historicas”.

The conference “2011: A Pest Odyssey, 10 years later” was held at the British Museum in London and showed how many topics had moved forward in the time since the first conference in 2001. There were 27 papers presented from 11 countries together with 18 posters. Participants came from many other countries and this resulted in important exchanges of information and future international collaboration. There were two notable changes in pest status with the remarkable increase in problems with webbing clothes moth Tineola bisselliella, particularly in the UK, but also reflected in other countries (Xavier-Rowe and Lauder, 2011; Querner and Simon, 2011). The other was the increasing spread of the brown carpet beetle Attagenus smirnovi in the UK and Europe, possibly linked to climate change (Pinniger, 2011; Hansen et al., 2011). It was agreed at this meeting that the next International conference needed to be held outside the UK and Pascal Querner from Austria took up the challenge and organised an excellent conference in Vienna only two years later (Querner et al, 2013). A total of 31 papers were presented from 12 countries with an even wider participation including delegates from many other countries showing that IPM was on the map across the world.

FIGURE 5. An Insects Limited bullet lure, the first commercial pheromone for webbing clothes moth Tineola bisselliella. Photo: DBP Entomology.
then laid eggs, resulting in a heavy infestation of larvae eating the protein-rich dried peas. Options for treatment of a 35 tonne work are very limited. Awareness of the risks posed by such exhibitions is essential to avoid serious pest and fungal problems and communication between countries is even more important when such installations move across international boundaries.

Communication and the future

The next international conference in Paris in 2016 consolidated the progress made in Vienna, but there was a general feeling that the economic downturn had affected IPM by reducing resources not only for implementation and operation, but also for training and research. The development of the internet as a tool for communication and sharing data and images has therefore been crucial to promote the low-cost exchange of IPM information between IPM practitioners. The very useful USA based website Museumpests.net was introduced to an international audience in 2011 (Arenstein et al., 2011) and the UK website Whatseatingyourcollection.com (WEYC) in 2013 (Pinniger, 2013). It is hoped that the pest distribution database on the WEYC website can be expanded to include data from other countries. It is fitting that

A result of the collaborative work set up in Vienna was that my book “Integrated Pest Management for Cultural Heritage” (Pinniger, 2015) was translated into German by Pascal Querner and Bill Landsberger as “Handbuch Integriertes Schädlingsmanagement in Museen, Archiven und historischen Gebäuden” and published in 2016.

Art for art’s sake

We are well aware of the potential pest problems of caring for more “traditional” collections such as costume, furniture, books, ethnography and natural history. In recent years there has been a huge increase in pest problem challenges posed by art installations that frequently include materials that are not often encountered in museum collections. These include living trees, dead fish and pigs’ heads (French, 2011) and piles of rags, pasta and dried prawns (Pinniger, 2013). More recently I was reintroduced to Trogoderma angustum, now called the Berlin beetle, in that very city. An art installation, which was constructed of very large lead sheets made into huge books had been placed into storage. To create the installation the artist had fired dried peas into the artwork, which were then embedded in the lead sheets. Unfortunately, the peas had attracted Trogoderma adults, which had

FIGURE 6. Distribution of Attagenus smirnovi, the brown carpet beetle or Vodka beetle, in the UK. Screenshot from whatseatingyourcollection.com.

the first international collaborative project on pest distribution is with IPM practitioners in Sweden (Thompson Webb and Pinniger, 2017).

The use of communication technology has huge implications, which can benefit the future of international IPM. However, we have seen from the evidence of the 25 years that there is no substitute for the stimulation and inspiration of meeting fellow IPM enthusiasts and it is very encouraging that so many people are able to participate in this 2019 conference in Stockholm. It is by demonstrating that IPM can preserve collections for posterity in a cost-effective and sustainable way that we will secure the future for the important exchange of information between our countries.

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Heriot-Watt University, Edinburgh, Scotland, 7–10 July 1996.


A helpful guide to insect pests found in historic houses and museums. English Heritage and Collections Trust. Poster available from customers@english-heritage.org.uk. Product code 52010.

Website giving information on IPM and pest identification. It also includes an insect pest reference database. www.whatseatingyourcollection.com

Website for IPM information in the USA: http://museumpests.net/
Website for IPM information in France:
http://www.montpellier.inra.fr/CGP/
insectes-du-patrimoine/
http://insectes-nuisibles.cicrp.fr/en
Are we really integrating pest management? 
Reducing pest risk at a large national museum

Abstract
Integrated Pest Management (IPM) is widely accepted as a crucial aspect of collections care. The British Museum aims to protect its vast collection from pest damage with a holistic approach to IPM. The museum has a clear policy, strategy, set of procedures and an outreach and training programme designed to incorporate pest management into every aspect of museum life. However, due to the complexity of its estate and organisational structure, and with increasing demands to use its collections, it can be challenging to ensure that measures to reduce the risk of pests are truly integrated into all activities and initiatives.

The British Museum’s pest management plans are successfully integrated into activities such as large collections moves and creating new permanent storage. In these projects, IPM awareness has been an essential element of the programmes, with dedicated members of staff and evidence based learning. It is more difficult to ensure the same methodological approach with some other activities, such as loans, acquisitions, events and refurbishment projects. With pressing deadlines and changing team members, it can be challenging to adhere to our standard procedures. However, the effects of an infestation on mixed collections can be far-reaching and difficult to control. To those with collection care experience, the impact this might have on the preservation of the collection seems obvious, but conveying these potentially devastating effects to members of staff at all levels and with different backgrounds is imperative.

For this paper the authors have reviewed the effectiveness of the museum’s pest management policies and procedures, and identified a number of obstacles to incorporating an IPM approach into all museum activities. Consistent communication and integrating pest management from the inception of projects has obtained the most positive results so far. Much work has gone into training and awareness and this has helped to improve aspects of planning. The aim is to enable a thorough understanding of the importance of a successful IPM programme and reaffirm the responsibility of all museum staff for the long-term preservation of the collection. This paper hopes to share the lessons learned for the benefit of other organisations with similar challenges.

Keywords: (IPM) Integrated Pest Management; IPM awareness; IPM communication; IPM training; IPM responsibility

Introduction
The British Museum (BM) cares for over eight million objects, many of which are vulnerable to pest damage. For centuries, the museum used a range of pesticides to control insect and vertebrate pests in the building and collections (British Museum, 2016). However, in view of increasing restrictions and health and safety awareness on the use of pesticides, and with more pressure on resources, a move towards a more holistic approach to reducing the risk from pests has been developed over the last two decades (Phippard, 2011). These days, the museum aims to use integrated pest management (IPM) principles to protect its objects and estate by considering pest risks in every aspect of museum life and with an involvement of all members of staff.
FIGURE 1. A timeline of the development of pest related activities at the British Museum shows a progression away from chemical control towards an IPM focus.

FIGURE 2. The BM’s IPM Strategy outlines the basic principles of risk reduction.

AVOID

- Make the environment unsuitable for pest and fungal development. Keep areas and objects clean and follow good working practices.

BLOCK

- Deny pests access to the building by blocking openings and faults in the building. Prevent pests entering the collections by keeping unnecessary materials and activity out of storage areas; inspect and treat all incoming material.

DETECT

- Recognise the main species of pests and the damage they cause. Carry out regular inspections of the building and collections.
- Maintain a monitoring system to keep track of insect populations and locations.

ASSESS

- Determine the risk to collections and establish the severity of any problems found. Treat or quarantine any objects suspected of harbouring pests. Find the sources of infestations and remove them.

TREAT

- Treat problems promptly. Create a suitable treatment plan to clean and disinfect all affected areas or objects.

Principles of pest management based on T. Stang (1996)
The strategy document reinforces that staff in every museum department should understand their role in preventing pest damage to the collections.

Responsibilities and Procedures

The museum has a dedicated IPM Manager who is responsible for the IPM programme at both managerial and operational levels. Where IPM issues directly affect collections, the IPM Manager is supported by staff in conservation, collections management and curatorial departments. In addition, there are IPM representatives across non-collection departments who support the programme.

The IPM Manager role requires a strong understanding of collections care but sits within the facilities department instead of within conservation, a strategic decision made to ensure operational involvement across the estate. Many activities essential to the success of the IPM programme, such as cleaning, waste management and catering, are carried out by external companies on contract to the museum. The IPM Manager liaises with staff members who have responsibility for the museum’s facilities management contractors and

Background

*Museum IPM Policy and Strategy*

The museum has an Integrated Pest Management Policy which states that:

‘there is an imperative to use Integrated Pest Management techniques across the estate in the interests of protecting the collections, libraries and archives held by and used for research in the Museum’

(The British Museum, 2010)

This includes regular monitoring and the completion of risk assessments for all collections and materials entering the site, and stipulates that measures will be based on the concept of pest risk zones. The document emphasises that the success of the programme relies on all members of staff across the museum.

This policy is supported by a strategy that establishes the principles of pest management at the museum (see Figure 2), and IPM is referenced in various sets of procedures with the aim to incorporate pest management in all core museum activities.

![Diagram of Responsibility](image-url)

**FIGURE 3.** Due to its complicated administrative structure, responsibility for IPM related tasks at the museum is shared among numerous departments.
has oversight of the museum’s pest sub-contractor. Crucially, the IPM Manager assists with the specification of these contracts to ensure they will comply with standards set out in the IPM strategy.

Collaborating on activities linked to the collection falls within the remit of the preventive conservation team, with the support of the whole conservation department as well as the collections management teams. These activities include object movement, treatment of objects for pests and processes such as loans, acquisitions and photography.

Challenges
An important aspect of the museum’s IPM programme is to ensure activities linked to facilities and collections correlate and work in a fluid manner. In the 1990’s there was some preliminary work linked to pest management (Phippard, 2011) but it was mostly reactive instead of a holistic scheme across the organisation. It wasn’t until 2004 that IPM became the primary method to prevent pest damage to the collections (Phippard, 2011). From the beginnings of the IPM programme, the museum has aimed to have an integrated approach to all its activities but, perhaps unsurprisingly, along the way the programme has faced numerous challenges.

Responsibility and staff continuity
Integrated Pest Management is understood to be a shared responsibility within the whole museum. However, in such a large and complex institution, it can be difficult to ensure that responsibility for key tasks is identified. Standard protocols can fall by the wayside if they relate to an undefined area of responsibility, for example within storage spaces shared by multiple curatorial departments.

Projects often have staff hired on fixed term contracts and as people leave or move along to other roles, some of the information, decisions and processes established can get lost or altered. This is also true for facilities, which, as mentioned above, can manage changing contractors with a higher turnover.

Planning
Over the last 20 years, one of the main goals of the IPM programme has been to consider IPM as a crucial element of the initial process of every new project within the museum. This has often been a challenge for projects that are not directly related to collections and where the direct effect of IPM might not be as clear, such as special events or construction in non-collection areas.

Projects directly linked to collections but with tight deadlines, such as large loans and acquisitions, can fail to emphasise IPM as a priority towards the end of the project when the solutions become mostly reactive.

The planning of pest reduction improvements has been complicated by the fact that the funds for such activities have been held by different departments, or rolled into budgets for larger contracts.

Security and access
The challenges regarding access can be divided into two subgroups. For public areas, one of the main obstacles to IPM is the increasing demand on the use of spaces for income generation. The museum is open 7 days a week and often has events before and after opening hours, making it challenging and often expensive to schedule housekeeping programmes. In areas behind the scenes, the challenges can be linked to providing the required security access to undertake certain activities. An example of this is facilitating access for contactors to clean inside high security areas such as collection stores, which are often under the direct control of individual curatorial departments that do not have spare capacity for supervision.

Success so far
Training and outreach
The museum has a multi-level training programme to raise awareness of the importance of IPM across the organisation. The training sessions aim to ensure members of staff understand risks and how their everyday actions are crucial to the delivery of a successful programme. Furthermore, the museum has resources and a pest reporting tool available on the museum intranet and the IPM Manager gives talks to every department to promote the understanding of IPM in their specific areas and job roles.

The long-term goal of the training programme is to make IPM training mandatory for all members of staff working directly with collections, as well as converting the induction training to an eLearning tool for all members of staff to complete within six months of joining the museum.
The museum also has other IPM outreach activities to promote IPM awareness with visitors and external colleagues. This includes participation in events such as Science Saturday, which coincides with National Science Week, a day each year when conservators and scientists talk to the public about their work behind the scenes. Another example is the recent creation of a museum audio trail about IPM, pests, and the work that we do to keep objects safe from this agent of deterioration in the museum. The trail allows visitors to walk around galleries taking into consideration a different aspect linked to the care of the collection. IPM is also an important part of training programmes such as the International Training Programme, a scheme that allows museum professionals, predominantly from Africa, Asia and the Middle East, to come to the British Museum for six weeks of training on a broad range of museum topics. Other outreach activities include behind the scenes tours, gallery talks, podcasts and participation in members and patrons events. These activities are well received and are a valuable tool to spread the awareness about IPM outside the museum and heritage field.

**Gallery Refurbishments**

Since 2006, the British Museum has had a pest reduction guidance document (Pinniger, 2006), which has been issued as part of the documentation package for project tenders. However, over time it became clear that the guidance was not always fully adhered to and this was leading to pest problems later on. This situation was substantially improved for the temporary exhibitions programme by dedicating a preventive conservator to join each exhibition project team. Building on this success, for the past three major gallery refurbishment projects, a preventive conservator has been assigned as a core team member, to bring IPM expertise to the project, and to follow it through at each stage of the process. Previously, the Con-

### TABLE 1. IPM related training courses

<table>
<thead>
<tr>
<th>Training session</th>
<th>Who is it for</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mandatory IPM briefing</td>
<td>Contractors working on site</td>
<td>10 minutes</td>
</tr>
<tr>
<td>IPM Introduction during staff induction</td>
<td>All new members of staff</td>
<td>20 minutes</td>
</tr>
<tr>
<td>IPM Introduction: Pests and their risk to the collection</td>
<td>This course is open to all Museum staff. Staff working in the Collections and Operations Directorates are encouraged to attend.</td>
<td>Half day</td>
</tr>
<tr>
<td>Intermediate IPM: Standard Procedures and Pests ID</td>
<td>This course is open to all Collections staff who have already attended the IPM Introduction course.</td>
<td>Half day</td>
</tr>
<tr>
<td>IPM Users training: Assessing and Preparing Objects for Pest Treatments</td>
<td>All staff who work directly with the collection.</td>
<td>Half day</td>
</tr>
<tr>
<td>Training given by external contractor- Pesticide regulation training (understanding health and safety risks of pesticides and hazardous residues in collection materials).</td>
<td>IPM Manager, Preventive conservators and Collections Managers.</td>
<td>Full day</td>
</tr>
<tr>
<td>IPM Refresher Training</td>
<td>Members of staff who attended the IPM instruction course over 3 years ago.</td>
<td>1 hour</td>
</tr>
</tbody>
</table>
The Conservation Department was not considered a key stakeholder until later on in projects, during the ‘fit out’ stage of the process when showcases and other display related matters were being discussed. It is now recognised that it is necessary to have this awareness much earlier in the process, during the infrastructure renewal phase, as decisions made during this part of the project can have a significant impact on pest reduction for decades afterwards. The IPM Manager is also consulted at critical stages during the planning and construction stages to ensure that essential issues are raised and to reinforce good practice throughout the project. Important things to consider include understanding where the electrical, heating and other services run and ensuring that these features are properly pest-proofed, making sure voids are sealed or are accessible for inspection and cleaning, and specifying the correct type of mesh to screen windows and skylights. This is then followed through in later stages when showcases and other displays are designed. Fulfilling this role on a project team requires a specific set of skills that may need to be developed in conservation staff, from being able to read technical drawings and inspect prototypes, understanding the language of designers, architects and engineers, and understanding the needs of staff in facilities and curatorial departments who will use and maintain the spaces for years to come. It is little use having a guidance document if there is nobody on the project to ensure that is translated into action at each stage and detail of the design. An IPM focused design inevitably also reduces risks from other factors such as dust and humidity, and does not necessarily need to increase build costs. In fact, it can significantly reduce costs to the museum later on if spaces are designed to be easier to clean and maintain.

New builds and collections moves

The World Conservation and Exhibitions Centre (WCEC), completed in 2014, is the most recent addition to the BM’s historic Bloomsbury estate, and one of the largest construction projects in its 260-year history. The new building provides the museum with significant new spaces to improve the access to, and care of, the collection including a 70 metre long temporary exhibitions gallery, bespoke conservation studios and scientific research laboratories, logistics facilities for loans, a dedicated IPM
facility and approximately 6,000 m² of environmentally controlled storage spaces for some of the museum’s most vulnerable collections.

This project was the first time the museum had seriously considered pest risk from the building design stage, which resulted in features with pest-proofing in mind, such as avoiding hard corners and crevices within the building to facilitate cleaning. A meaningful addition to the new site was the establishment of a dedicated central IPM space to ensure all objects can be isolated, quarantined or treated prior to entering the collection. This was achieved through the involvement of Conservation and Science staff, and later the IPM Manager, who helped specify the design of the spaces and commissioned the treatment facilities.

The collections move project for the relocation of approximately 200,000 objects into the new storage spaces within the WCEC had IPM as a core aspect of the project. In fact, IPM was built into the job descriptions of the project team members. The creation of a preventive conservator post for the project was also crucial to provide an effective liaison between the project, the IPM Manager and the rest of the preventive conservation team. It was agreed that every object entering the new stores should be pest treated or quarantined as a precautionary approach which would enable the space to be considered an ‘IPM zero reference’ area. This reference means that all objects were deemed pest free at a specified date and will help to identify any new problems if they arise in the future.

The project incorporated an upgrade of the documentation for IPM risks, procedures and treatments within the collections database. From this point forward, the museum has established a methodology to clearly record pest treatments and pest treatment suitability linked to individual object records. The successful results have become a standard procedure within the collections management teams and will be taken forward to all activities and new programmes across the museum.

Lastly, the project, which is still ongoing, aims to establish a set of clear procedures regarding object movement to ensure the new storage spaces remain pest free after the completion of the project.

In 2015, the UK government made a decision to sell Blythe House, a government owned shared
effectively, especially in the more popular galleries. This has meant that maintenance has been done on a more ad hoc basis, sometimes having to take advantage of gallery closures planned for larger infrastructure or redecoration projects. The BM is moving towards a more coordinated programme of regular gallery maintenance to allow the many teams who need access to work in a more efficient way, in order to have the galleries closed for as short a period as possible. This is now more commonly being programmed to coincide with the already established regular rotation of objects for conservation reasons, which provides a good opportunity to clean displays and update labels, as well as service equipment, change lights, deep clean the spaces and undertake any other maintenance, inspections and repairs as required. It is hoped that a regular programme of short maintenance closures will improve the overall condition of the building and displays whilst being more cost effective and less disruptive to visitors and staff.

**Measuring success**

The IPM Manager supports and develops initiatives from the soft services contractor in maintain-
ing housekeeping levels through key performance indicators, and auditing sub contractual operations including cleaning, waste recycling and disposal.

The BSI *British Standard for Integrated Pest Management for protection of cultural heritage (BSEN 16790:2016)* is a suitable baseline to help define and identify the effectiveness of an IPM strategy and ‘a management tool describing IPM policies and procedures.’ (2016). The BM is currently investigating options to work towards this standard tied in with its Collections Care Strategy, to develop a strategic approach to improving levels of compliance. Working towards meeting this standard should help to identify how well the BM is actually integrating pest management principles throughout the museum and give a framework to track progress.

**Conclusions**

It has taken almost two decades to establish IPM at the British Museum, and there is still future progress to be made. This paper has shown that even in a large national museum, which is often assumed to have access to considerable resources, the sheer size of the collection and estate, and the complexity of the institution’s management and activities, can pose barriers to effective management of pest risks.

Communication has been identified as key to understanding of IPM as a shared responsibility across all members of staff. As well as having a clear IPM Policy and Strategy, the museum’s active outreach and training programmes ensure both staff and the public learn more about IPM. Moreover, training and outreach aim to convey the impact of all museum activities on protecting the collection from pest damage.

As well as training and outreach, the museum has had successes incorporating IPM into the core of new projects such as gallery refurbishments, new builds and collections moves. Challenging aspects such as standardisation of processes across the organisation, management of external contracts, increasing pressure on the use of the estate for income generation and projects with tight deadlines require further work to ensure IPM is considered early on and in a consistent way. Further work is still being done to integrate risk reporting and mapping IPM data in conjunction with environmental data.

Improvements related to IPM across the museum are positive but also represent a permanent commitment, which can, in certain cases, increase the workload and lead-in times for activities. It is clear the benefits outweigh the extra effort; however, it is important to ensure this is understood by all members of the organisation and that adequate resources are allocated. It should be emphasised that pests are not a standalone risk within collections care but a part of the whole interconnected array of risks to the collection. A truly integrated pest management programme requires on-going effort and a willingness to adapt to changing circumstances and demands. The BM has come a long way to realising its goals for pest risk reduction, and with collaboration, good communication and determination, it can continue to protect its collections for generations to come.

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Train-the-trainer: Newhailes, a moth case history

Abstract

The National Trust for Scotland’s (NTS) Integrated Pest Management (IPM) programme relies on the NTS conservators training property staff to carry out IPM duties: pest trapping, identification, record keeping and limited treatments. Competing priorities and changes to the role of NTS conservators mean there is less time to train individual staff members. At the same time emphasis is placed on all staff and volunteers delivering high standards of collection care, including IPM to give visitors a day they’ll remember. In order to provide training of a high conservation standard and focused on ensuring a high quality visitor experience the NTS is trialling a train-the-trainer approach to staff training; subject-matter experts (conservators) share expertise with a group of ‘trained’ trainers and this group uses the information to instruct another small group. A pilot to test this approach was identified during a pest management project at a Trust property in 2018. A small group of trainers, with NTS conservators present, were trained using an external consultancy to deliver specific areas of collections care training for a group of non-specialist volunteers; emphasis was on training trainers to become skilled in effective speaking, targeting key collections care information in accessible forms for a wide learning audience and designing modular workshops that could be repeated by any of the trainers. Critically the conservators were trained in evaluating the effectiveness of the training and incorporating constructive criticism into the training process. The pilot also focused on how to use IPM as part of the storytelling brief; to identify the IPM stories conservators wish to bring out but have had no time to develop. The story of conservation is one of the most under-utilised narratives and is currently done piecemeal. The training methodology was targeted to identify good collections care stories to tell and the appropriate method of delivery; including developing relationships with the Communications Department to issue clear accurate information for press releases. This paper looks at the steps involved in implementing the pilot train-the-trainer approach to IPM in the National Trust for Scotland (NTS), identifying issues highlighted in the trial, assessing the efficacy of the programme for future collections care training and evaluating whether the investment to engage an external training company is worthwhile and if it delivers benefits that would not otherwise be achieved.

Key words: IPM; training; National Trust for Scotland

Why train-the-trainer

Train-the-trainer is a model used to describe training potential in-house instructors or less experienced instructors in techniques to deliver material to others (Bowie, 2018). This is of particular interest to the National Trust for Scotland (NTS) as demands on the conservation staff resource has increased beyond capacity and the role of the conservator within the organisation is changing. The NTS currently has a National Preventive Conservator role to lead the IPM programme, implementing IPM at 30 properties, providing annual training opportunities, managing data collection and analysis and advising on appropriate responses to infestations. The role supports three regional conservators who assist property staff with all aspects of conservation, including IPM. These roles assist staff with accurate pest identification and appropriate mitigation and treatment programmes at each property. The programme is also supported by contracting in a subject specialist to lead an annual workshop of pest identification training for all
addresses the need to have a number of trainers trained in a short period of time, to alleviate the capacity issue to deliver effective training. Trainners can be taught specific material and also learn how to effectively deliver to diverse groups. Many questions arise about its proper use, efficacy and its optimal role in preparedness training. The train-the-trainer model has not been used in the NTS for collections care training before and the author was keen to use the IPM project for initial evaluation of the method to help clarify optimal ways of using the train-the-trainer model for collections care training of NTS staff.

The pilot

Newhailes House, outside Edinburgh has experienced a significant increase in webbing clothes moth, *Tineola bisselliella*, from 2016 to 2018 (Bon, 2018). Existing housekeeping regimes and localised treatments were not proving effective to manage the moth infestation. The infestation was assessed by the author and the regional conservator for the property, who jointly recommended a major investment for a comprehensive treatment plan with public engagement opportunities, a review of housekeeping procedures and an increased monitoring programme, post project. The four month project involved a deep clean of 20 rooms, low temperature treatment of hundreds of collections items on site, targeted chemical treatment of objects and interior spaces unsuitable for freezing, enhanced pheromone monitoring and extensive public visits. The property would be open during the project for tours, showing visitors how the NTS were tackling a pest infestation, letting visitors ‘have a go’ with supervised deep cleaning activities, issuing pest blunder traps to the public and schools to encourage public involvement and build up a picture of *Tineola bisselliella* populations in the surrounding area.

The scale of the project to manage the moth numbers was unprecedented for the NTS; a major house, major collection, significant scale of problem and significant public engagement programme, all to be managed by property staff, with limited conservator input. Newhailes was chosen as the pilot for a train-the-trainer model for aspects of collections care, IPM and training for public engagement opportunities specifically identified for the pest management project.
An external training company, Communicate, was commissioned to train the house team in the train-the-trainer model through a one-day workshop. The external training company was recommended to the author by the NTS Human Resources department. The content of the workshop was based on specific needs for project delivery and acknowledged the varying experiences the house team had in both delivering training and collections care experience. The external trainer was asked to focus half the course content on general trainer skills: a general introduction to the concept of good training, clarity, learning styles, creating an effective learning session and effective training delivery. The second half of the course consisted of critiquing a series of 30 minute training sessions that the author had allocated to each trainer in advance. These sessions covered the following topics:

1. An overview of IPM principles
2. Pest treatment options
3. Packing and wrapping collections for low temperature treatment
4. Moving and handling collection objects
5. Basic textile cleaning techniques
6. Collections management documentation requirements
7. Public engagement awareness

Peer review of the train-the-trainer workshop

The external trainer led the peer critique of the delivery and content of the training sessions prepared by the trainers. Unsurprisingly, experienced trainers had a more interactive approach and ran sessions to time; less experienced trainers acknowledged they focused on text heavy PowerPoint slides and ran over the time allocation. Overall content was of a proficient level, trainers with limited collections care backgrounds (with some guidance from the conservators) produced accurate and well thought out modules. The feedback to the author from the external trainer after the session confirmed that the trainers were highly motivated, energetic staff who had devised well thought out training sessions that would be engaging and informative for project volunteers.
Some assistance was required from conservators when volunteers asked questions beyond the trainers’ collections care experience. This was especially the case for questions related to pests and IPM that were not covered in the modules. The trainers all acknowledged an awareness of their limitations to volunteers during the sessions. Feedback from the volunteers on their taster day was positive and 15 decided to sign up for the project.

Ongoing observation by conservators of trainers with volunteer staff

During the four month project, the two project managers (author and regional conservator) continued to monitor the performance of the trainers through actively participating with volunteers in some of the project activities and when called on site to troubleshoot any issues raised by the team, such as preparing vulnerable collections for low temperature treatment. This ensured the trainers were not burdened with the feeling of continuous assessment and helped develop a good working relationship with the conservators who turned up to ‘lend a hand’. The project managers felt confident they were seeing an accurate picture of how...
the project was being managed. Overall the trainers were not deviating from the training they had devised for the seven collections care modules of the project. Consistent messages and reinforcement of good practice prevailed. It was noted some trainers without a collections care background tended to diverge from procedures they themselves had devised when there was perceived pressure to achieve daily goals. This was evident when a time pressure was felt to complete a task, this would result in less knowledgeable trainers using poor planning for an object move, inaccurate assessment of logistics for an object move, i.e. 'have a go and get it done' and asking volunteers to cut corners to save time. It was felt that the trainers had not internalised their own messages sufficiently and this is a criticism that has been levelled at train-the-trainer training. Consistently the trainers and volunteers gave a high level of customer service with public engagement activities. Visitor feedback for public tours during the project work was extremely positive and encouraged the team to devise further opportunities. This was an excellent example of trainers taking ownership of the project, developing new strands such as hosting a 'Moth Family Day' in the grounds to show the conservation of native species of moth and insects on the estate. Trainers were articulate and on message when interviewed for radio and television about the project, about the problem and about the specific pests in the property and consistently gave clear and accurate information on the specific pest issues at the property.

Evaluation of volunteer knowledge by conservator staff

Through actively participating in project activities the project managers were able to gain a sense of the volunteer knowledge without resorting to ‘testing’ which was thought to be too aggressive for the spirit of a volunteer based project. Volunteers demonstrated a good knowledge of what they had been taught and generally were careful to follow the training more closely than some of the trainers. The information they were given by the trainers was often the extent of their knowledge (and of the trainers). The one-way transmission of knowledge and the limitations of non-subject specialists delivering training more generally in the NTS is a factor of the train-the-trainer model that needs careful consideration and management.

Overall assessment of the staff training

The challenges mentioned above indicates the train-the-trainer appears to be suited for relatively straightforward, technical content that doesn’t require much in the way of background knowledge and specialist experience. Hence the public engagement element of the project worked extremely well, as all trainers were able to actively engage with the message to involve visitors as much as possible in the project. Within the project it was possible to deliver training to the trainers that equipped them adequately to manage the collections care issues required. It was not possible to enable staff to perform outside of the training parameters in relation to devising solutions that were beyond their conservation knowledge and experience.

Within the constraints of the project it was not possible, mainly because of time, to commission the external trainer to evaluate the training being given by the new trainers at the later stages of the project. This would have given the NTS the opportunity to evaluate the non-technical training aspects of what was being delivered, i.e. the soft skills required by the trainers when delivering training to adults, whether they were able to effectively and consistently engage the volunteers, whether they worked well as a team. Did they effectively deliver the training they themselves received in the manner they were shown? The project managers would have benefitted from an external perspective on the training delivery, rather than relying on their own assessment of the training delivery, as they were not specialists in training provision.

Scarce literature exists on the use of sustainable models of train-the-trainer in heritage, collections care or IPM. Managing expectations of senior management in the NTS (and other organisations that rely on non-subject specialists to provide care for collections) of the efficacy of the model relies on further research to establish the limitations of the method and ways to use the model effectively to ensure the safety of collections and goals of the organisation are achievable.
Lessons learnt: tailored train-the-trainer

The following observations were made from the pilot:

The role of the specialist advisors, subject specialists and external consultants

For collections care train-the-trainer programmes it is crucial to have a subject matter specialist to assist and help prepare the content for delivery. If the specialist has training/facilitating experience, then they should be encouraged to use their own style and content knowledge in devising high quality presentations and session training modules. The specialist advisor role should have a watching brief to continually evaluate the effectiveness of the training given by their trainers. External training consultants can be of great benefit when designing a train-the-trainer session and their input should not be limited to delivery of training. External consultants can bring an authority to a training workshop, which in house trainers may lack. It may be cost effective as the cost per delegate is less than when compared to sending the same number on public courses. The customisation of the programme allows training to be focused on elements that the organization needs to address. In this pilot we found it was useful to have delegates from different departments train at the same time, which helped foster a team spirit and mutual respect. External consultants have an important role in giving feedback and advice with training sessions as the trainers’ progress and develop their skill and styles. In the final analysis, to make sure a train-the-trainer programming succeeds, it is important to take the time to observe the initial set of trainees delivering their first round of training sessions and then follow-up with positive constructive feedback, tips, strategies, and additional ways to be effective. Access to an external specialist aids this process greatly.

Be Hands-On

If possible, a train-the-trainer programme should be tailored as much as possible to the skill set of the initial set of trainees. If they are experienced facilitators or have a reasonable amount of train-
ing experience then it may be possible to spend more time developing course content than on the training approach. The pilot project for the Newhailes moth project allowed one day for train-the-trainer training as the learning outcomes were clearly defined and time limited. Project managers needed to play a significant role in administering the training and this should be taken into account, as the time factor can be significant. The more time that trainers can spend with trainees the better, this fosters good working relationships and ensures training and working practices do not become stale.

For training of wider collections care and IPM responsibilities more manager time would need to be spent on devising an ongoing assessment of performance and mechanisms introduced for retraining or supplemental activities for development as the cascade system does not easily encourage learning outside the designed sessions.

**Workshop/Network**

One disadvantage to the train-the-trainer model is the sense of isolation that may accompany training that is led by in-house staff and ensuring against passing on institutional inefficiencies, perpetuating bad practice and keeping up to date and communicating changes to best practice in the sector. Allowing trainers to develop through attending courses on related material with delegates from other institutions should be encouraged. During the pilot at Newhailes IPM staff from other NTS properties and heritage institutions were invited to join the project team for a day, to experience how the project was being managed, learn what techniques for pest treatment were being used and exchange ideas on aspects of collections care that arose during discussions. This also helped to further ownership of the project by the house team and gave them a sense of accomplishment when they reflected on what they were achieving.

**Conclusion**

The train-the-trainer pilot allowed the NTS conservators to test the training method ahead of a potential fuller roll out of this type of training in the organisation. Irrespective of training methodology adopted in the future, this gave a better understanding of what good training should look like, a better understanding of how to plan training events, a better understanding of the skills required to run a good training event and a better understanding of how to train adults with varying learning styles.

Going forward train-the-trainer can be used with confidence for some aspects of collections care when the right subject specialist and support are in place and well briefed. One of the key concerns, whether non specialist staff can be relied on to consistently pass on accurate information has been addressed, cascading information is positive and accurate as long as checks and balances are put in place to compensate for over confidence or practical inexperience in breadth of collections care. The role of an external consultant to facilitate initial training sessions has proved extremely useful and this should be expanded to help evaluate training as it evolves and develops and may assist in arresting the slight distortion of training messages and technical content which was noted in the project. More networking, sharing of outcomes and research by the NTS should be considered to inform management of the optimal ways to use this training methodology which has become a norm in the world of in service training.

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Introduction

Established around 1750, Princeton University Library (PUL) has grown from an initial gift of 474 volumes to a collection of over 11 million. This collection is housed in several buildings around campus and, in addition to the circulating collection, contains extensive holdings of audiovisual material, digital resources, and special collections. Rare materials in the collection include early printed books and literary manuscripts, textiles, sculpture, paintings, prints, ephemera, and realia. As one of the preeminent research libraries in the United States, PUL and its collections are heavily used by scholars from around the world. They are also increasingly in demand for exhibitions in the Library's new Ellen and Leonard Milberg Gal-

Abstract

The Princeton University Library (PUL) Preservation and Conservation Department serves a library system of over 11 million volumes, held in 12 buildings around campus. With a small staff of one Preservation Librarian and the support of a Conservation Unit of four, successful preservation practice is highly dependent upon engaging staff throughout the library system. These staff members provide on-the-ground knowledge of current conditions in their branches and departments and, with training, are able to respond appropriately to preservation concerns as they arise. They also spread awareness of preservation issues and good collections care practices among their colleagues.

Official Preservation Liaisons are designated within each branch and major collecting unit of PUL, as well as key departments such as Circulation, Inventory Management, and Facilities. These liaisons meet regularly as a group and are trained in a variety of preservation topics, including emergency response, environmental monitoring, and integrated pest management (IPM). They serve as local experts within their units, providing real-time feedback to the Preservation Librarian about conditions within their collections. In this way, the Preservation & Conservation Department is able to expand its footprint to cover all areas of the library system in spite of a limited staff.

PUL’s integrated pest management program seeks to minimize the use of pesticides by taking a systematic, preventive approach to pest management including staff education, monitoring, environmental control, housekeeping, and facilities management. In order to advance staff education, the Preservation & Conservation Department is working with Princeton University’s McGraw Center for Teaching & Learning to develop and share training modules to lead staff through a preservation self-study program. These online modules will be supplemented by a calendar of in-person trainings and will be integrated into the onboarding process for new staff. By weaving preservation awareness into the role of each staff member, PUL is building a holistic culture of responsible collections stewardship.

This paper will cover the steps taken to establish the PUL Preservation Liaison Program, including gaining support from Library leadership, identifying liaisons, providing training, and setting goals, as well as tips for success and a discussion of lessons learned along the way.

Keywords: preventive conservation; collections care; environmental monitoring; integrated pest management; education and training; online learning
Informal links have existed between the Preservation & Conservation Department and collecting units of PUL for many years. Often, these links evolved in response to a specific incident, need, or particularly high-value or fragile collection rather than as part of an overall plan for collection care. Pest management at PUL has followed this trend, with monitoring generally only taking place in response to an outbreak. In addition to creating an incomplete patchwork of services that were not always consistent among different organizational units, this reactive approach tended to benefit libraries with special collections or a staff member who had some previous familiarity with preservation practice. As the Library moves toward an increased awareness of itself as a single entity, rather than as a collection of disparate branches, a more systematic approach is required. Indeed, one of the key tactics of the PUL 2018–2021 Strategic Plan is to “develop a holistic preservation plan that addresses physical, digitized, and born-digital collections, defines appropriate methodologies for prioritization, and is responsive to the evolving needs of the Library.”

There are significant benefits to developing local expertise in preservation practices within each library location. Branch Library staff have first-hand awareness of conditions within their collections storage spaces and are often the first to know if a problem arises, but they have not consistently received training in how to monitor their spaces or respond to collection emergencies. With training, these staff members are able to provide on-the-ground knowledge of current conditions in their branches and departments and to respond appropriately to preservation concerns as they arise. They also spread awareness of preservation issues and good collections care practices among their colleagues.

**Preservation Liaison Program Concept**

First proposed in 2018, the Preservation Liaison Program provides a direct link between the Preservation & Conservation Department and staff distributed throughout the Library. Official Preservation Liaisons are designated within branches and major collecting units of PUL, as well as in key departments such as Circulation, Inventory Management, and Facilities. These liaisons meet regularly as a group and are trained in a variety of pres-
vation topics, including emergency response, environmental monitoring, and IPM. They serve as local experts within their units, providing real-time feedback to the Preservation Librarian about conditions within their collections. In this way, the Preservation & Conservation Department is able to expand its footprint to cover all areas of the library system in spite of limited staff resources.

The benefits of the program are substantial. Preservation Liaisons receive valuable training that enhances their skill sets for the length of their careers. They also provide on-the-ground feedback for Preservation & Conservation and Facilities staff about conditions and needs within their spaces and are able to provide basic preservation training and guidance for their colleagues. Some Preservation Liaisons serve as members of the PUL Collections Emergency Response Team, which is mobilized to address collection emergencies anywhere in the system. Previously, this response was handled almost exclusively by Preservation & Conservation staff, sometimes working alongside PUL and Princeton University staff who had not received training in proper collections salvage techniques, personal safety, and other essential skills. Having a larger team of trained responders provides additional capacity and flexibility for emergency response.

There are additional benefits that are less tangible, but no less important. Through participation in regular trainings and meetings, the cohort of Preservation Liaisons identifies areas for collaboration and shares challenges, successes, and lessons learned. As they gain expertise, the Liaisons contribute to formal and informal training and staff education efforts, engaging even more PUL staff in preservation endeavors. This broad awareness of stewardship has the potential to positively impact the longevity of the entire collection for a much smaller investment than remedial action.

Participants in the program receive professional benefits in the form of enhanced skills and engagement with a Library-wide initiative. In exchange, they are expected to commit to making certain contributions in their role as a Preservation Liaison. These include attending monthly meetings, participating in regular trainings, serving as a local point of contact and information for other staff in their work location, and contributing to creation of instructional/informa-

tional materials for patrons and staff. Liaisons are also asked to carry out monitoring tasks including collecting environmental data, checking and replacing sticky traps in their area, and conducting stacks walkthroughs to check for evidence of mold, pests, or other issues. Finally, Liaisons are asked to promptly notify the Preservation Librarian of building issues such as leaks or poor housekeeping to ensure that they do not impact the collections. The subset of Preservation Liaisons who have opted to participate in the Collections Emergency Response Team are also asked to participate in collections salvage training and to respond to collections emergencies at any Library location.

Resources for the Preservation Liaison Program

One important element in developing the Preservation Liaison Program was consideration of the resources necessary for success. The single most important resource for the Preservation Liaison Program is staff time. Other key resources include buy-in from supervisors and library leadership to ensure that each Liaison’s contribution to the Library is recognized and supported, and funds to purchase training supplies and materials. The materials needed for the underlying preservation operations (supplies and equipment for environmental monitoring, integrated pest management, and emergency salvage) are purchased using Preservation & Conservation Department funds.

Establishing the Preservation Liaison Program

The first step in establishing the new program was to gain buy-in from key stakeholders throughout the Library. The concept was presented at a meeting of the Branch Libraries Information Sharing & Synergy Group (BLISS), an affinity group for the heads of PUL branch libraries. The group asked many important and challenging questions about the impact of the program on staff time, the extent to which the program might interfere with existing workflows, and the relevance of the general preservation training to staff whose work is narrowly focused on a specific format of material. This feedback proved essential in refining the proposal to ensure that it met the needs of the people it was intended to serve. The process of sharing the proposal and soliciting feedback also helped promote the program and clarify its
purpose as a service to the Library as a whole, rather than to a single location or collection.

Once input from BLISS was incorporated, a formal proposal was submitted to the Library Leadership Team for consideration. One unexpected challenge in gaining administrative support for the program was concern about the impact of participation on support staff whose employment is covered by a union contract. While union staff are encouraged to engage in voluntary professional development activities, any substantive change in their working responsibilities must be reflected in an updated job description, which must then be reviewed to determine whether a change in employment classification is warranted. If the change exceeds a certain percentage of the staff member’s duties, the position must be re-posted and opened to a competitive application process. In order to avoid any unintended implications of participation in the program, the language of the proposal, announcement, and application form required close review by Human Resources before the program could proceed. This process delayed final approval but ensured that the program was in proper alignment with existing agreements and verified that union staff could participate fully. As a result of HR review, updated program literature clarified that staff could not be required to participate in any activities outside of their regular working hours, that each participant needed approval from their supervisor, and that only staff who explicitly volunteered would be part of the Collections Emergency Response Team.

After the proposal and application form were approved by library leadership and HR, a call for applications was distributed to all Library staff. The hope was to form a cohort composed of staff from all PUL branches and locations, as well as representatives from key units that serve the entire Library. In order to engage a broad range of PUL staff, the program sought to attract a mix of union and non-union staff. In addition to the emailed announcement and reminders, informal presentations were given at some branches to promote the program and spread awareness.

The program received 32 applications, more than twice the maximum number of available slots. Criteria for selection included supervisory support, an interest in gaining knowledge and skills related to collections care, and the ability to commit approximately 4–5 hours per month to participating in program activities. Preservation Liaisons who intended to serve as members of the Collections Emergency Response team were also asked about their availability to respond to emergencies outside of work hours. Finally, applicants were selected with an emphasis on broad distribution around the physical spaces where PUL collections are stored and a focus on job functions that require hands-on work with the collections.

The 2019 cohort of Preservation Liaisons is comprised of 15 PUL staff members and includes representatives from all but one branch library, as well as the departments of Circulation, Physical Collections & Inventory Management, Collection Development, the Digital Studio, Cataloging, and Public Services. The first meeting took place in January 2019.

The cohort receives bi-monthly training on a preservation topic. These topics include general care and handling, preservation best practices, environmental management, integrated pest management, mold identification, and collections emergency response. Additional topics may be added according to need and interest. The training materials assembled and produced for these meetings will be refined by the Preservation Librarian and the Liaison group and shared more widely with PUL staff via in-person trainings and on the Preservation website. Where appropriate, educational materials will be produced for the benefit of PUL patrons and the Princeton community. The group may also attend webinars and participate in preservation-related activities offered outside of Princeton as they arise. Because the membership of the cohort will evolve over time, training will continue on an annual cycle. As specific Liaisons gain experience with a particular preservation topic, they may take the lead on providing future training in that area. Over time, the group will develop a range of training modules that can be used for staff presentations and self-study online.

**Integrated Pest Management**

Started in 2016, PUL’s integrated pest management program (IPM) currently includes the Preservation & Conservation Department, the Preservation Liaisons, and PUL Facilities, as well as staff and institutional partners from the shared high-density storage facility located on campus,
the Research Collections and Preservation Consortium (ReCAP). The program seeks to minimize the use of pesticides by taking a systematic, preventive approach to pest management including staff education, monitoring, environmental control, housekeeping, and facilities management.

The Preservation Liaison training module for IPM builds on a previous training developed by Preservation & Conservation staff. While that training focused on identification and immediate response to a suspected pest outbreak, the updated training builds awareness of the role that each staff member can take in preventing such outbreaks from occurring. Liaisons learn to monitor their spaces not only for evidence of infestation, but for environmental conditions that could promote an outbreak. These include high temperature and relative humidity, leaks, holes in walls, and poor housekeeping, especially in staff areas where food may be consumed. The training emphasizes the compounding benefits that can be achieved through good preservation practice; for instance, the same environmental conditions that help deter pests improve the chemical and mechanical longevity of the books and other paper-based materials that make up the bulk of PUL’s collections. Similarly, many of the same steps that help prevent mold outbreaks, or at least ensure early detection, will have the same effect on pests. This focus on a holistic network of environmental considerations helps all PUL staff understand the positive impact that they can have on preservation of the collections.

It is important to note that while the Preservation Liaison training modules are packaged for PUL staff (and are not currently available to the public), they rely heavily on existing resources. A key resource for all Preservation Liaisons is an annotated bibliography, to be reviewed and updated by the group each year.6

In addition to completing readings and training on integrated pest management, Preservation Liaisons are directly involved in the IPM plan for their location. To gain a deeper understanding of the specific needs of their space, liaisons participate in annual walkthroughs with Facilities and Preservation & Conservation staff to check for building and landscaping issues that need to be addressed. Liaisons also work one-on-one with the Preservation Librarian to develop monitoring plans, including determining the type and placement of data loggers and sticky traps. Monthly reporting is accomplished by mailing thumb drives containing downloaded environmental data and the sticky traps themselves to the Preservation & Conservation Department for review. These data are used to produce quarterly reports on each space. Incidents or issues of concern are reported to the Preservation Librarian and tracked using the Preservation Incident Report, a simple Google Form. Because information entered into the form can be exported as a spreadsheet, data can be sorted according to date, location, or type of issue, allowing for analysis to spot trends.

PUL’s formal Integrated Pest Management Program is still evolving. Planned next steps to enhance the program include the establishment of a designated quarantine space for new acquisitions and materials returning from exhibition loan, and development of an anoxic treatment protocol for infested collections. The Preservation Librarian and the Library Facilities Manager are also in the process of writing an Integrated Pest Management Policy. The Preservation Team has also been working with the Princeton University McGraw Center for Teaching and Learning to develop and share training modules7 to lead staff through a preservation self-study program, based on content developed for the Preservation Liaison Program. These online modules will be supplemented by a calendar of in-person trainings and will be integrated into the onboarding process for new staff.

Challenges and Advantages of the Preservation Liaison Program

The challenges associated with establishing the program have included overcoming skepticism from some supervisors, keeping the program moving forward through many layers of approval, and the time commitment required to bring together disparate training resources and adapt them for a non-specialist audience. This last challenge has been particularly pronounced for the IPM module, where important resources are sometimes gleaned from other industries, such as food safety. Other IPM-specific challenges include the struggle to find consistently high-quality images for a broad range of pests, the occasional “gross-out factor” or fear of insects impacting staff willingness to participate, and the difficulty of maintain-
Work with what you have: Before launching a completely new program, take stock of existing relationships, structures, and workflows. Where possible, consider adapting and enhancing, rather than starting from scratch. Model new initiatives on successful programs that are already underway.

Be inclusive: When identifying staff to serve as liaisons, remain open-minded about potential contributors. While some liaisons may have prior experience with collections care, a staff member with no previous exposure to preservation concepts may bring a new and important perspective and may have more to gain from training. Consider making an open call for applications, rather than handpicking participants. Including a broader range of staff functions, locations, and classifications will lead to fuller engagement.

Patience is a virtue: Expect the process to take longer than planned. Gaining buy-in, integrating feedback, and ensuring compliance with human resources may take several months. Simply scheduling and coordinating meetings for a

The Preservation Liaison Program raises the profile of the Preservation & Conservation Department and provides an opportunity for liaisons to get to know Preservation & Conservation staff. It provides a substantive training opportunity for support staff, who generally do not receive support to attend workshops, conferences, and other professional development opportunities. It strengthens relationships with Facilities and other key departments throughout the Library and the University. And, as stated before, it provides enhanced monitoring and faster detection of environmental issues in collection storage spaces.

Tips for Success

Whether developing a full preservation liaison program or an initiative focused specifically on IPM, establishing strong connections with staff throughout the institution is well worth the time and effort. Principles that can help ensure that the work that goes into creating new programming has the desired outcome are listed below.

- Work with what you have: Before launching a completely new program, take stock of existing relationships, structures, and workflows. Where possible, consider adapting and enhancing, rather than starting from scratch. Model new initiatives on successful programs that are already underway.
- Be inclusive: When identifying staff to serve as liaisons, remain open-minded about potential contributors. While some liaisons may have prior experience with collections care, a staff member with no previous exposure to preservation concepts may bring a new and important perspective and may have more to gain from training. Consider making an open call for applications, rather than handpicking participants. Including a broader range of staff functions, locations, and classifications will lead to fuller engagement.
- Patience is a virtue: Expect the process to take longer than planned. Gaining buy-in, integrating feedback, and ensuring compliance with human resources may take several months. Simply scheduling and coordinating meetings for a
group can be surprisingly time-consuming, and newly trained staff may make mistakes. Anticipate delays and acknowledge that incremental progress is still progress.

- Create buzz: Prior to formally proposing a new initiative, begin talking about it with colleagues. When a problem arises, share the ways that a new program could help address that type of problem.
- Seek feedback: Share ideas with colleagues and stakeholders and pay attention to their questions and reservations. Try to gain an understanding of how a new initiative or workflow might impact staff in other areas of the institution. Plan periods of assessment and revision into new programming. Consider launching the program as a pilot for a period of six months to a year.
- Don’t reinvent the wheel: Use existing training resources if possible. Familiarize staff with organizations that produce information on preservation and collections care so that they are empowered to find information on their own. Engage staff participants in the process of assembling training materials. Bear in mind, however, that web-based resources, in particular, can be fragile; if a given resource is central to your training program, think about how to archive it.

Conclusion

As collections continue to grow, the number of staff explicitly dedicated to care and protection of those collections often does not keep pace. While improved efficiency and a focus on prevention rather than cure can go a long way toward enhancing collection care with limited resources, the value of broader staff engagement cannot be overstated. This principle is particularly true for preventive programming that depends on monitoring and modification of staff behaviors. By weaving preservation awareness into the role of each staff member, PUL is building a culture of responsible collections stewardship that will benefit the collections for years to come.

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Endnotes
1 http://library.princeton.edu
2 https://recap.princeton.edu/about
3 http://library.princeton.edu/preservation
4 “Support staff” positions are paid by the hour and generally do not require an advanced degree. They are distinct from professional positions such as administrators, librarians, and conservators. Within PUL, union support staff roles include conservation technicians, clerical assistants, digital imaging technicians, and pre-bindery assistants.
5 The new training is currently under development, but the previous version can be seen at http://library.princeton.edu/sites/default/files/Mold%20and%20Pest%20Training%20Presentation_1.pdf
6 The IPM section of the annotated bibliography can be viewed here: https://tinyurl.com/yxv7bjol
7 This platform is still under development using edX (https://edx.org), a non-profit massive open online course (MOOC) provider that was developed by Harvard University and the Massachusetts Institute of Technology in 2012. We use EdX Edge, which allows creation of Princeton-specific courses that are open by invitation only. There is also a free, open-source version of the platform called Open edX.
Abstract

The Pew Research Center documents that between 2005 and 2015 social media participation rates for adults in the U.S. rose from seven percent to 65 percent. Now, in 2018, it seems that participating on at least one social media platform is imperative in world-wide networking, audience building and asserting relevance in society. This explosive rise mirrors a shift in the view of social media from a form of entertainment to a means of connecting personally and professionally. In 2016 the Integrated Pest Management Working Group (IPM-Working Group), an ad hoc group of museum professionals which has been working for over a decade on promoting IPM for cultural heritage, took the plunge, re-branding our Facebook page, launching a Twitter account and creating videos for a new YouTube Channel focused on driving traffic to our website www.MuseumPests.net.

Insect and rodent pests leave tactile, if unwelcome, evidence of their activities in our institutions, a scattering of frass, a hole in a textile, a stain on a book page. It is information with no need for translation into other languages. Photographic evidence of insect infestations and resulting damage evoke fascination and horror in equal measure. It can thus prove challenging to translate this information into something more palatable that will promote the cause of IPM rather than repel viewers. Via short, concise tidbits of information utilizing links, photos, and hashtags, many times with a humorous slant, viewers are directed into our world of IPM. The audience is encouraged to let their guard down and participate in combating an ugly reality within our institutions.

This paper will examine the IPM-Working Group’s efforts on social media and whether the use of these platforms translates into increased awareness of IPM goals and traffic to our website and listserv which provide access to professional resources.

Keywords: IPM Working Group; MuseumPests; social media; Facebook; Twitter

The role of social media in the IPM community

Museums and similar cultural institutions worldwide have embraced social media. “Social media has blurred the lines between traditional roles of exhibition developers, designers, educators, and conservators, merging with roles previously assumed by marketing and public relations departments” (Gonzalez, 2017). “In recent years social media managers at institutions around the world have been reaching out to audiences via witty posts on Facebook, Instagram, Snapchat and Twitter” (Hannon, 2017). Collections, events, renovations, installations, the roles of employees, activities that generally occur behind the scenes, are now being brought to the forefront through social media in the drive to build communities, educate audiences, and increase relevance.

Over the past fifteen years participants in the IPM-Working Group have striven to ensure that pest management is seen as a core collection activity essential to good preservation policy. Lifting the stigma of talking about pests in our institutions has been an essential first step. Unlike most social media posts that are designed to promote an institution in its best light, sharing information on
information on collaborative projects. At the IPM-Working Group's 2007 meeting, we were stunned to learn from our programmer that the website was receiving hundreds of hits a month, meaning that people not in our group were accessing the site. We began receiving requests for information and advice, and it was clear that the website had begun filling an informational void for members of our field. Since then, the MuseumPests.net website has gone through two updates to improve the organization of the site.

A discussion during the IPM-Working Group's 2016 meeting focused on how to promote knowledge of the MuseumPests.net website to increase its visibility in the field. Creating a social media presence was seen as an important tool in driving traffic to the MuseumPests website. Three people volunteered for this task forming a small committee to consistently add and monitor content of the chosen platforms. Creating vibrant social media feeds, while seemingly quick and easy, takes time and concerted effort. Many institutions have a staff member dedicated to filling as many social media platforms with content as they can, every day. The IPM-Working Group's participants all have full-time jobs and IPM responsibilities are generally only a small portion of their work responsibilities. Generating new content for our social media streams is often one more task added to overfull schedules. To remain focused and ensure timely postings, our group has focused efforts on only two platforms: Facebook and Twitter. Other platforms could be added over time based on interest of IPM-Working Group members. Widgets with the ubiquitous tag line “Find us on Facebook and follow us on Twitter” were added to the MuseumPests website, conversations, and e-mails.

MuseumPests.net website analytics show that 50 percent of the site's users find us via search engines such as Google. Forty-three percent of users navigate directly to the site indicating that they have heard of the group and the website. The remaining seven percent is driven to the site via links from other websites or social media platforms. While mobile phones and tablets are increasingly used to access MuseumPests.net, the majority of users are accessing the site using a PC based during traditional working hours. Social media however can encourage users to revisit the site to view changes and updates to content. Most
As a result, posts on sites like Facebook and Twitter are well designed to break down barriers that might intimidate the less informed or initiated. This is especially important for topics like IPM that may, under most circumstances, seem unappealing. A MuseumPests Facebook post might pop up in your feed between pictures of a friend's baby pictures and a video of a singing cat. Research has shown that people can blend their worlds even when one topic is out of context from the next. In doing so, they are in a more comfortable setting to receive information, and more inclined follow up on leads. Studies showing the physiological response to social media support this idea that we become receptive to new ideas via social media.

“Oxytocin, [is] sometimes referred to as “the cuddle chemical” because it’s released when you kiss or hug. Or … tweet. In 10 minutes of social media time, oxytocin levels can rise as much as 13% – a hormonal spike equivalent to some people on their wedding day. And all the goodwill that comes with oxytocin – lowered stress levels, feelings of love, trust, empathy, generosity – comes with social media, too. As a result, social media users have shown to be more trusting than the average Internet user. The typical Facebook user is 43% more likely than other Internet users to feel that most people can be trusted. So between dopamine and oxytocin, social networking not only comes with a lot of great feelings, it’s also really hard to stop wanting more of it” (Seiter, 2017).

Photographs and illustrations are the best tool for a comfortable experience on social media. Original images from IPM-Working Group members (Figure 2), material from MuseumPests.net, material submitted by colleagues and information gleaned from reliable entomological sources form the basis for posts. Proper accreditation is always used if material is not the author’s original work. Images are typically used as a starting point to conversation, quickly grabbing the attention of the viewer and hopefully leading them to click through to an article on our website.

Damage caused by pests and pest identification are aspects of IPM most easily explained and examined visually creating a large, effective impact.
forcing them to stop and increase the chance of them taking notice of the group’s feed (Figure 4).

Requests for pest identification are the most prevalent topic on the IPM-Working Group’s PestList with responses posted with impressive speed by members of the email list. Periodically, we are tagged on Twitter with a question. Therefore, it only makes sense that images of question-able insects, frass and mysterious casings make an appearance on social media platforms in order to help solve a mystery or answer the ever-present questions in IPM of “What is it?” and “Should I be worried?” The ability to crosslink social media platforms has proven a valuable and timesaving tool for learning.

Hashtags continue to expand and grow in popularity in social media platforms, especially Twitter. They are designed to collate information, allowing viewers to find specific topics or at least nar-
row down the large array of posts to locate what is most relevant to their needs or wants. Our twitter posts have embraced some of the platform’s popular hashtags such as: #tbt (Throw Back Thursday), which focuses on historical items or images from “the past”. We have used hashtags that could be easily inferred such as #ipm, and #museumpests in hopes of expanding our audience. Currently, MuseumPests’s Twitter feed has 220 followers, at a slower growth rate than our Facebook page, but never the less non-existent prior to first posting in 2016. And there have been some amusing and unexpected mashups. Members of the IPM-Working Group social media team like to think we coined the hashtag #FrassFriday a catchy alliterative hashtag conditioning our audience to expect a post on our platforms each Friday that focused on insect excrement. A review of this hashtag’s collated posts however shows that the majority tracing back to August 2009, relate to a group of Friday night dance parties in California. It is amusing to think that their audience may occasionally be viewing IPM related content.

Our group’s mission to be a reliable core resource on IPM requires that all information whether on our website or social media platforms is informed by accurate IPM knowledge. A light-hearted approach can be invaluable but the overall tone must still relay professionalism. Mistakes can and will happen in the fast-paced world of social media. Errors in spelling and grammar are our biggest foible, typically the result of a hurried posting in the interest of getting content onto a social media in a timely fashion. Proper attribution of content at the time of the initial post is essential in avoiding what can be an awkward correction at a later time. The key after making any mistake is making a speedy correction after an issue has been brought to our attention. Facebook allows content to be edited even after a post has gone live. Twitter posts must be deleted completely and “retweeted” with corrections. To date there have been no negative responses or feedback from MuseumPests’s audience.

**Is it working?**

Unlike topics in pop culture and the news, IPM rarely makes an appearance in casual conversations around the proverbial water cooler or lunch table at work. Social media metrics allow us to quantify word of mouth transmission with quantifiable data. In the past two years since launching the MuseumPests Facebook page, it has garnered 482 followers. Facebook measures *Reach*: “The number of people who had info about your event enter their screen” (Facebook Help, 2018) and *Engagement*: “the total number of actions that people took on your Facebook Page and its posts” (Facebook Help, 2018). Facebook’s *Insight* screen allows page managers to view metrics going back 28 days. In a typical month MuseumPests Facebook posts reached 1,491 viewers (averaging 300 people per post). Between mid-November – mid-December, 2018 496 viewers engaging with MuseumPests posts on Facebook meaning that they “liked” it, commented, clicked on a link or shared it on their page. The most popular individual posts generated almost 70 engagement actions (Figure 5). While these are not viral numbers, they have been rising steadily each month. We do not pay for ads or to boost posts.

A review of the most popular MuseumPests Facebook posts show those with a comical slant have the highest rates of engagement. More regular review of these metrics will allow our social media committee to continue to build audience over time. Each click or view represents an opportunity to educate and advance our group’s mission. Based on the trends and statistics of each social media platform the IPM-Working Group utilizes, the future points to maintaining our activity level and increasing it as we can. We feel the time and effort put in thus far has been well spent. At the time of writing this paper we are not actively exploring other social media platforms such as Instagram, simply due to the factor of time able to be given by our participants managing our social media. Exploration of other social media platforms is likely to be encouraged, if an individual or group shows interest and is willing to give it the time required.

**Conclusion**

While it can be challenging to measure the success of using social media, participation in some form is imperative in our current media environment. We reveal much about ourselves and our interests on these platforms. “68% of people say they share to give others a better sense of who they are and what they care about. But the biggest reason we share is about other people: 78 % of people say they share because it helps them to stay connected to peo-
ple” (Seiter, 2017). Not long ago, blogs were overwhelmingly the most popular means of showing your presence on the internet, expanding your ability to share thoughts and ideas. Long before blogging, simply having e-mail placed you in a different ranking in the technologically savvy. Merely following suit with the world’s trends may not justify the voluntary hours members of the IPM-Working Group spend posting on social media platforms. But perhaps, we dedicate a portion of our time to promote and share knowledge freely and casually in a manner that doesn’t feel like work. Innumerable connections, friendships and colleagues are made daily via social media. Our hope is that in a virtual world, where we find ourselves overwhelmed with information, we provide a professional community with reliable knowledge in a comfortable manner that may advance the difficult work we are trying to accomplish in protecting our collections in the real world.

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References


Good practice in IPM

IPM as a practice is extending its reach across cultural heritage institutions throughout the world (Crossman and Pinniger, 2013). Good practice is established, defined and shared amongst professionals with responsibility for collection care (Pinniger, 2008; British Standards Institution 2016). This leadership has led to clear practical guidance for avoiding, reducing and monitoring pest infestations. Furthermore, networks exist which share IPM resources such as monitoring the spread of infestation (Birmingham Museums and Art Gallery), offering suppliers information on responses (Pinniger, 2008) and sharing good practice in easy-to-follow guides (Museum of London, 2013). Despite all this good practice, there are surprising areas of IPM data management that are not standardised, particularly regarding data collection, and areas where practice is under developed, such as data analysis and communication. These challenges are linked: the current methods of communicating pest data often obfuscate the lack of standardisation of data collection with potentially serious implications for data interpretation and subsequent action.

Current practice in data collection and communication

Communication of data

A review of publicly available reports on pest infestations in museums and other cultural heritage organisations revealed that a remarkably narrow range of options for data representation exists (Henderson, Baars and Hopkins, 2017). The primary mechanism of reporting pests found in this research was a simple ordinal measure or count of the number of pests by type (Hopkins, 2015). It is very common for spreadsheets to be developed which collect such data and which in turn are easily converted into traditional EXCEL style outputs such as bar and pie graphs. These familiar forms of data representation are often presented without commentary regarding their selection because their existence is ubiquitous and familiar, generating few questions about their validity. Beyond the bar and pie graphs the other common form of pest concentration representation is a map of pest numbers by location normally representing insects by colours or pictograms on floor plans. These diagrams aim to represent the scale of...
the problem but to be more precise they represent the extent of detection. The challenges for these forms of data management are two-fold: firstly, a challenge exists as to whether the data present an accurate reflection of the number of pests in a room and, secondly, whether data shared in this way is effective in serving the purpose for which the data was collected.

**Accuracy of data**

To be confident that any data are valid, it is necessary to establish that the number of pests found correlates with the scale of the insect pest problem. It is the authors’ hypothesis that in many cases the number of pests found in an institution correlates to the room size and the number and density of pest monitoring traps set, necessitating a more carefully defined method of counting and representing numbers, for example, using the Pest Occurrence Index (POI) described in Baars and Henderson (2019). Whilst there is a correlation between numbers of pest occurrences in a place and the number of pests caught in pest monitors, there is also one between the numbers of pests caught and the number of monitors. Figure 1 shows the numbers of pests trapped in the National Museum Wales over the period of 2013–2018.

The first figure might suggest a plausible narrative of an increase in pest activity that would suggest a growing pest problem. Despite the familiarity of the expression ‘correlation does not equal causation’ the confirmation bias (McKenzie, 2004) generated by the expectation of an increase in pest numbers, perhaps heightened by a greater focus on IPM within the organisation, means that creating a graph that appears to represent an increase in pest density would be easy to accept and act upon. Figure 2 represents the same total pest data on the y-axis, but replaces the timeline with the number of traps showing an equally plausible correlation between monitor and pest numbers. The comparison between the two graphs should prompt reflection on how the IPM managers organise the data collection process when reporting pest numbers (Baars and Henderson, 2019).

Within the sector, advice on placing monitors tends to follow a similar format: target areas where food is consumed and disposed, target...
reception areas, window sills, chimney breasts and dead spaces. There are sound entomological reasons why these locations are good places to monitor and the detection of pests in these contexts would indicate a threat. If the purpose of trapping is to detect the presence or absence of pests, this method would have a simple validity. If the purpose is to monitor the change of scale of an infestation (increasing or decreasing numbers) and the total numbers of pest caught on monitors will be reported, then the number of monitors placed within each space needs to be factored in to standardise the data. A common response to the discovery of a pest on monitors in a particular space is to increase the number of monitors. This will limit the validity of any comparison of the density of insects in areas with fewer monitors per unit area because a subsequent increase in the number of pests caught in monitors may be the result of an increase in pest activity or an increase in monitor density, or both. If the actual cause of the increase in pests detected is not explored further, data interpretation may suffer from confirmation bias, resulting in the reporting of a potentially non-existent growing pest problem.

The authors recommend that pest counts are reported not as number of pests, but as number of pests per monitor per m² in areas with a common density of pest monitors (Baars and Henderson, 2019). Whilst it might feel inefficient to place monitors in areas where no threat was reported, some forms of data representation will be more consistent if the density of monitors per m² is controlled. The task of collecting null data is essential to good hypothesis and prevents any complacency-led oversight of pest movement. There is no need to standardise the density of monitors if the purpose of monitoring is simply to identify the presence of a particular pest within a specific location. This may be the case, for example, if finding a single pest in a temporary exhibition gallery may require action. Such a ‘presence or absence approach’ reflects the minority of IPM applications.

FIGURE 2. Pest count (y-axis) by number of pest traps (x-axis) with colour to differentiate spring/autumn total catch.
Purpose of data collection
Evidence based and resource effective collection care requires the collection of data. However, data collection is only valuable if it addresses a specific question and is communicated to those who need to know the results in order to act. Many of the challenges within IPM represent dynamic situations where staff need to know if a new pest is spreading through the sites of the museum, if a new hygiene regime in the kitchen is working, or whether a reduction in the temperature set points has led to a decrease in pest activity. Many of the representations of pest data in the heritage sector traditionally offer uniformity but do not demonstrate that they are tailored to a specific audience or intended to inform a dynamic situation (Henderson, Baars and Hopkins, 2017). The challenge is to offer powerfully influential, accurate representations of pest data that support improved communication and more effective advocacy.

Communicating pest data
Once the method of measuring insect activity has been standardised, the next step is to consider how it is communicated. In any communication strategy there are many factors to consider, one of which is content: this can be a traditional message such as a report or email however, an influence strategy need not be verbal. A message can also be a ‘symbolic transaction’ such as bringing someone a cup of tea or sending a birthday card (Perloff, 2014). When evaluating attempts to communicate for influence, social interactions should merit equivalent levels of reflection to words. The way messages are constructed, the tone of language and presentation all matter, as do other factors such as the source of the message, the context in which the message is exchanged and the receiver of the message (Henderson, 2001). When receiver needs are not fully considered, there is a danger that the communication will not be attended to, ignored, misunderstood or rejected.

Influence and communication
When planning a communication to influence a receiver, it is important to consider receiver needs. Pfau and Parrot (1993) identify five receiver decision stages. At each of these phases, a message should be constructed differently to achieve maximum effectiveness. The five stages identified by Pfau and Parrot are awareness, information seeking, discrimination, choice and post decision:

1. At the awareness stage, generating awareness of the issue is the key objective.
2. At the information seeking stage, the persuader should provide issue relevant information.
3. At the discrimination stage, it can be useful to attack any alternative choices available to the receiver or encourage any pre-existing doubts about alternatives.
4. Once the receiver discriminates (decides) the opportunity to evaluate the effectiveness of persuasive communication arises.
5. After a choice or decision is made, it is useful to reinforce the receiver decisions.

Theories of influence also identify the receiver’s willingness and ability to process information as being critical factors to them considering it. Some influence techniques rely on simple heuristic triggers to illicit an instinctive response. Such simple measures can be effective even if the receiver allocates very little cognitive energy to considering the message. Where a complex message is being communicated, it should be carefully developed to offer high levels of relevance to the target receiver and be presented in a format that the receiver is capable and willing to consider (Henderson and Waller, 2016). As people are ‘cognitive misers’, the majority of their decisions are made under conditions of low engagement with the detailed argument, so when attempting mass communication simple, visual and compelling messages must be a feature.

An assessment of receiver needs and abilities should be undertaken prior to communicating an IPM message. If the receiver has no awareness of the challenges of IPM, the message must aim to target the need for pest management and the potential consequences of inaction. In this context the message should catch the receiver’s attention, which is achievable through both visual and verbal means such as an image of pest damaged objects or a verbal report suggesting that an effective IPM strategy will help with their concerns, such as the current accreditation application/funding bid/benefactor event.

In the information seeking phase, the receiver is ready for data and will be looking for issue relevant data that helps answer the questions they are ask-
Reinforcement can be in the form of normal activity management reports, but can also be communicated in a more inclusive manner such as through posters celebrating vigilance and noting how everyone shares in the maintenance of best practice (Figure 3).

Communication goals
In devising an effective IPM communication strategy, the definition of communication goals and the outcomes required from the pest management activity will be fundamental in defining, delivering and assessing success. It is in this area that the performance of the main modes of communication currently in use in the sector could be challenged. The goals of IPM communication will tend to be themes such as to

- monitor the spread of a new threatening species (Goddard et al., 2016),
- measure the effectiveness of pest control measures,
- achieve staff behavioural changes that would result in improved cleanliness,
- provide reassurance to lenders or insurers that good practice is being maintained,
- provide managerial authority to support the IPM manager’s recommendations.

One easily neglected aspect of receiver decision making is post decision change. Influence can be described as the shaping, changing or reinforcing a target’s beliefs, attitudes or behaviours (Miller, 2002). In a post decision situation where pest trapping, quarantine and housekeeping are all part of the daily life of the organisation, reinforcement of the value of these actions is essential. Participation in self or external evaluations, such as ‘Benchmarks in Collections Care’ (Dawson, 2011) or accreditation where reporting is part of the process, is a standard way to reinforce practice. Reinforcement can be in the form of normal activity management reports, but can also be communicated in a more inclusive manner such as through posters celebrating vigilance and noting how everyone shares in the maintenance of best practice (Figure 3).

FIGURE 3. Example of a possible poster (inspired by building site safety) celebrating vigilance in pest management.
Each of these themes goes beyond the detection and identification of a species within a space and relates to a changing state, normally the changing distribution and composition of pest populations. Yet IPM recording tends to prefer formats which show static indicators of presence and total numbers. Even in a museum where the goal is simply to eliminate pests and set a goal of zero occurrences, few museums can deliver such clinical conditions and reporting would still focus on the change in pest population towards the desired level. In almost all cases, as with other agents of deterioration, the target in pest management will be an optimised cost benefit consideration: aiming to create a situation that is better than before or at least no worse. The goal in most pest reporting must therefore be to communicate change.

Research questions
Establishing the purpose of research should influence the nature of that research. A well-defined research question helps ensure that data collected can be used and interpreted, that unnecessary data is not collected, and that data collection serves a purpose. Research questions can be open or closed, from ‘We are just starting to consider IPM and want to establish which pests we have and where’, through to ‘Which species of silverfish are active in store 2?’. Research into open questions is as hard to manage as research into closed questions. With complex questions there is a natural human heuristic for attribute substitution where, when faced with a difficult question, someone responds to an easier to answer question instead (Kahneman, 2003). Attribute substitution is not uncommon in collection care, in this context a broad but poorly focussed enquiry such as ‘What pests do we have and where are they?’ can easily morph into research that answers ‘How many pests have we trapped in the locations where we have placed monitors?’. As a simple guide, looking at the titles given to your pest trap data may provide insight into what question is being answered and from this suggest for whom the data is intended. A graph titled ‘Numbers of pests trapped in store 3’ may only be of interest to the person checking the monitors in store 3.

Visual communication and decision goals
Effective sharing of IPM data is therefore connected to the research question and to the needs of the receiver(s) being offered the information. Effective communication of IPM data to a message receiver who is at the awareness stage will be about drawing attention to the issues to try to push it up their mental agenda. In this context, a powerful visual message will activate their attention, and the sense of potential loss should activate concerns (Kahneman and Tversky, 1979). Threat-based messages are often ineffective (Miller, 1987) so it is wise when communicating with decision-making colleagues to avoid saying ‘If you don’t stop people eating in the store, bad things will happen’ whereas the same message framed positively can activate their powerful loss aversion heuristic. A more positive message such as ‘If you authorise the deep clean, we can prevent the spread of this pest’ might prove more effective. In this context, a visual image of an infested item (one which your receiver considers to be valuable) with a carefully worded message will be far more evocative than a bar graph for decision makers in the awareness phase. Influence need not be restricted to verbal messages, for example giving key staff or, for that matter, the public (Xavier-Rowe et al., 2018) pest monitors to place in their home is a symbolic transaction that could increase awareness, especially if the receiver discovers moths in their own wardrobe.

It might be imagined that at the information seeking phase the bar graph would come into its own. This however, requires the graph to communicate meaning to the receiver. In evaluating this, the priorities of the receiver or target need to be considered carefully; while some conservators have managers who want to know the ratio of larval to adult stages and the breakdown of proteinaceous and keratinaceous pests, many managers want to be informed about procedural things: ‘Are we deploying our staff time effectively?’ or ‘Do we have to clean the gallery carpet again?’. In these contexts, the title of the graph should indicate that it answers the receiver’s questions, for example ‘Silver fish numbers since the last carpet clean’. We do not argue for a cessation of the creation of bar graphs with total pest numbers, but to use them as an interim point in data collection and interpretation, not as a communication tool.
Looking at post decision processing, the influence goal would be the reinforcing of attitudes and behaviours. A manager who has identified IPM as a core task for their team will be pleased to be offered evidence of the success of their decision. Evidence to support good management is more likely to be passed on by that manager as evidence of their abilities, and this reinforcement and public restatement of the value of the task will contribute to reinforcing the manager’s commitment to their team. Success, in this context, can lead to null data. Null data is a hard thing to work with but this image (Figure 4) of moth traps from Eton conservators provides a quick and simple visual reassurance that the IPM strategy to reduce moths is working. This visual communication might be sufficient to reinforce decisions that the current practice is effective and should be supported.

**Conclusions**

Improved communication of IPM data can enable more support and resourcing for its practice and is therefore an essential feature of an effective IPM strategy. This paper has identified that there is a weakness in how pest data are analysed, interpreted and represented in many heritage contexts. The weakness applies both to the accuracy of the data and the efficacy of its communication. Effective IPM requires that actions are taken, decisions are made, budgets released or practice changed. To achieve this, more work is required on the consistent and influential representation of pest data. At present, much of pest data representation is static, standard and dull. To better represent and communicate IPM data, the rational for its collection must be considered, the basis of its collection standardised and the target for communication defined. Data collection intended to affect change must be informed by the change that is sought. Data collection that serves only to fulfil the goal of collecting data, will have limited interest for anyone but the data collector. In identifying the person, group or institution that the IPM manager aims to communicate with, it is important to consider their needs, pre-existing knowledge, engagement in the topic, IPM’s place in the receiver’s priorities and the time and space in which they will consider the message.

Standardisation improves shared data resources, but this is only meaningful if that standardisation
is based around a well-considered model. There is a need for a measurement of pest occurrence within a heritage institution that is neutral to the density of pest monitors and room size and that provides a stable index against which change can be measured. This leads to the proposal for a consistent reporting unit for pest density: the pest occurrence index (Baars and Henderson, 2019).

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Visualisations are the quickest and most impactful ways of communicating data. As a result of a partnership project between National Museum Cardiff (NMC) and Cardiff University, Henderson et al. (2017) suggested the use of novel dynamic, visually attractive and meaningful graphical data representations to achieve improvements in communication. At present, the choice of graphical tools is frequently limited by a lack of effective data analysis. One reason for this is that standard advice on pest monitoring explains how to set up a monitoring programme, how to identify pests and how to record numbers, but stops short of suggestions about what to do with the resulting data. Data interpretation and communication

**Introduction**

Effective communication of pest monitoring data should result in the message recipient concluding that a preventive approach to collection care is the best tactic to protect heritage collections from pest damage. Consequently, messages should be targeted at shaping the recipient’s attitude accordingly, to encourage their support for pest management efforts. One hurdle to communicating IPM messages effectively is that recipient decision makers are understandably not as familiar as the IPM manager on issues critical to successful pest management such as the building, collections, collection vulnerabilities, pest species or the likelihood of damage resulting from a pest threat.

**Abstract**

In a bid to improve communication of data relating to the conservation of cultural heritage collections, the authors present a solution and technique that makes analysis and communication of pest monitoring data more user-friendly. This novel technique includes calculation of the new Pest Occurrence Index (POI), which integrates recorded pest occurrence numbers over number of pest monitors and room size, decreasing unintentional bias introduced by previously used analytical techniques. Calculation of POI requires that contextual information such as type of collection affected, room size, and number of pest monitors deployed also need to be reported during pest monitoring to enable meaningful data interpretation. Trials at National Museum Cardiff (NMC) using different types of illustrations, based on the newly developed POI and with messages targeted at specific recipients, indicated that risk perception based on visualisations is affected by user background, expertise in relation to pest management and familiarity with certain types of graphical representations. The introduction of novel and comprehensive forms of graphical data interpretation at NMC, including greater focus on developing visualisations with specific messages for different target audiences, resulted in increased staff buy-in and willingness to assist with pest management and a demonstrable decrease in pest occurrences in collections areas of the museum.

**Keywords:** IPM; museum; pest monitoring; data analysis; Pest Occurrence Index; visualisation; communication
are an essential step in a pest management programme with consistent data collection being critical to allowing the success or failure of pest prevention and/or treatment measures to be judged objectively.

Pest monitoring

It is an axiom of cultural heritage conservation that pest management is important. Most heritage objects comprised of organic materials are susceptible to being damaged by pests, and pests are regarded as the third agent of deterioration (Strang and Kigawa 2018). A rapidly increasing amount of research literature assists with the development of ever-refined pest management methodology (Crossman and Pinniger, 2013), which, during the past 30 years, shifted from previously reactive in response to now preventive with the intention of avoiding outbreaks in the first place (Henderson, Baars and Hopkins, 2019). Increasingly, the use of non-chemical means for monitoring and control of pests – driven in part by the negative impacts on human health from the use of chemical biocides, and the realisation that pest damage to cultural objects is more time-consuming and expensive to resolve than the prevention of damage – is resulting in preference for an Integrated Pest Management (IPM) approach (Child, 2013; Querner, 2015; cf. Kingsley et al., 2001).

One crucial element of an IPM programme is continuous monitoring of the occurrence, and frequency of occurrence, of pest insects with the aim of identifying change points, such as a sudden increase in pest counts that may constitute an increased risk to collections. The literature on monitoring methodologies is exhaustive, but a few examples serve to illustrate the volume of references available for monitoring methodologies ranging from visual inspections of pest activity to the use of various types of non-attractant and attractant pest traps: Child and Pinniger (1994); Pinniger, Child and Chambers (2003); Querner et al. (2013); Pinniger (2015).

Data capture

If undertaken regularly, and given a sufficiently large institution, pest monitoring can result in the creation of large amounts of data: the almost 200 pest monitors currently deployed at NMC are checked twice annually; data fields include room name, number of monitors in room, room size, and 18 fields for different pest species/pest indicators (Table 1), resulting in more than 8,000 individual potential data points per year. Setting out pest monitors and never checking them, or collecting data without analysing them are, at best, a waste of time and resources; at worst, this practice endangers the collection. Good data analysis is crucial to assist with interpretation and assessment of the effectiveness of a pest management strategy, and for communicating findings for the purposes of outreach, engagement and decision making.

Data analysis

Unfortunately, the literature lets the conservator down just at this crucial point of data analysis and communication. Beyond the general advice that ‘over a period of time a record of what is caught (in pest monitors) will build up a picture of the distribution of insects’ (Child, 2006), none of the references cited above contain any suggestions about what to do with all those data. Even the otherwise comprehensive standard BS EN 16790:2016 does not go beyond suggesting that ‘data collected from monitoring can help to map the scale, type, location and seasonal cycles of a pest problem’ – as in other documents on pest management in cultural heritage collections, how to achieve this is left to the individual conservator to figure out.

To the conservator tasked with monitoring pest activities, the all-familiar pie, bar and line graphs of pest counts provide hazard data about the ability of different species to penetrate the building envelope and establish populations within a building. They do not indicate the magnitude of risk arising from that pest occurrence which is dependent on, amongst other factors, which part of the building or collection is affected by what pest species, and the number of individual pest organisms. Species numbers alone present a restricted image of the problem. Crucially, if there are changes to the number of monitors or surface area sampled during a monitoring period, the data are rendered almost useless.

An example illustrates this problem. Pest monitoring data from NMC appeared to suggest that there was a dramatic increase in the number of pests recorded during the five years since 2014 (Figure 1.A). Staff knowledge and a review of data collection methods (Henderson et al., 2017) prompted
a review of how data were presented (Figures 1.B–D). Correlating pest numbers with the number of pest monitors, the number of rooms and total floor area monitored showed that there was a risk of data interpretation being skewed by gradual improvements to the monitoring programme, resulting in the potential to draw incorrect conclusions about the size of pest populations based on a simplistic interpretation of Figure 1.A. The tendency to confirmation bias, from an apparently plausible narrative about a pest increase over time, would be tempting for staff who were evidently increasing their focus on pest management. An examination of the correlation coefficient between pest numbers and a range of factors (Table 1) exposes the danger of seizing on an initial plausible explanation, the apparent increase in the size of the pest population (Figure 1.A). Examination of a range of correlations exposes many other relationships, suggesting the more compelling explanation that the increase in numbers of pests detected is best explained by an expansion in the pest monitoring programme (Figures 1.B–D).

The current practice of only recording the numbers of individuals of each pest species detected is more suited to mapping the hazards than to demonstrating the resultant risks. This poses a problem for the conservator attempting to make sense of pest monitoring data – does an increase in the number of pests recorded relate to changes in the pest population or to changes in the monitoring technique? Conversely, how is it possible to measure the success of a pest management programme if presentation of

<table>
<thead>
<tr>
<th>Correlation between</th>
<th>Correlation coefficient ($r$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>pest count and ...</td>
<td></td>
</tr>
<tr>
<td>time</td>
<td>0.82</td>
</tr>
<tr>
<td>number of monitors</td>
<td>0.80</td>
</tr>
<tr>
<td>number of rooms</td>
<td>0.82</td>
</tr>
<tr>
<td>total floor area</td>
<td>0.77</td>
</tr>
</tbody>
</table>

FIGURE 1. An increase in pests detected over time since 2014 at NMC (A) may suggest an increase in total pests. Further investigation revealed many other plausible correlations: pest count over number of pest monitors (B) number of rooms monitored (C) and floor area monitored (D; see also Table 1).
the monitoring data – one of the crucial elements of any evaluation – is biased in such a dramatic way by the monitoring programme methodology? One answer is to collate and present information in addition to the numbers of pest occurrences, such as numbers of pest monitors, numbers of rooms monitored, floor area monitored, historic numbers of pests over time and types of collections or materials affected. Commercially available software commonly used for pest data analysis, such as ZPEST or KEMU, whilst offering an off-the-shelf data recording, analysis and visualisation tool, do not account for the number of monitors in a given space, or the size of the space monitored. Consequently, the options for meaningful data analysis are limited, and the resulting graphs are not helpful in addressing the needs of target audiences, as outlined by Henderson et al. (2019). The initiative to create a national repository for pest monitoring data via the website ‘What’s Eating Your Collection’ is an incredibly positive step in sharing and responding to data on pest activity, but the lack of data fields in this database limits the scope for exploring these data and eliminating any biases such as the one demonstrated above.

Pest Occurrence Index POI

An alternative approach to analysing pest monitoring data was developed and tested successfully at NMC. The Pest Occurrence Index (POI) integrates the number of individual pest counts with the number of monitors deployed and the area monitored in square meters. This requires the collection of a small amount of additional data during pest monitoring than was previously the case. To facilitate this, the existing Microsoft Excel data recording sheets are augmented by adding one column for the number of monitors per room, a second column for the size in square meters of the room, and a third column for the calculation of POI (Table 2).

The resultant Pest Occurrence Index POI (Figure 2) with the unit [pests trap\(^3\) meter\(^2\)] is comparable across rooms, collections, buildings, organisations and time. Using the same data as in the example above, closer analysis of the POI at NMC (all data for the entire building) over time illustrated a rapid decline in pest numbers between 2014 and 2016 due to successful introduction of a comprehensive IPM programme in the building. The increase in POI from 2017 is explained by the fact that at NMC the IPM programme was, from 2017, extended beyond collection areas. The extension of monitoring to kitchens and offices revealed a greater pest density in those spaces, resulting in an overall increased POI for the building. Introduction of the POI enables comparisons between collection and non-collection areas – the latter, such as kitchens, offices and corridors, may have considerably larger pest problems than those spaces where collections are stored (see also Figure 4). The POI also reveals that pest counts were generally slightly higher during the summer months (autumn data) compared to the winter months (spring data).

The greatest benefit of a coherent index of pest occurrence is that it allows easy analysis and communication of a pest problem. These findings helped shift the emphasis of the IPM strategy towards training and awareness-raising for all museum staff to share in pest management in every space within the museum.

One advantage of calculating POI as explained in figure 3 is that no specialist software is required – a spreadsheet may be set up using widely available software such as Microsoft Excel. A template spreadsheet is available on the National Museum Wales website under the document title ‘Pest Record Datasheets NMC Template’ (permalink: https://museum.wales/media/45874/Pest-Record-Datasheets-NMC-Template-2018.xlsx; see

TABLE 2. The minimum data fields required in a pest monitoring record data table include the number of monitors per room and the room size. Insert as many columns under ‘F’ (pest species) as relevant to the property.

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F1</th>
<th>F2</th>
<th>F3</th>
<th>G</th>
</tr>
</thead>
<tbody>
<tr>
<td>Room name and/or number</td>
<td>Date checked</td>
<td>Date of current inspection</td>
<td>Number of monitors</td>
<td>Room size [\text{m}^2]</td>
<td>Pest species 1</td>
<td>Pest species 2</td>
<td>Pest species 3</td>
<td>POI: pests per monitor per \text{m}^2</td>
</tr>
</tbody>
</table>
FIGURE 2. The same data as used in Figure 1 were here calculated and represented as POI.

**Calculating the Pest Occurrence Index (POI)**

The POI (column ‘G’ in table 2) is calculated by initially computing the sum of the numbers of all pest species in each row (all ‘F’ fields for the same row):

\[
\text{pests}_{\text{sum}} = \sum_{i=1}^{n} F_i
\]

The resultant sum ‘pests\text{sum}’ is then divided by the number of monitors per room (column D) and the size of the room (column \(E\)):

\[
\text{POI} = \frac{\text{pests}_{\text{sum}}}{D \times E}
\]

\(F\) = number of occurrences recorded for each pest species,
\(D\) = number of monitors in this room,
\(E\) = the room size in \(m^2\).

The resultant POI is a rational number expressed as a decimal. It is widely known that many people have considerable difficulties with numbers expressed as decimals (Hiebert and Wearne 1986, Putt 1995, Lortie-Forgues et al. 2015). Because our emphasis is on communication in an easily understandable format to broad types of audiences who do not necessarily have specific mathematical expertise, the result of equation 2 may be multiplied by a factor of 1000 to create a natural number for POI (POI\text{\text{L}}) for the purposes of easier communication.

\[
\text{POI}_{\text{\text{L}}} = \text{POI} \times 1000
\]

The decision to introduce a factor is therefore communication-led with the intention of decreasing natural number bias.

FIGURE 3. Calculation of the Pest Occurrence Index.
Data Communication
The recently (2014) implemented IPM programme at NMC presented an opportunity to experiment with novel forms of graphical data visualisation, as suggested by Henderson et al. (2017), and undertake some basic user testing to assess the most effective way of establishing awareness amongst museum staff. Two goals were set: firstly, to achieve staff behavioural changes that would result in improved cleanliness, and secondly, to provide managerial authority to support the IPM coordinator's recommendations (cf. Henderson et al.; 2019). Museum staff were presented with the same data from pest monitoring at NMC visualised in two different graphs: as a bar chart and bubble chart. Feedback from these informal discussions with colleagues suggested that bar graphs were preferred by those with higher levels of technical knowledge and engagement in the topic.

Appropriate messages for different audiences
Figure 4 shows an early output of experiments with different visual representations of pest data that attempted to represent pest counts in different parts of the building for one monitoring event. This graph was distributed around the building in staff rooms and kitchens for general staff information and used in internal IPM training sessions. This 'all things to all people' approach was revised subsequently based on a consideration of the goals of IPM in context. Whilst the graph captures a great deal of information, it does not target the information at specific user needs. Subsequent user testing at NMC demonstrated that at least three different groups of users of pest monitoring reports exist:

Table 3. Screenshot of one of the data entry sheets in the Pest Record Datasheets NMC Template. The final column contains the POI formula; once the sheet is populated with data, the POI fields will update automatically.

![Table 3](image-url)
FIGURE 4. Early graphical output capturing a lot of data but aimed at more than one audience.

FIGURE 5. Use of symbols focuses attention at a single glance on areas affected by pest occurrences, based on data generated by calculating POI.
1. Users with little prior awareness of pest management. The communication goal here is to raise awareness of the scale and general consequence of pest infestation and provide issue relevant information about actions they can take.

2. Informed users: those who care for vulnerable collections and have experience of pest management.

3. Decision makers responsible for allocating resources.

The goal for group 1 users is to encourage behaviour change, especially in non-collection areas where awareness is lowest. The main concern of group 2 users is for the collection they are responsible for. This group of well-resourced specialists welcome tailored and detailed information, which is targeted to their specific needs and concerns; some of this group may welcome bar graphs due to their familiarity with the IPM literature. The continued support for IPM from managers is the goal from communication with group 3 users whose backing during a period when finding more pests, as outlined above under ‘Calculating the POI’, actually reflects an improvement in practice requires a technical understanding of the data collection process. This message may include the request for support to extend the pest monitoring programme beyond the ‘traditionally’ monitored collections areas, and for additional resources to implement and sustain increased monitoring and associated data analysis.

For group 1, the goal is to achieve a behavioural change rather than give detailed information and Figure 5 is the response to this challenge. By identifying where the greatest density of pests exists, it focuses attention on the perhaps surprising core of the current pest problem (non-collection areas) and motivates staff to act to contribute to pest management through their own practice by maintaining a clean workplace. This message is appropriate for all users but as Figure 5 communicates a simple message quickly and intuitively, it particularly satisfies the needs of group 1, explaining that pest management is everyone’s concern and that staff behaviour in non-collection spaces forms an important contribution to IPM. The use of infographics maximises the audience who can comprehend the message. The use of pest symbols contributes to focussing attention and reinforces that this is an institutionally authorised message.

**FIGURE 6.** Similar data as Figure 3 (but for 2018) represented as a more comprehensive message for managers.
fied the location of the largest pest problem as being in kitchens. These colleagues understood that while not ideal, the high occurrence in non-collection parts of the building did not necessarily constitute a direct risk to collections. User perception clearly plays a role in the interpretation of these visualisations (cf. Henderson and Rumsey, 2015).

**Conclusions**

IPM has been implemented holistically at NMC since 2014, including building maintenance with the aim of excluding pests, improved housekeeping in stores and galleries, updated guidance to staff, comprehensive pest monitoring, object quarantine and treatment, and staff training. The application of pest management zones is currently being planned. Starting in early 2018, visualisations of pest monitoring data have been publicised routinely around the building – for example, in staff kitchens – and used as part of staff pest awareness training. The successes achieved by the introduction of IPM are demonstrated by a reduction in the numbers of pests in collections areas during the first two years of the IPM programme. More recently, attention has shifted towards achieving the same results in non-collection areas, which is expected to be more challenging. To assist behavioural changes, new ways of communication were developed at NMC in partnership with Cardiff University. This required the development of a measure of pest activity that allows comparison of areas with different uses across a large and complex building: the Pest Occurrence Index (POI) which integrates pest counts as well as the numbers of monitors deployed and the size of rooms monitored. This index provides data that are comparable across rooms of different sizes, different collections, different areas of use within a building and even across buildings and institutions. Collecting data on pest occurrences is a time-consuming task, which needs to be justified to museum management. If pest monitoring data are collected, they ought to be analysed appropriately to be of any valid use. POI can be used as a real and objective measure of the success of pest management efforts, and visualisations based on POI may be used to engage staff in new ways. There is no one-size-fits-all solution for this type of communication; instead, reports with specific messages need to be tailored to definite target audiences.
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References


Introduction

“Hi, I found a bug in my museum, should I fumigate everything?”

This is a question I have been asked many times since I started as the museum pest researcher for the Canadian Conservation Institute (CCI) in 1988. It is not a silly question. In fact, it is a bit daunting without more information. The question summarizes the asker’s quest to determine the risk a pest poses their collection, albeit jumping directly from discovery to reaction in a conversational gambit.

In response I’d ask what type of collections they have, how large and how stored, to develop a sense of collection vulnerability to the pest and scale of problem. Some items are of high nutritional value and consist of fine details that are readily destroyed. Other materials are not readily digestible by the particular pest. I’d ask about the organization to find out who they have to assist in taking care, and to imagine how they might organize their response. I’d explain alternatives to the popular concept of ‘fumigation’ and ask about specific capacities such as freezer space to discuss how they might stop pests found on objects. Did they have a past history of infestation? How did they find the pest, adventitiously or by methodical survey?

I’d ask them to send me the body, exuviae, frass or scat to confirm the identification if they feel unsure. The course of these hundreds of personal conversations over many years was a distilled form of IPM method teaching.

However, to underline the value of consistent IPM programs we need reasoned means to convey pest-borne risk to collections. Examples and photographs of pest harms pack a punch, but rarely indicate the rate of harm – they are often records of static discoveries. Time lapse of museum objects being destroyed by an organism are rare. Recently in North America, some large museums trimmed IPM capacity then several years later suffered five-figure pest crises – partly out of administrative ignorance of pest population dynamics, perhaps a consequence of humanity’s growing “nature deficit”.

Keywords: IPM; population models; teaching risk
This paper looks at a way for teaching around the decision: how soon and to what extent must I respond? Alternatively, it examines what happens if I find a pest insect and said “Humph, so what” and sought no further?

A room awaits an elephant
– the conundrum of good storage and easy pest discovery

Combating infestation is a practical problem with fractal dimensions. The nesting of ‘cubes’ from building to room, cabinet, shelf, box and vial is a common geometrically recursive arrangement in natural history museums. Pests are very much smaller than humans for whom the museum is arranged. The greater area available for pests than that which humans normally see is the significant contribution to pest growth without detection, presenting opportunities for pest damage (food and shelter) and resistance to pest removal once found. Any museum with a broad collection can confidently advertise itself with the ‘Dr. Who’ TARDIS catchphrase, “It’s bigger on the inside” (BBC One).

Imagine a cabinet for medium sized birds, spread neatly in five rows of twenty on twelve one meter square drawers. When the insect has access throughout it has an enclosed world with 2,400 tops and bottoms of ‘food cylinders’ of which only 1/24th of the total area at a time is observable with the most minimal human effort. The feathers overlap 50 percent, amongst which pests can rummage a meal. Now add layers from two wings per bird at say another third of their body area. Not counting individual feathers there are now 7,200 object-level layers to crawl among and approximately 75 m² (12 drawers × 100 birds × bird area (= 3.14 × 0.05 m × 0.2 m × 1.5 × 1.33) of surface to eat, estimating the inhabitable area about 6.25 times the cabinet storage surface and 75 times its footprint on the floor.

A garment approximates a collapsed tube with four major faces (inside and outside, top and bottom), then there are pockets and collars and maybe it is folded double in the drawer. Rolled carpets on rods are compact, creating ‘invisible’ surfaces to human inspection yet allowing insect access to the entire surface unless it was bagged clean and sealed.

It is no surprise that response methods are judged by their ability to penetrate this expanded landscape and ‘short-cut’ the path for a human predator to its pest prey. The ability to shrink the protective effects of time and space is why some pest control methods find favour over others despite all arguing high efficacy if employed properly.

The worst damages are usually consumption, where damage is proportional to the number of pest mouths. Disfigurements like rodent urine and feces are also proportional to the intake through mouths supplying the conduit organs. As pests can eat vulnerable museum structures, the objects within and any human detritus/garbage, an intriguing thought-experiment for not cleaning a very messy museum would be that “in probability” any pest found would be on valueless surfaces rather than on the objects – so no harm done. This method has been used with food-baits, a controlled form of leaving attractive ‘rubbish’ around for pests to eat and lure them to traps.

It is a tenet of IPM programs that we lay down traps in museums to detect pests. There are two common expectations. The first is easiest to convey: identification of pests tells us we have pests! But there is an asymmetry at the heart of IPM. Even when we do not detect pests we know the unexplored landscape is much larger than our purview, leaving us the possibility of pests. Collapsing uncertainty of planning for all possible pests to the particular capabilities of a discovered pest and resultant vulnerabilities exposed in the collection is a galvanizing moment.

The second expectation is: traps will capture a proportion of the pests roaming at large. However well designed, entering the trap is a statistical event. Optimizing placement, checking regularly, we record results. But as the trapped numbers go up and down have total pest numbers gone up and down? We often deal with low number scatter. We never know the ratio of trapped to free pests since mark and recapture is not practiced in museum IPM, nor many of the other available ecological study methods (Southwood, 1966).

Traps are small compared to the floor. Life would be miserable if we covered the floor with sticky compound. Even this ‘maximum efficiency’ would only examine some of the routes that pests might travel. So when we place a trap 1/1000th the size of our floor, what’s the real chance of it getting a pest? At first blush it is related to 0.001 × human landscape area / pest landscape area.
An elephant disappears from the room – exploring loss in collections beyond individual damages.

To elaborate on these issues, the author developed simple spreadsheet models to explore pest population growth with workshop participants and highlight reasons for conducting effective IPM.

To begin, view a photo of an elephant hide (Figure 1) and ask the students to imagine the real risk of loss. Why an elephant? How could you miss seeing it! How could a pest miss finding it? One elephant hide can stand-in for hundreds to thousands of other pest-edible objects summed together.

Case 1: One elephant hide, one perpetually inhabiting pest insect and all of time before us.

Let’s see what can happen. An African elephant hide is 13.3 m², 30 mm thick and 210 kg (Leach, 1995). Dried from live moisture content it might yield 105 kg in our cabinet. From Stengaard Hansen et al. (2012) (Figure 2) a median rate of 0.03 mg/day for our hypothetical dermestid to eat the old dry hide will take 3,500,000,000 days, or 9,589 millennia.

An immortal feeding individual *D. sisyphusi* represents the asymmetry of concern: “I don’t see any pest, is there one somewhere?” It doesn’t matter if any of these estimated values are out ten-fold, the calculation expresses the stupendous possible future of time to total loss.

Despite mathematically inevitable total loss, the result is graphically in favour of imagining the elephant skin’s survival and makes expression of concern over a single little insect in the museum sound ridiculous. It is possible that a decision maker would not consider it worth their while to act, based on their calculation of fraction of their salary invested, tedious effort involved to find the insect, repulsion to squishing it and having to wash their hands before returning to a comfy desk. Dollar spent for dollar saved, absolutely not worth the effort. What consequential harm will that one insect do before this human safely moves on to another job?

That fictitious situation is nearly identical to a well IPM’d museum, with constant yearly reports of none or little pest activity. Later, when the IPM capacity has been compromised by economic downturn, staff layoffs, surviving staff burnout, etc., low initial population num-
**FIGURE 2.** Consumption rates and population limits for some museum pests (Baker and Bry, 1987), (Stengaard Hansen et al., 2012), (Strang, 1992).

**FIGURE 3.** Loss of object with two population scenarios: drop into a tank full-o-bugs and geometric growth with carrying capacity limit.

**Magic Trick: Make an Elephant Disappear!**

**FIGURE 3.** Loss of object with two population scenarios: drop into a tank full-o-bugs and geometric growth with carrying capacity limit.
Poof, the elephant disappears rather quickly (Figure 3). Temporally, the fantastical *A. prolifagatus* is 1.5 million times more damaging than *D. sisyphus*. Welcome to Planet Exponential, it’s hungrier on the inside.

Changing area per insect from a crowded 5 mm² to a selfish 100 mm² per insect stretches out the hide survival to 72 years in the tank, and 74.4 when the population has to ramp up from one fecund female. So, let’s unroll it every year and broom it almost clean of bugs – what happens?

Further, a modeled rabbit skin of 70 grams and 0.15 m² would be gone in 2.2 years. A house fly is consumed in a few days (author’s time-lapse video). On forensics, Byrd and Castner (2009) report how a human body can be reduced to bone in 24 days by a colony of dermestid beetles, and once the flesh is gone dermestids will continue and bore into the bone (Parkinson, 2013).

**Figure 4.** Simple consumption model with elephant example.

Case 2: One elephant skin, a breeding pest insect, all of time before us.

A simple geometric growth model simply adds known pest fecundity to the information we already have and projects the harm descending from one fertile insect. There are assumptions about insects’ tolerance to their population density, mini-exponentials of each insect’s growth (Dyar, 1890), time spent eating, lack of predation, parasitism, cannibalism, dispersion, recruitment, toxifying with their own waste, and other factors seen in more elaborate population modelling often under the catch-all of “density dependency”. However, this simple model does calculate a fundamental worst-case curve for loss. And have we collected any other information yet on which to reliably adjust our decision? No.

The hide is 13.3 m², our insect 5 mm², so 200,000 packed per m² gives 2,660,000 mouths. Dropping the hide into a tank full of bugs to cover the hide, it takes 3.6 years to be eaten. To start with one fecund female (60 eggs at two generations a year), then reach saturation with insects then subsequent linear loss. It takes 6.3 years under model conditions of only thickness loss so edible surface area is maintained to the end.
Malthus’s and many other’s failure to converge predictions of human population limits on earth (Cohen, 1995) illustrates difficulty in the search for limits. In Solomon (1953) a brace of factors was illustrated to show how storage pest populations deviate from unrelenting upward growth. However, limited downward pressure in early infestation supports using geometric growth for this period. Nor has the idealized sigmoid model of populations been proven in long running tests (Kingsland, 1985). Fates are twisty.

**Casts, poops, and leaky information – examining methods of discovery**

Dead do not walk into traps so visual inspections should garner more evidence of life than just live bodies (Figure 5). Chew marks, insect exuvia (shed exoskeletons from larval development) and piles of frass or rodent feces and piddle trails seen with ultraviolet light are examples of such findings. What is the ratio of these to a living population? How informative is a human sense of little or lots?

Another model incorporates more of this information and looks at the institution (Figure 6). Passage of time is a simple generation step, modeling those pests which have a short adulthood birth-pulse reproductive cycle (hide and wood beetles, clothes moths). Birth-flow organisms (silverfish, cockroaches, termites, rodents) have significant juvenile phases and longer overlapping adult lives to sprinkle progeny about, better modeled with a matrix method discussed below. A table of fecundity values from pest literature accompanies the spreadsheet model.

**TABLE 1. Sample fecundities of common museum pests, from citations in Ebeling (1975). Top two are birth-pulse, bottom two are birth-flow.**

<table>
<thead>
<tr>
<th>Organism</th>
<th>Fecundity eggs, young</th>
<th>Lifespan</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Tineola bisselliella</em></td>
<td>40–50</td>
<td>50–90 days, 48 months unfavourable</td>
</tr>
<tr>
<td><em>Anthrenus scrophulariae</em></td>
<td>60</td>
<td>77–110 days</td>
</tr>
<tr>
<td><em>Lepisma saccharina</em></td>
<td>100</td>
<td>3–4 months, 42 months unfavourable</td>
</tr>
<tr>
<td><em>Rattus norvegicus</em></td>
<td>70</td>
<td>9–12 months</td>
</tr>
</tbody>
</table>
FIGURE 6. Model parameters and results with highlighted thresholds (0.001) and greyed ‘Stupid Numbers’. The overlaid area plot and histogram show “bigger on the inside” values for human footprint, pest food and habitation of the modeled space. Here thirty percent of the cabinets contain edible items.

FIGURE 7. Matrix models can sum across the damaging stages to look at fluctuations of intensity of harms. Variations in trap results are seen since the mobile portion fluctuates in number. Recovery from blanket or stage-selective control measures can be examined. Here a birth-flow silverfish population with long adult lives is shown. With dermestids the effect of diapause can also be modeled.
Maximum fecundity estimates a worst-case scenario. Lessening fecundity models growth when there are high losses to unknown agents or a percentage efficacy of control. Lifespan also governs the impact of a population, particularly the span of time until the females are finished laying eggs.

There are insect species which may shift sex-ratio, so the model allows examination of this factor (Andersen and Sogaard, 1961).

The size of the pest and estimated area of food consumed to grow to adulthood adjust the 'Stupid Number' thresholds. Loss per pest is entered as an area rather than the mass rate used above to help imagine the scale of surface harms. Casts per insect (or feces per rodent, etc.) helps model the accumulating signs of infestation.

To model the vulnerable content, building volume is divided into two conceptual types: single plane and multiplane. Single plane is used to model open floor or exhibit space with vulnerable objects on view. Multiplane is the floor area occupied by cabinets or shelves with an estimate of the mean value of object layering. If there are rows of shelves six high with books, then one can enter '6'. If there are two stacked quarter units each with twelve shelves each filled one deep in study skins, one can enter '48' as the object’s underside is also vulnerable. In this manner, a “bigger on the inside” factor is discussed and estimated.

Adjusting the fractions of single and multiplane food examines the significant effect of taking vulnerable collections ‘offline’ by good containment.

The point of playing with ‘Stupid Numbers’ is to explore plausible thresholds for the minimal population: to start showing up in traps, to be seen in inspections, to be blatantly obvious there is a pest problem. These fuzzy-valued thresholds have to exist between the bounds of disquietingly zero and ridiculously large, and they only exist if people are determined to prevent and react to pest harm instead of ignoring it.

Using matrix models – introducing current ecological methods

Matrix methods were introduced for demographic modeling by Leslie (1945) and extended to size classes by Lefkovitch (1965). This author has used them to demonstrate birth-pulse and birth-flow organisms, say dermestids versus silverfish, and model age or size structure developments in populations (Figure 7). Size structure is already apparent to those who have trapped insects, seeing small to large larvae or nymphs of the same species at the same time, or over time. In ecological work these demographic structures improve understanding of a population, is it predominantly young or old, growing exponentially or stabilizing in balance with downward pressures (Caswell, 2001). The matrix approach is most flexible and is well adapted to model what is shown in Figure 5 and easy to do with a spreadsheet.

Detailed modeling of pest species for museums often suffers from the “demographic uncertainty principle” seen in human demographics where the more factors that are examined the thinner the available data becomes (Cohen, 1986). Literature on our pests was not always driven by population model building needs. The author has undertaken a review of pest literature to garner information to further examine the utility of matrix models for museum pest control.

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FIGURE 8. Population development from one female with three (left) versus four (right) surviving progeny. Bold text emphasizes the dominant column between live and dead.
population or protracted low growth. The former is diagnosed by common sightings of live or frequent trap entries, the latter by fruitless inspections with deep cleaning.

The simple geometric model also estimates hours of visual inspection needed to find pests dispersed singly or in clusters. This plays with the trade-off of earliest detection at some level of accumulated harm versus labour costs.

IPM combats a regenerating force with adaptive behaviours. We never have total information about the situation and have laborious steps to get more to design responses. To top it off, there is an inexact future benefit for dealing with a current small problem. Payoff is the forecast unharmed portion over future time and prevention of reputational harms (Strang, 2012), see Figure 9.

Without action against a pest population, there is a reasonable expectation that it will continue to damage and grow rapidly. If a population flattens off to a 'sustainable' number a vulnerable collection continues to suffer cumulative incremental loss.

**Some lessons for the classroom**

Looking at the generation of live insects, expected numbers of their dead and augmented by other signs of life, we see there is a switch in detection probability from visual inspection to trapping as the population growth/survival rate increases. With an even sex-ratio the number of birth-pulse live only outnumber the accumulating dead once the average surviving progeny exceed three per female (Figure 8).

A well IPM’d museum is going to hopefully approach low survival numbers through the composite impact of cleaning away comestibles, blocking access to habitat, and destroying pests where they are found. Unknowingly from the pest’s side, dispersion, fertility failures, parasitism, cannibalism, diapause, thermal environment, etc., may lower maximum population growth rates. This observation depends on relative evidence and its acquisition is an argument to have both traps and visual inspection as complementary protocols in our IPM toolkit. An accumulation of corpses is consistent observation with either an explosive population or protracted low growth. The former is diagnosed by common sightings of live or frequent trap entries, the latter by fruitless inspections with deep cleaning.

The simple geometric model also estimates hours of visual inspection needed to find pests dispersed singly or in clusters. This plays with the trade-off of earliest detection at some level of accumulated harm versus labour costs.

IPM combats a regenerating force with adaptive behaviours. We never have total information about the situation and have laborious steps to get more to design responses. To top it off, there is an inexact future benefit for dealing with a current small problem. Payoff is the forecast unharmed portion over future time and prevention of reputational harms (Strang, 2012), see Figure 9.

Without action against a pest population, there is a reasonable expectation that it will continue to damage and grow rapidly. If a population flattens off to a ‘sustainable’ number a vulnerable collection continues to suffer cumulative incremental loss.
How the population rebounds from IPM driven suppression measures governs the amortized gain in benefits. A rapid rebound greatly reduces a treatment’s worth. Total extinction of pests is the ideal; giving an indeterminate time without loss it makes the treatment ‘worth every penny’. However, a continued IPM program is the only way to ensure resilience against small numbers of pests gaining entry but then being ignored for too long

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**References**


We have an IPM standard – now what?

Abstract
In 2016, a new European standard, EN 16970 Integrated Pest Management of Cultural Heritage was adopted. It is a managerial standard, stating what is essential in a museum, an archive or similar institutions, in order to keep pests, including mould, to a minimum. The Swedish National Heritage Board has, since the start of the standardisation within CEN/TC 346 Conservation of Cultural Heritage in 2004, been engaged in contributing expertise to the different working groups. Since 2014, several actions have been taken in order to make the standards better known: translation to Swedish, brochures and leaflets, and Swedish National Heritage Board staff promoting them at conferences and seminars, and most importantly, making them free of charge for a three-year period. For the IPM-standard in particular, the Swedish National Heritage Board has organised two-day courses for IPM-coordinators and launched e-learning training courses on toxic substances.

Key words: IPM; standardisation; EN 16790

Introduction
In 2016 the European standard EN 16790 Conservation of cultural heritage – Integrated pest management (IPM) for protection of cultural heritage was finally launched and introduced to the cultural heritage IPM community at the 3rd international IPM conference in Paris the same year. The authors of this paper have been involved in creating the standard as experts and mirror committee members and have an invested interest in seeing that the standard is known and followed. Almost three years later, we have come quite far in implementing the standard in Sweden, and aim further.

European standards for cultural heritage – background
Work on creating European standards for the protection of cultural heritage, started in 2004 with the establishment of the Technical Committee 346 Conservation of Cultural Heritage within the European standardization body, Centre Européen de Normalisation (CEN). The aim was to establish standards in the field of “…processes, practices, methodologies and documentation of conservation of tangible cultural heritage to support its preservation, protection and maintenance and to enhance its significance” (Fassina, 2015). Since then, more than 30 standards have been published, and others are in the making. They span from standards on test methods for laboratory work, to indoor climate, storage, packing, transport, light and other museum and archive related topics. A standard on improving energy performance in historic houses (EN 16883) has generated a lot of interest in the building conservation community. There is also a relatively new standard on the conservation process and its decision making, planning and implementation (EN 16853), which may help commissioners and practitioners to better communicate specific cultural heritage requirements, for example, when procuring services.

Every new CEN standard is written in English and is always translated into French and German directly. It is then up to each country whether to translate it to their national language or not.
Creating the IPM-standard took approximately four years. It was sometimes hard to comply to the specific standardisation language, trying to avoid handbook writing, and instead list the dos and don’ts. There were two issues where consensus was hard to reach. The first was whether to include microorganisms (mould, photosynthetic organisms and bacteria) into the definition of pests. After long discussions and expert opinions, it was decided that the definition of pests, for the purpose of the standard, was to be defined as a “living organism that is able to disfigure, damage, and destroy cultural heritage”, and as examples were given: insects, rodents, fungi and bacteria. The second was how to specify quarantine for incoming materials – there were many different options and it was impossible to conclude a safety level depending on the type of institution or organisation. The final text was a compromise, stating the importance of quarantine, but not detailing how to obtain it.

The normative text in the standard is actually not more than 14 pages long, followed by five informative annexes (another 13 pages) and a bibliography. Here follows a short presentation of some major themes in the normative text.

**Defining roles and responsibilities**

It was deemed necessary for an institution to have an IPM policy as a way to put IPM on the agenda on a continuous basis and firmly establish the concept at senior management level. Having an IPM policy can also make it more difficult to neglect IPM when there is a need, for instance, to save money, especially since any policy should be authorized and signed by the senior management.

Equally important was the role of IPM coordinator. Such a position may be a full time job for one person in a big museum or archive, whereas in a smaller workplace, the position could be held by someone responsible for the collections or other similar functions. The workload of the IPM coordinator will vary depending on the size and type of collection, but some tasks will probably be very similar: training other staff, creating and maintaining procedures for inspection, dealing with external pest companies, etc. The IPM coordinator will report back to management and suggest improvements for reducing risks.
Risk reduction
Preventive conservation today is focused more and more towards risk assessment. The same goes for IPM, as it is an integral part of risk management within an organisation. For example, during exhibitions, transport, functions and other activities, IPM must be a part in the planning process, as well as when building or constructing new storage. EN 16790 points towards another standard, ISO 31000, Guidelines for risk management, which is not sector specific, and provides a common approach to managing any kind of risk.

Preventive measures – IPM procedures
As the reader will know, prevention rather than cure is the goal for any IPM programme. There are many cost-effective and easily managed tasks that will effectively diminish risks and subsequent outbreaks, and they have been listed in the standard. The concept of the ten agents of deterioration, as developed by the Canadian Conservation Institute, with the control methods avoid, block, detect, respond, recover (Michalski, 1990), were very suitable to the purpose.

Annexes with further information
At times, information that is not normative, but still deemed necessary by the experts creating a standard, can be put in an annex. The annexes in EN 16790 give examples on what an IPM policy may look like, what so called risk zones are, and how a checklist for inspection can be put together. There is also an annex listing treatments for pest infestations. Finally, the longest annex is quite descriptive, outlining general characteristics, prevention, detection and diagnosis, response and treatment for five different kind of pests: insects, rodents, fungi, photosynthetic organisms, and bacteria.

Implementation of the IPM standard – the Swedish example
When a standard has been published, a new line of work starts, namely implementing them and putting them to use. The task of implementing cultural heritage standards is high on the agenda at the Swedish National Heritage Board. Several measures are in place for implementation and spreading of the standards within the technical committee CEN/TC 346 Conservation of cultural heritage through information and communication, translation of standards, case studies and best practice, access to standards for cultural heritage organisations, and even a museum test group trying out a selection of standards (Nilsen, 2017). Below we list some of the actions taken to promote standards in general and the one on IPM in particular.

1) Agreement on providing published standards free of charge
To encourage the use of standards in the heritage field, the Swedish National Heritage Board and the Swedish Institute for Standards (SIS) concluded an agreement of sponsorship to make all the published standards within CEN/TC 346 accessible in Sweden to download free of charge during a period of three years starting 1st January 2018. During these three years, several activities will be carried out to further raise the awareness and use of the standards. In order to read and download standards, one has to register with name and affiliation. It is important for SIS and the Swedish National Heritage Board to have statistics on the use of the standards. At present, almost a year and a half after the release, 505 user accounts have registered. The main part of users represent museums of all categories, state owned national museums to small municipal museums (67 organisations, with 158 accounts). The second largest user group represents the private sector, represented by architects, consultants and contractors (68 companies), mostly within the building conservation sector. Other public organisations and institutes such as state, county and municipal administrations, and universities, is the third largest group (61 organisations). Another big user is the Church of Sweden, with 36 different registrations. A substantial increase in the number of downloads can be detected after specific information campaigns at conferences and seminars. As for the IPM-standard SS EN 16790, it is second on the list with 130 downloads after SIS-CEN/TS 16136 Guidelines and procedures for choosing appropriate lighting for indoor exhibitions (which is a so called technical specification) (Hultsten, 2019).
2) Training future IPM coordinators

EN 16790 states the following: One staff position shall be appointed as coordinator of the IPM programme, henceforth called IPM coordinator. The IPM coordinator shall be responsible for developing and implementing an IPM strategy. He/she shall act as a project manager, able to collect and communicate information effectively to senior level management and other relevant positions.

The IPM coordinator shall be knowledgeable and experienced in IPM, including identification of cultural heritage pests, pest biology, and treatment methods used for cultural heritage. If needed, special training shall be provided to increase competence.

It is not realistic that Swedish museums would, among their staff, find people “knowledgeable and experienced in IPM”. Only a few museums would have that kind of expertise. That is why the Swedish National Heritage Board and PREMAL (see below) organised two two-day training courses: “Becoming an IPM coordinator”. The aim was to encourage museums to focus on this important area, and launch the IPM-standard.

The courses were held at the National Museums of World Culture in Göteborg and Stockholm. The contents were built on EN 16790 and included general information regarding what is expected from museums and archives following the standard, and organisational actions facilitating an IPM programme. Tutors were conservators with different specialities (natural history, paper and preventive conservation), an entomologist, a microbiologist and a specialist from the Swedish Work Environment Authority. Course participants came from the museum and archive sector, and they were a very mixed group: curators, antiquarians and archivists, conservators, technicians, and cleaners.

Presentations on identification of insect pests, mould, health hazards and documentation of findings were followed by realistic risk finding scenarios in the museum storage areas. Participants were also given blunder traps with pests in them to try to identify insects as they are often found, stuck in the glue, not prime examples from a study collection.

Focus was also given on so called soft skills, inspired by a presentation from the recent IIC conference (Wickens & Hess Norris, 2018). It is deemed necessary to communicate in a manner that lifts the importance of IPM and preventive conservation without scaring off managers and colleagues.

The courses were quickly fully booked, and the Swedish National Heritage Board is going to organise two more courses in 2019. One main feedback from participants was that managers ought to participate in this kind of training. They shall sign the policy and provide funding for IPM. It is therefore important that they know more about IPM.
3. PRE-MAL

Sweden is very lucky to have a lively IPM community centred around the working group PRE-MAL, which stands for Pest Research and Education – Museum, Archives and Libraries. PRE-MAL was founded in 1984, then considered to be only a temporary necessity (Edmar, 1998). As we all know, IPM is more than ever in focus and PRE-MAL is still thriving. PRE-MAL was awarded an Europa Nostra Medal in 2004 for “a continuous, up-to-date and free source of practical information, as well as commendable educational initiatives, on non-toxic insect pest control in archives and museum collections” (Europa Nostra, 2004).

Today PRE-MAL is managed by the Swedish National Heritage Board. PRE-MAL has taken an active part in spreading knowledge of IPM in general and the IPM standard in particular through its extensive mailing list (65 organisations within the cultural heritage sector), yearly seminars and Facebook. PRE-MAL is no longer an active research body, however, they can propose and initiate research, for example research on the grey silverfish and a newly published report (Szpryngiel, 2018).

For PRE-MAL, health hazards and toxins have always been an integral part of IPM. An expert in work environment and health has always been part of the PRE-MAL steering group.

4. Fact sheets on IPM

Since 2013, the Swedish National Heritage Board publishes online fact sheets on preventive conservation, so-called Vårda väl-blad. The primary target group is smaller museums, churches and local historical societies with little knowledge on conservation and preservation. The fact sheets are illustrated, 2–6 pages, and written in a manner to assume little or no prior knowledge of the subject in question. In 2018, seven fact sheets on IPM have been published, following the contents of the standard and the control methods avoid, block, detect, respond, and recover. In tandem, several fact sheets have been published on health hazards in collections – there are for example texts on old poisons and biocides such as arsenic, DDT, naphthalene, as well as instructions on the safe use of desiccant dust. Next in line are fact sheets on mould: prevention and health hazards. Until now, the fact sheets have had approximately 10,000 viewings. The number of downloads are always higher after a conference or course where they have been highlighted.

5. E-learning

A subject bordering to IPM is health hazards and toxins – for PRE-MAL (see above) this was always a very important part of IPM and has been these last 30 years. In 2016, the Swedish National Heritage Board launched an e-learning project on hazards in museum collections and contaminated materials, since the awareness and knowledge about health issues related to collection work was deemed insufficient. An educational package was developed, aimed primarily at managers, but available for everyone. To date, approximately 200 users have gone through the e-learning course.

6. Other means of communicating

The Swedish National Heritage Board has established a routine to present all published standards with an article on their website when they are launched. Call for experts on new work items are also presented with articles. Each new standard is also presented in an information leaflet that can be downloaded as pdf. A total of 13 leaflets have been published and more are produced as new standards are being published. And of course, information has also been distributed to the County Administrative Boards and to a broader public through social media. The IPM standard, and the grey silverfish, were for example topics in the Conservation Podcast (K-podd), hosted by the Swedish National Heritage Board.

The yearly national conference on collection management took place in November 2018, with best practice and standards as a main topic, and the IPM standard was highlighted in a workshop. A peak in downloads of standards was notable the month after the conference (Hultsten, 2019).

Discussion

Managerial interest?

A crucial point when it comes to IPM, standards and preventive conservation overall, is the engagement of the institution’s managers. EN 16790 states the following: The IPM policy shall be authorized by management and included in the institution’s policy documents. IPM shall be a standing item on the agenda at both senior management level and in the conservation department, where one exists. IPM shall
be incorporated into job tasks of staff; endorsed by policy and supported as a core activity. Without managerial support, IPM risks being void of resources. At the training course for IPM coordinators, the participants stated that the managers and museum directors should really be the prime targets for such a course. The lack of understanding for preventive conservation and IPM from a managerial level is a challenge that we need to continue working with, emphasizing that there is money to save when working according to a standard.

Translation of standards
Though Swedes in general are proficient in the English language, the specific wording in a standard could be daunting even to a native speaker. Translation of the standards is therefore high on the wish list. As stated in Nilsen (2017), a standard needs to be translated into Swedish in order to be referred to in general regulations, recommendations or any other official government documents. Unfortunately, this is an area where we have not been seen much progress so far. To date, only one standard has been translated. The lack of translation may be the single biggest obstacle to their implementation.

Use of standards after the agreement is finished?
The amount of downloads for the Conservation of Cultural Heritage standards, and EN 16790 Integrated Pest Management for Cultural Heritage in particular, has been a success. Swedish museums and other cultural heritage institutions have a unique opportunity to start working according to standards related to their field at no cost at all thanks to the agreement of sponsorship. Will they find that working according to standards is indispensible? That the enhanced communication with other stakeholders facilitate work and saves time and money? Or will the zeal to comply with standards vanish in 2020 when the agreement is over and new standards will cost around 100 Euro?

The future
All European standards are up for revision every five years after publication. Then there is time and possibility to correct and, if deemed necessary, change or amend the text. In 2021, EN 16790 is up for revision. The more the standard is used, the more constructive criticism may help to make the standard better and update it for future use. If you, as a reader of this article, are interested in joining for revision, contact your national standardisation body.

By organising this conference, the Swedish Heritage Board and partners want to strengthen the knowledge of standards in general and particularly EN 16790, the standard on IPM.

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Bibliography


Webbing clothes moth *Tineola bisselliella* and the risk to historic collections in England

**Abstract**

Webbing clothes moth *Tineola bisselliella* catch data from English Heritage and other United Kingdom museums as well as from the general public following the Operation Clothes Moth campaign, are analysed. It is confirmed that *T. bisselliella* numbers have significantly risen to a level that represents the highest insect pest risk to collections housed in historic buildings in the UK. A review of the established annual total measurement and a new average per trap metric is undertaken. Total annual catch combined with insect pest management expertise remains essential for judging the risk posed by webbing clothes moth and other insect pests. *Monopis crocicapitella* the pale back clothes moth is also highlighted as a possible future new pest species for historic house collections.

**Keywords:** webbing clothes moth *Tineola bisselliella*, insect pest management, heritage collections, pale backed clothes moth *Monopis crocicapitella*

**Introduction**

English Heritage (EH) became a charity in 2015 and is responsible for the conservation and presentation of over 400 historic sites including 115 properties housing over 500,000 objects across England. Preventing damage from insect pests to historic house collections, where objects are on open display, presents a major challenge to staff and owners. The presence of floor, roof and wall voids as well as chimneys and vulnerable organic materials, creates the ideal environment for insect pests particularly webbing clothes moth *Tineola bisselliella* to thrive. Heating to comfort levels for winter opening, events and for family use in the case of private homes has also increased webbing clothes moth activity. Once established in a historic house, webbing clothes moths are very difficult to eradicate and are therefore emerging as the insect pest of greatest concern. This paper outlines insect pest trap data from a number of sources in order to review the level of risk from webbing clothes moth to EH and historic collections generally. It also mentions the possible risk posed by the pale backed clothes moth *Monopis crocicapitella*.

**Biology and behaviour of webbing clothes moth *Tineola bisselliella***

Webbing or common clothes moth *Tineola bisselliella* has been recorded as a museum and domestic pest in many countries. In recent years there has been a rapid increase in numbers, particularly in the United Kingdom (UK) and Northern Europe (Pinniger, 2013). *Tineola* was not recorded as a species by Linnaeus in the 18th century and it was probably spread to Europe from southern Africa in the mid 19th century with the increase in international trade (Plarre and Kruger-Carstensen, 2011). There has also been a large increase in moth problems in cities in the USA in the last few years. Kelley (2018) lists the top 15 cities with high levels of webbing clothes moth with those on the eastern seaboard being the worst affected.

The biology, behaviour and life cycle of *T. bisselliella* are well documented by Cox and Pinniger (2007). Recent work by Plarre (2014) has demonstrated that it is an urban pest which will not survive winter conditions outdoors in northern Europe and does not generally live in bird nests as previously thought.
Webbing clothes moth larvae eat a range of animal protein-based materials with consequent severe damage to wool, fur, feathers and skins. Silk can also be attacked if it is soiled and although the larvae will not survive on cotton or synthetic fabrics, large larvae will chew holes through them before they pupate.

The life cycle is very dependent upon higher temperatures and at 25 °C each female will produce 100 eggs over a few weeks resulting in three generations a year in a centrally heated house or museum (Pinniger 2015). This rapid escalation of moth numbers has been seen in many houses in the UK over the last few years, including EH properties.

It is not clear why numbers of *Tineola* have increased so dramatically over recent years. The availability of effective pheromone traps gives us a better tool for detecting moth populations, but the data shows that numbers in EH properties have increased over the last three years up to 2017 with no increase in trap numbers (Figure 1). One contributing factor may be the banning of DDVP [dichlorvos], which was exceptionally effective at killing adult moths at very low dose exposure to the insecticide vapour.

**Webbing clothes moth at English Heritage**

English Heritage has been running an Integrated Pest Management (IPM) programme since 1997 (Xavier-Rowe and Lauder, 2011). The insect pest traps were in place at 72 properties across England at the end of 2017. One to two blunder traps are located in each room where vulnerable collections are displayed or stored. The traps are placed in or near the fireplace and diagonally across the room sitting on the floor against the skirting board.

For the 21 properties that house materials susceptible to webbing clothes moth, pheromone lure traps (manufactured by Killgerm Chemicals) are deployed usually one per room on the mantelpiece above the fireplace or at head height on a shelf. Identification and recording is undertaken by trained staff, coordinated by the Collections Pest Control Manager. The combination of trained staff and central co-ordination has resulted in high quality trapping data that is actively used to help prevent damage to vulnerable collections. The impact of the IPM system is evidenced in the low risk score for insect pests in the State of EH Collections survey (Xavier-Rowe and Fry, 2011) and the low incidence of damage to historic objects.

The insect pest species presenting the highest risk to EH collections is the webbing clothes moth *Tineola bisselliella* as measured in annual catch totals. Case-bearing clothes moths *Tinea pellicionella* numbers have been reducing over the same period and pale-backed clothes moth *Monopis crocicapitella* numbers remain low. Over recent years, *T. bisselliella* numbers caught in blunder and pheromone traps have increased from 1142 in 2012 to 2514 in 2017 (Figure 1). From 2008, *T. bisselliella*
Webbing clothes moth data from UK museums and heritage organisations

Reviewing webbing clothes moth data available for over 130 sites (including EH) on the What’s Eating Your Collection website (http://www.whatseatingyourcollection.com/) reveals a similar picture in terms of the risk posed by this insect pest across the United Kingdom. In terms of numbers, webbing clothes moth are significantly higher than any other recorded pest. They are spread across the UK with a clear concentration in London and the southern England (Figure 3).

Webbing clothes moth levels in domestic homes in England

During 2017 English Heritage conceived a campaign called Operations Clothes Moth to help raise the profile of preventive conservation through highlighting the emerging risk from clothes moths in England (Xavier-Rowe et al, 2018). Webbing clothes moth pheromone traps supplied by Russell IPM Ltd. were distributed to all staffed EH properties and the public encouraged to pick up a pheromone lure boards in AF ‘Demi Diamond’ holders supplied by Killgerm Chemicals have been used. The annual ‘total numbers caught’ data indicate a significant rise in T. bisselliella numbers, 216 percent over five years.

Assessing the catch data from 2014 to 2017 there are five properties (Eltham Palace, Rangers House, Kenwood House, Osborne House and Cobham Hall School) that are consistently identified as having webbing clothes moth infestations. An infestation is broadly defined as a total catch of greater than 31 at a property (Xavier-Rowe, 2018).

Separating catch data from infested properties potentially provides further insight into the national risk level from webbing clothes moth (Jarvis, 2016). Focusing on the catch on pheromone lure boards the rise in total annual catch numbers at five infested EH properties, and those properties monitored but not infested (21 sites, with numerous buildings at some sites) shows a rise in webbing clothes moth in both cases (Figure 2). Comparing 2017 and 2014 totals, both groups have approximately a threefold increase in the quantity of webbing clothes moth caught. For infested properties, the total catch in 2017 was 3.15 times that in 2014. For the other properties there were 3.06 times more webbing clothes moth in 2017 than 2014. For the first three years pheromone trap numbers were consistent at 96, 96 and 94. In 2017 this increased to 124 pheromone traps. Taking this increase into account, there is still an increase of 2.5 times or more for both groups from 2014 to 2016, when trap numbers are more comparable. Clearly the threat from webbing clothes moth to vulnerable objects in EH properties is high and has increased significantly over the past five years.

FIGURE 2. Webbing clothes moth Tineola bisselliella annual totals from pheromone lure boards used in 21 properties, separated into infested properties and non infested English Heritage properties from 2014 to 2017.
FIGURE 3 (left). Webbing clothes moth Tineola bisselliella numbers recorded by museums and heritage organisations in the United Kingdom up to December 2018 from What’s Eating Your Collections website.


FIGURE 5. Webbing clothes moth and pale packed clothes moth on the same trap. Photo: DBP Entomology.
free trap to deploy in their home for three months. They were asked to record on the EH website the number of webbing clothes moth and pale-backed clothes moths Monopis crocicapitella caught (Figure 4).

The pale-backed clothes moth, Monopis crocicapitella, is another species of moth that has been found on Tineola pheromone traps in increasing numbers over the last five years (Figure 3). Although closely related to Tineola, its natural home is bird nests and also bat guano (Heckford and Beavan, 2018). There are very few records of damage by Monopis (Gerard, 1995). The pest status of this species is not yet clear and more evidence is needed to establish if Monopis could be a problem pest in the future.

The media response to the press release was unprecedented with over 19 BBC national and regional radio interviews, five TV news features and six articles in newspapers and magazines. This level of media interest on its own would suggest that webbing clothes moth is an issue in domestic homes in England.

In total 4,500 traps were distributed to visitors, 213 moth counts were recorded, a return rate of 4.7 percent. Participants recorded information on a form on the English Heritage website. This had restricted fields, aiding data analysis, which covered postcode, property type, and trap location, amongst others.

The total number of T. bisselliella caught was 3,607. On average, 17 were found on each trap. In total, 69 of the 213 traps reported catching pale backed clothes moths Monopis crocicapitella, with a total of 460. This catch result for M. crocicapitella is much higher than expected when comparing previous totals from EH properties suggesting that this species is becoming established in domestic homes and could possibly pose a threat in future years to historic house collections.

Data was returned from 42 counties. Compared to EH data from 11 counties this allowed an insight into the distribution of webbing clothes moth across England. To help normalise inconsistent returns from different English counties, an average per trap metric was used. The reported catch of webbing clothes moth was higher in the northeast of England (average 23 per trap) (Figure 6). This then appears to radiate outwards, with the southwest and west Midlands the next highest (17 and 16 per trap). The east follows (12 per trap) with the northeast, northwest and east Midlands much lower (6, 5 and 3 per trap).

Participants were asked to record whether they had noticed damage from clothes moths: 40 percent of respondents reported seeing damage. The average webbing clothes moth catch per trap when damage was seen was 31, statistically significantly different to when no damage was seen, at seven per trap. This presents a potential threshold value whereby 31 or more webbing clothes moth on a trap indicates a serious infestation. However, more research is required to confirm this threshold. The evidence from Operation Clothes Moth data suggests that webbing clothes moth is becoming a major issue in domestic homes in England.

**Total catch compared to average catch per trap**

The experience of analysing webbing clothes moth data generated by the general public resulted in a review of how to better measure EH webbing clothes moth catch data. Could the average per trap metric provide further insight into the risk level in addition, or in place of, the traditional annual total count method?
Presenting the EH data as an annual total for each property has proved to be an effective way to highlight the risk from insect pests. EH focuses webbing clothes moth pheromone lure traps at properties where vulnerable materials are on display or in store to provide an early warning of activity. Another reason for monitoring is to understand infestations, where they are located and to ultimately identify their source. The key potential weakness with reporting the catch as an average per trap at a property is that it disguises infestation levels on one or two traps in an individual room. Using the annual totals metric has also proved useful for tracking changes over years to highlight risk levels and to support the case for actions and resources required to mitigate the risk posed by insect pests.

Webbing clothes moth catch data at properties with pheromone lures for the years 2014 to 2017 were reviewed. For each site the average catch per trap trend was compared with total annual numbers. To aid comparison between the two methods specific traffic light risk levels were created where:

- **Green** – no concerns, continue as we are;
- **Amber** – low numbers per trap, general decrease in trend, be vigilant in looking for signs of infestation and continue cleaning as we are;
- **Red** – increase in trend, but low numbers, be vigilant in looking for signs of infestation and continue cleaning as we are. Or previous infestation that we appear to be managing, continue to be vigilant, continue good housekeeping;
- **Black** – infestation established. Continue work to combat infestation, or increase measures to combat infestation.

Comments recorded in the annual site IPM reports, which include background observations further highlighting potential risks also contributed to the traffic light level for total count results.

Generally, the results were similar for total count and average per trap except for four properties (Down House, Dover Castle, Marble Hill House and Osborne House) out of 21 where webbing clothes moth pheromone traps are used.

Marble Hill House in London was assessed differently using each method. Average catch per trap of webbing clothes moth returned an amber risk level. This indicates that numbers are decreasing which is a marked improvement, however good cleaning needs to continue. For total annual catch and also reflecting comments in the annual IPM report the property was assessed a red risk level as there was an action to improve the standard of cleaning.

Marble Hill house has a long history of webbing clothes moth activity and has been part of an on-going trial for measuring the effectiveness of the Exosect webbing clothes moth population suppression method (Lauder, 2013). The source has been narrowed down to detritus trapped beneath the floorboards on the first floor. The floorboards are significant, being original to the construction of the 18th century building making lifting and cleaning underneath not an option. Maintaining a high standard of conservation cleaning to prevent webbing clothes moths from becoming established in expensive replica curtains and other soft furnishing is therefore essential. The observation that standards of cleaning have slipped is an early warning that needs to be addressed and suggests that a red risk level is more appropriate.

Osborne House, the home of Queen Victoria and Prince Albert, on the Isle of Wight was another site that showed different risk levels depending on analysis method used. Average catch per trap figures show a marked decrease over the last three years, designated as a red risk level highlighting a previous infestation which appears to be under control but there is a need to continue control measures. Whereas the total catch figure and annual IPM report noted an active infestation, and that treatment was needed as well as improved conservation cleaning resulting in a black or highest risk level reflecting an active infestation which is not under control (Figure 8).

Additional webbing clothes moth pheromone traps were deployed at Osborne over 2017 to help identify the source and this may be contributing to the apparent decline in numbers when averaged. The highly significant historic materials densely displayed in period rooms are a cause for concern and will require additional targeted conservation cleaning and potentially additional resources to complete deep cleaning and treatments over many years to prevent damage.

These examples illustrate the need for IPM expertise alongside accurate catch data to make judgements about risk and the actions required.
highlights that they present the highest insect pest risk for historic house collections in the UK and potentially in other countries. Key to preventing damage from webbing clothes moth and other insect pests is IPM expertise combined with a coordinated trapping programme. Recording annual total catch results each year remains an essential part of a successful IPM programme.

Acknowledgments

Conclusion
Reviewing webbing clothes moth *Tineola bisselliella* catch data from EH, UK museums and heritage organisations and the general public, clearly to control and prevent damage from webbing clothes moth and other insect pests. The average catch per trap measurement does not give a significant amount of additional information in terms of risk levels at a site-based level and may mask early infestations, which in the case of webbing clothes moth are essential to control before they become established in the building.
**Materials**

*T. bisselliella* pheromone lure boards in AF ‘Demi Diamond’ holders supplied by Killgerm Chemicals

*T. bisselliella* pheromone traps supplied by Russell IPM Ltd

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**References**


DIANA DAVIS

Bringing IPM to historic ships in the UK

Abstract

The National Museum of the Royal Navy (NMRN) has the largest collection of historic ships in the UK, located across five different sites within the museum group. These include HMS Victory, HMS Warrior, HMS Trincomalee and HMS Caroline, ships of differing periods and materials of construction. Until recently, there has been no consistent means of identifying and controlling museum pests within these historic structures. Introducing IPM practises to the ships will be discussed along with the challenges faced.

The main challenges centre around dealing with inherited pest infestations that include well-established wood-borers such as death watch beetle (Xestobium rufovillosum) on HMS Victory. This presents a significant threat to a high-profile item of national heritage, and has generated some pilot studies into the relationship between the wood-borers and fungal species on board the ship, as well as ways to quantify the damage from the beetles that are non-invasive.

Another challenge is found in communicating the importance of IPM to all staff and teams across a multi-site museum. A shared workshop space and pressures of time and resources within the busy museum sites often mean that proper quarantine measures have not been observed. Controlling the movement of objects and pests between sites is further hampered by a lack of quarantine facilities at many sites.

This paper is intended to discuss the problems and successes that have been experienced in introducing IPM to an unusual museum environment, where the historic ships are de facto gallery spaces that the visitors may walk through.

At the time of writing we have just had confirmation that an unusual silverfish discovered in the HMS Victory timber store is Ctenolepis lineata, which is the first known report of this species in the British Isles. Collaborating with other institutions and specialists, including the Museum of London, we are looking into the implications for museums and collections care in the UK, in the light of this new potential risk. This find has highlighted the importance of accurate species identification in IPM practices and the vital need for quarantine facilities.

Key words: pest; ship; wood rot fungi; death watch beetle; silverfish

Introduction

The National Museum of the Royal Navy (NMRN) cares for the largest collection of historic ships in the UK, located across several sites. The main site is at Portsmouth Historic Dockyard, where HMS Victory and HMS M.33 are located in dry dock, and HMS Warrior is still afloat but permanently moored within the museum site. At Hartlepool in the north-east of England is HMS Trincomalee, launched in 1817 and the oldest warship still afloat in Europe. In Belfast is HMS Caroline, a light cruiser from the First World War afloat in permanent dock, the only surviving vessel that took part in the Battle of Jutland. The collection also includes three smaller Coastal Forces craft from the Second World War, in storage at the Fleet Air Arm Museum in Yeovil, Somerset, and several submarines at Gosport, including
archaeologists, conservators, curators and shipkeepers; in total 29 roles that must care for all the NMRN historic vessels across five sites.

The challenges
Conservation of historic ships is a challenging undertaking that combines all the issues facing very large objects, displayed outdoors in a maritime environment, and with thousands of visitors each year who walk through the interiors. The ships are open for schools workshops, special events and are dressed as museum spaces, in some cases with historic objects as well as replica material on board.

It quickly became clear that there were inherited pest issues, of varying severity, existing in many of the ships. A common driver to all these issues was that of high humidity, which is very difficult to remediate since the larger vessels are not in enclosed environments and cannot be entirely sealed against the weather. In the case of the sailing ships HMS Victory (Figure 1) and HMS Trincomalee, there are open brows and gunports, and on the steel vessels HMS Caroline and HMS Alli-

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FIGURE 1. HMS Victory in dry dock in Portsmouth Historic Dockyard, an open coastal environment. Photo: National Museum of the Royal Navy.

FIGURE 2. Example annotated deck plan from IPM document for HMS Trincomalee. Source: Diana Davis, NMRN.
Once the main issues had been identified, the conservators led the way in carrying out the necessary works to resolve those issues that could be resolved quickly, with help from the shipkeepers. The shipkeepers are a small team within Historic Ships, recruited specifically to care for the daily housekeeping needs on each of the ships (McCormack 2016). They have been given basic training in conservation cleaning and how to recognize pest activity and carry out simple remedial treatments, for example, freezing treatments to eradicate moth infestation of woollen blankets in hammocks. Furniture beetles found within replica trunks in displays within HMS Trincomalee were eradicated by disposing of the replica objects and deep-cleaning the space, which led to a full ‘de-cluttering’ of display spaces and storage cabins throughout the ship. These materials and spaces then went through works to either replace the material at risk, or to treat with deterrent chemicals such as Constrain (based on permethrin) to prevent re-infestation (Figure 3). This preventive spraying is repeated on an annual basis in order to remain effective. This

Environmental control measures, including use of internal heating and dehumidifiers, can only ever be of limited success, and so we are facing a long-term risk of pest activity within the ships. An integrated approach to pest management is therefore of critical importance.

**Step one**

The first aim has been to get a clear picture of all the pest issues and to build awareness in order to prevent the situation from getting worse. Each ship has been (or will be) surveyed and an IPM document provided for that ship, which lists and illustrates the species found on board, where issues are located, what objects/materials are at risk, and tracks treatments and progress through an annual review (Figure 2). The method used to produce these was based on advice taken from published works (Pinniger, 2015). The documents are made available to all museum staff, and notifications are circulated about any significant finds.

At the Portsmouth site, one large workshop is shared by the entire team, for work on all the ships. This space was formerly dedicated to HMS Victory alone, but with the incorporation of other sites and the growing team and demand for space, it now serves as the main Historic Ships workshop. The space includes a timber store, workshops, office spaces, and storage areas for historic fabric and even archaeological material. The team are based in Portsmouth but travel to the other NMRN sites, often carrying equipment from the workshop with them. Significantly, there is no provision for quarantine facilities within the workshop buildings, and with the demand for space it is difficult to keep a dedicated area clear in the long-term. The risk of cross-contamination is therefore high, between ships within the Portsmouth site but also across NMRN sites, and the need for IPM once again becomes very clear. It is hoped that through the information gathered using IPM surveys and tracking of pest treatments, the need for investment in the on-site facilities can be demonstrated, and provision of a dedicated quarantine space can be prioritised.

**Step two**

Once the main issues had been identified, the conservators led the way in carrying out the necessary works to resolve those issues that could be resolved quickly, with help from the shipkeepers. The shipkeepers are a small team within Historic Ships, recruited specifically to care for the daily housekeeping needs on each of the ships (McCormack 2016). They have been given basic training in conservation cleaning and how to recognize pest activity and carry out simple remedial treatments, for example, freezing treatments to eradicate moth infestation of woollen blankets in hammocks. Furniture beetles found within replica trunks in displays within HMS Trincomalee were eradicated by disposing of the replica objects and deep-cleaning the space, which led to a full ‘de-cluttering’ of display spaces and storage cabins throughout the ship. These materials and spaces then went through works to either replace the material at risk, or to treat with deterrent chemicals such as Constrain (based on permethrin) to prevent re-infestation (Figure 3). This preventive spraying is repeated on an annual basis in order to remain effective. This

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FIGURE 2. The NMRN team carry out surveys within the ship. Photo: Diana Davis, NMRN.

FIGURE 3. Shipkeepers undertake preventive and remedial treatments under the direction of a conservator, HMS Victory. Photo: Diana Davis, NMRN.
In this case it has resulted in the introduction of a pest species over a large area spanning three interconnected workshop/stores, and yet left us without exact knowledge of how and when this species was able to settle in these spaces. It also creates the risk of cross-contamination between these areas and the rest of the wider museum site, including the historic ships, galleries and library.

The death watch beetle on *HMS Victory*

The death watch beetle was first confirmed as present on the ship in 1932, and at that time was linked to infestation by several species of wet rot fungi (namely *Polyporus sulphureus*, *Poria vailiantii* and *Poria xantha*); it was further suggested that this may have been caused by use of infected timber in the repairs to the ship since her permanent dry-docking in 1922 (Bugler 1966). The fungi were described in the 1932 survey as causing visible decay to the outer hull planking, including on teak planking around the bow, and the beam ends on the boom deck fitted in 1922. At this point however, the survey relied on general sampling and impressions since there were no dismantling works possible, and the distribution of fungal activity could not be fully determined. Despite various attempts to eradicate the beetle, it has been active on the ship ever since this first report. Between 1937 and 1988, the Royal Navy assigned two persons each season (March to June) to collect beetles from the ship as they emerged. Over this period the records show a total of 120,497 individual beetles were captured. The annual counts are useful in illustrating the success of insecticidal treatments carried out and also the spread of beetles associated with reported spread of fungal contamination (Table 1). For example, in three successive years of the 1950s, methyl bromide fumigations were carried out, over which period the annual beetle count dropped from 953 to 72 individuals (McGowan 1999); the effect of this treatment on the fungal growth was not recorded. These numbers can be compared to the counts given during years of passive trapping with glue traps; we have now tasked the shipkeepers with live collection counting, although due to staff time constraints, this is done during the course of their regular duties and is not a specific hunt as was carried out between 1937 and 1988. The numbers resulting from these counts are included in the table below and demonstrate that

![FIGURE 4. Showing historic damage to the jeer capstan, HMS Victory, by death watch beetle. Photo: Diana Davis, NMRN.](image)

Step three

Some more complex issues came to light, however, that cannot be resolved so easily. The biggest pest problem was the death watch beetle infestation on *HMS Victory*, of which there is extensive historic evidence in the timber fabric (Figure 4), but also significant current activity.

This issue needs a more considered approach, and some pilot research studies have been completed to test some initial ideas. The second most concerning issue brought to light was the identification of grey silverfish in the timber store. These will be discussed below.

With the implementation of the IPM, general housekeeping standards have been improving and many small-scale pest problems have been uncovered and resolved. The larger problems are related to environmental and site conditions that are difficult to resolve. The death watch beetle infestation on *HMS Victory* is very well-established, and will be difficult to control completely as the ship is exposed to the elements and as such the relative humidity and timber moisture levels are difficult to control. They tend to be much too high and therefore promote the conditions needed for the beetle to thrive. The identification of the grey silverfish on site has also highlighted the significance of a lack of quarantine measures and the problems this can cause.

In this case it has resulted in the introduction of a pest species over a large area spanning three interconnected workshop/stores, and yet left us without exact knowledge of how and when this species was able to settle in these spaces. It also creates the risk of cross-contamination between these areas and the rest of the wider museum site, including the historic ships, galleries and library.
and swabs from each deck as a representative sample of the growth on accessible surfaces on board (Figure 5).

The list of 24 species identified included known lignin-degraders and known cellulose-degraders (Table 2), all of which are clearly a significant risk to the historic fabric of the ship, to which the beetle attack is most likely a secondary effect. Air tests concluded that there was no health risk as spore levels were still within safe parameters within the ship.

Since we know that fungal activity aids the beetle in attacking timber, but we are still unclear on exactly how far the beetles depend on the fungal decay to allow them to do so, it was recognised that more complete information on the extent of fungal contamination in the ship was needed. A conservator specialising in fungal activity within heritage structures visited the ship and took samples and swabs from each deck as a representative sample of the growth on accessible surfaces on board (Figure 5).

The list of 24 species identified included known lignin-degraders and known cellulose-degraders (Table 2), all of which are clearly a significant risk to the historic fabric of the ship, to which the beetle attack is most likely a secondary effect. Air tests concluded that there was no health risk as spore levels were still within safe parameters within the ship.
to be actively infested with death watch beetles, as well as areas of extensive visible rot. The readings are taken with a Protimeter Timbermaster D184T probe and also with a Tramex PTM2.0 pin-type moisture meter. Five areas of active infestation are monitored currently, and readings range between 9 and 22 % moisture content of the oak timber. The variation appears to be linked to weather conditions and water ingress, with readings higher after periods of heavy rain. Some surprisingly low values may be linked to the amount of surface damage and the localised drying this allows, added to the limited scope for good contact on the probes of the instruments on heavily damaged surfaces.

We are also interested in finding non-invasive means to quantify the damage by the beetle and fungi, since the problem is extensive and we are trying to preserve as much as possible of the ship without replacing historic material or having to resort to drilling tests with a decay-detector drill for structural assessments. An initial study was undertaken by a Masters student at Cranfield University, into imaging methods that might be used to investigate the extent of beetle damage (exclusive of fungal decay) and its effect on structural integrity of timbers. Sample material was provided from HMS Victory that comprised pieces of oak that had been removed in the past because of known death watch beetle infestation. The study generated and analysed high-resolution images of the external surfaces and mapped exit holes

<table>
<thead>
<tr>
<th>Fungi found</th>
<th>Number of species</th>
<th>Known to degrade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Penicillium</td>
<td>6</td>
<td>Cellulose</td>
</tr>
<tr>
<td>Cladosporium</td>
<td>5</td>
<td>Cellulose</td>
</tr>
<tr>
<td>Trichoderma</td>
<td>3</td>
<td>Cellulose</td>
</tr>
<tr>
<td>Alternaria</td>
<td>1</td>
<td>Cellulose</td>
</tr>
<tr>
<td>Ramularia</td>
<td>1</td>
<td>Cellulose</td>
</tr>
<tr>
<td>Aspergillus</td>
<td>1</td>
<td>Cellulose</td>
</tr>
<tr>
<td>Beauvaria</td>
<td>1</td>
<td>Cellulose</td>
</tr>
<tr>
<td>Acremonium</td>
<td>1</td>
<td>Cellulose</td>
</tr>
<tr>
<td>Yeast species</td>
<td>1</td>
<td>Lignin</td>
</tr>
<tr>
<td>Heterobasidion</td>
<td>1</td>
<td>Lignin</td>
</tr>
<tr>
<td>Hohenbuehelia tremula</td>
<td>1</td>
<td>Lignin</td>
</tr>
<tr>
<td>Bjerkandera adusta</td>
<td>1</td>
<td>Lignin</td>
</tr>
<tr>
<td>Coniophora marmorata</td>
<td>1</td>
<td>Lignin</td>
</tr>
</tbody>
</table>
on the chosen samples (Figure 6). It then used micro-computed tomography (µCT) to scan and record the internal damage to the samples, and was able to conclude that there was a general correlation between total surface tunnel area, mean internal tunnel volume, and structural integrity. This would suggest that the visible surface damage (i.e. density of exit holes) can be taken as a reliable indicator of the extent of tunnelling below the surface, and that re-use of exit holes by individuals is not a significant factor. It remains to be seen, however, whether this theory would hold true over a wider sample area, given that there is such a well-established population of the beetle on board.

While this study relied on destructive sampling, and could not be applied to in situ timbers in the same way, it does show that imaging of this kind may be useful in modelling or predicting the beetles’ behaviour within the historic timbers. For example, the µCT imaging showed clearly that the beetles’ pathways through the oak were not random, but often followed the summer growth rings and avoided the rays, with tunnels occasionally turning sharply if one was encountered (Southwell et al forthcoming).

The grey silverfish in the British Isles

An unusually large silverfish was first spotted in the timber store on pallets holding timber gratings from the ship. It could not be determined whether the silverfish had been brought in on pallets from outside the museum or on the gratings from the ship. Once again this highlights the disadvantages of a lack of quarantine procedures. After prompting from an article in Icon News by Museum of London conservators (Moore & Steer 2017), efforts were made to capture a specimen for identification, which was carried out by David Pinniger (independent IPM specialist) and Darren Mann (Oxford Museum of Natural History). This was found to be *Ctenolepisma lineata*, the four-lined silverfish (Figure 7), which had not previously been recorded anywhere in the British Isles. This species is much larger than the common *Lepisma saccharina* (also found at the NMRN) and has long appendages. It was previously known to be found across most parts of southern and central Europe and described as having body length up to 13.5 mm in length (Molero-Baltanás et al 2012).

A visit by the above-named specialists to the timber store also revealed the presence of *Ctenolepisma longicaudata*, living alongside the line-
ata within the stacks of unused timber on storage
racking (Mann, 2018). The longicaudata species
had been identified in the previous year by the
Museum of London conservators, but is also a
recent arrival to the country. This store is housed
in a historic ropeworks building in the dock-
yard (Figure 8), and is consequently poorly insu-
lated and subject to a wide range of environmental
conditions. Environmental data shows an annual
range between 35 and 85 %RH and temperatures
between 11 and 28 °C. This may support the idea
that the grey silverfish is capable of withstanding
warmer and drier conditions than Lepisma
saccharina, as discussed by Moore & Steer (2017),
although the silverfish are observed to seek darker,
sheltered areas. This has implications in collec-
tions care across the British Isles, as it represents
another risk to collections and the need for better
species identification in monitoring practises.

Since alerting the museum staff about the pres-
ence of these grey silverfish species on site, com-
mercial team members were able to find and catch
a specimen on board HMS Victory, in their store
in the grand magazine. Again, we are unable to
say for certain how the magazine came to host the
silverfish, but it is suggestive that this store holds
stock in cardboard boxes that is brought over from
the main museum building. The potential for
cross-contamination is certainly high, even if the
direction of travel of the silverfish has not been
correctly identified. These findings also under-
line the risks from lack of quarantine procedures
within a site where infestations are known in cer-
tain buildings/structures. The next step will be a
full survey of the timber store and workshops and
an options appraisal for provision of quarantine
spaces on site.

Communicating
As the 2018 summer season closed, the ship-spe-
cific IPM reports were updated. These were cir-
culated to all teams in the museum, and all teams
were offered a briefing session to discuss the doc-
ument. These sessions were tailored to the team’s
function and how they utilise the ship or ships,
and what their movement patterns around the
sites looked like. Learning, curatorial, commer-
cial, special events, visitor experience and main-
tenance activities were all included. Each team
was made aware of the existing pest problems and

FIGURE 7. Ctenolepisma lineata photographed in the timber
store at NMRN. Photo: Rosemary Thornber, NMRN.

FIGURE 8. Showing the timber stacks amongst which the grey
silverfish was found at NMRN. Photo: Diana Davis, NMRN.
how to avoid cross-contamination or infestation of their own materials and stores. The first section of the document outlined accountability, to show any staff member what their level of responsibility was, to encourage people to take ownership of the practises for themselves. In some cases this was just awareness and reporting anything observed, while with other teams it covered preventive treatments of materials and store inspections.

As the NMRN is such a large organisation, and even on the Portsmouth site alone there are three ships and five very large buildings with mixed workspaces, the next step is to work alongside the Collections team to bring all IPM practises in line. This goal is to bring the monitoring and management of galleries and stores in line with that carried out in the ships and workshops. The briefing sessions also put the message across to all teams that the success of the IPM system depends on it being adopted by everyone.

Conclusions
Bringing IPM to historic ships is challenging, due to inherited pest problems and a lack of environmental control. The process is ongoing and much work remains to be done, but there have been successes to encourage this. The establishing of a dedicated shipkeeping team has improved our knowledge and baseline conditions on board, and several small-scale infestations have been uncovered and resolved. Communicating the findings to colleagues in the museum at all sites has generated interest and support, and it will be important to continue with these aspects of the project to maintain this momentum. Initial research has also demonstrated the need to answer further questions about some larger problems, notably the extent of damage from, and the means of controlling, the death watch beetle on HMS Victory, and the potential risks posed by the new species of silverfish. The project has also generated initial proposals for improvement of on-site facilities and practises, in order to prevent the spread of pests between ships and sites. We must bear in mind that the nature of the outdoor maritime environment will always be a challenge and that a level of risk will always be present.

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Introduction

Pesticides that have been used on material culture have usually been insecticides and fungicides. Early materials such as sulphur were naturally readily available and found to be effective “bring sulphur old nurse, that cleanses all pollution and bring me fire that I may purify the house with sulphur” (Homers Odysseus circa. 800BC). The more toxic the materials were to biological organisms, the more successful they were considered, regardless of the hazard to people in contact with them (Pinniger and Lauder, 2018). Arsenic, commonly used in the 18th and 19thCentury as a pesticide as well as a pigment, was deemed responsible for the early death of large parts of the population (Whorton, 2011). Napoleon, even when incarcerated on the island of St. Helena, was found to have substantial arsenic residues in his hair, which subsequent research showed he had from an early age (Daily Mail, 2010). Mercuric chloride has been used from 1705 and is still in use in some countries continues, despite its known toxicity through skin absorption and breathing in mercury breakdown products (Figure 1). In the 19thCentury, designer insecticides started to be used with the development in Switzerland of dichlorodiphenyltrichlo-
2. Chemicals with high vapour pressure, such as Lindane (gamma-HCH), paradichlorobenzene, naphthalene and dichlorovinyldimethylphosphate (DDVP or VaponaTM), although they eventually can sublimate off treated surfaces into the atmosphere are frequently retained for long periods and may cause toxic inhalation hazards.

3. The residues can cause chemical and aesthetic changes to the objects they are designed to protect, so DDVP and other pesticides can cause corrosion of metals such as entomological pins. Fumigants such as thymol and naphthalene can have a solvent effect on many polymeric materials such as plastics, adhesives and surface coatings causing discolouration, softening and shrinkage. Many of the carrier methods to apply pesticides, such as wettable powders or oil-in-water emulsions can cause unacceptable aesthetic damage.

Pesticides can also interfere with some analytical techniques such as Carbon14 dating of organic materials.

Methods of detection

Some pesticides, such as naphthalene and paradichlorobenzene can be detectable by their smell, if they are, it is likely that their concentration in the air exceeds the legal minimum dose in some countries. Most others though, can only be detected by analytical methods. The principle ones being the following:

1. Visual techniques. Mercuric chloride in the paper of herbarium specimens can often be detected by its fluorescence under a simple hand held UV/A lamp (Purewal, 2014).

2. Portable x-ray fluorescence (XRF) is a technology that gives accurate qualitative and quantitative analytical results. Metal or metalloid based chemicals can be detected using this method. It is a non-intrusive analysis and does not require samples to be taken.

3. Fourier-transform Infra-red spectroscopy can normally identify organic chemicals. Small samples (≤mg) can be analysed and if the apparatus has a suitable database it can identify pesticide residues qualitatively and quantitatively. (Figure 2).
taxidermy specimens that have been treated with arsenic that has permeated through the skin layer to the fur surface. It is important that the vacuum systems used have High Extraction Particle Fil-

ters (HEPA) as ordinary domestic vacuum cleaners allow smaller particles to pass through their coarse filters and to be blown into the air space. Wet treatments were found to be effective on anthropological textiles in removing arsenic based contaminants (Hewett, 2011). Heat treatments such as the Thermolignum TM heat and humidity system have been shown to be effective in decontaminating pesticides with a high vapour pressure such as Lindane and DDVP. Liquid and super-
critical carbon dioxide have been used successfully as a cleaning and decontamination agent for ethn-
ographic materials and objects (Tello and Unger, 2010).

Risk assessments of the results should be made to assess both hazard (i.e. the potential to cause harm) and the risk (the possibility of causing harm) before determining a course of action that may include:

1. Disposal of the item by means that follow local regulations, this may include landfill, incineration or an appropriate sale.
2. Exclusion by limiting access to the affected objects with appropriate personal protective equipment (PPE) for safe handling and use.
3. Appropriate disinfection or sterilisation of the object may be feasible.

Cleaning and disinfection of treated objects
The risk assessment should determine what degree of disinfection is appropriate, this can vary from surface cleaning to more complex interventions.

Basic vacuuming of the surface of affected materials can be effective in removing loose dust that may have absorbed toxic chemicals from previous pesticide treatments (Schaeuffelhuth et al, 2000). This is known to occur with, for instance, taxidermy specimens that have been treated with arsenic that has permeated through the skin layer to the fur surface. It is important that the vacuum systems used have High Extraction Particle Fil-
ters (HEPA) as ordinary domestic vacuum cleaners allow smaller particles to pass through their coarse filters and to be blown into the air space. Wet treatments were found to be effective on anthropological textiles in removing arsenic based contaminants (Hewett, 2011). Heat treatments such as the Thermolignum TM heat and humidity system have been shown to be effective in decontaminating pesticides with a high vapour pressure such as Lindane and DDVP. Liquid and super-
critical carbon dioxide have been used successfully as a cleaning and decontamination agent for ethn-
ographic materials and objects (Tello and Unger, 2010).

The Law
Many countries in America and Western Europe developed stringent legal restrictions on the use of pesticides in the 1970's and 80's. These normally included an evaluation and registration process on
the biocides that could legally be purchased, used and disposed of under certain conditions. In the UK, The Control of Pesticides Regulations 1986 (COPR) regulated all biocides and their use. In 2012, the European Union issued the Biocidal Products Regulation 528/2012, and it has been controversial ever since.

Article 2 of the Biocidal Products Directive 98/8/EC (BPD) which legislation preceded the Regulation 528/2012, defines biocidal products as “active substances and preparations containing one or more active substances put up in the form in which they are supplied to the user, intended to destroy, deter, render harmless, prevent the action of or otherwise exert a controlling effect on any harmful organism by chemical or biological means” (Directive 98/8/EC). Concern was expressed as this seemed to control such attractants as cheese on a mouse trap and pheromone lures. These problems now appear to have been resolved: “Treated articles should not be placed on the market unless all active substances contained in the biocidal products with which they incorporate, are approved in accordance with this regulation” (REGULATION (EU) No 528/2012).

It has proved difficult to determine what the regulation means by “the market” and no clear answer seems to arise from treated objects bought, sold or auctioned or loaned and put on exhibition to other institutions. There is no clear advice on objects where any pesticide treatment is unknown or suspected, such as historic ethnographical material, objects treated with insecticides recently with materials that are now unregistered and objects that have been treated in the past with an unregistered material. The UK’s Health and Safety Executive’s Division, which is the Biocides Operational and Active Approvals have maintained a silence over the issues (Health & Safety Executive Biocides Helpdesk, 2017).

Conclusion
The perceived hazard of pesticide residues seems to be greater than the actual one. There are few known examples of people being affected by them in the heritage sector. However, there are hazards and risks in certain areas such as crowded herbariaums, entomology collections and furniture stores where the risk needs to be acknowledged, monitored and addressed. Otherwise, in most circumstances, standard precautions of good housekeeping, cleanliness and good hygiene will minimize any risks to personnel and the public.

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References
As a trained secondary school teacher I began my museum career as an educator; teaching and facilitating primary and secondary school students by developing programmes and resources that open up the learning potential of collections. Following this, I undertook formal training in Museum and Cultural Heritage Studies. I now work behind the scenes as a Collection Manager in the Collection Care team at Auckland Museum and am responsible for overseeing pest management. At Auckland Museum the foundations for IPM were initially established by conservators and responsibility was later passed to the collection management team who oversee preventive conservation. The intersection of my teaching qualification and my collection care experience has allowed me to draw on my knowledge of different approaches to teaching and encountering an infestation of *Reesa vespulae*. By reconsidering traditional methods for communicating IPM and utilizing new and innovative techniques, staff interest and involvement has increased with a rise in the number of pest sightings being reported and pest considerations from non-collections staff. Soft skills such as positivity, creativity and good communication play a proven and integral role in the success of any IPM plan.

**Keywords:** Integrated pest management; *Reesa vespulae*; Dermestid beetle; communication; education; training; technology; creativity; infestation; preventive conservation; agents of deterioration

**Background**

Auckland War Memorial Museum was built in 1929 in remembrance of the Aucklanders who died in the First World War and was extended in 1960 to include remembrance of the Second World War. The museum’s floor space was further increased by 60 percent in 2006 when a range of refurbishments took place including the development of subterranean collection storage and workshops, educational amenities, exhibition and visitor services, a theatre and an events centre. Today there are over 300 full time employees and 300 volunteers at Auckland Museum, and over 4.5 million collection objects, making it one of the largest cultural heritage institutions in New Zealand. The diversity of staff and breadth of collections, in conjunction with current extensive building renovations has implications for pest management at Auckland Museum.

**GEORGIA MILLER**

**Socializing Integrated Pest Management**

**Abstract**

Integrated Pest Management (IPM) requires a museum-wide approach to be successful, effective tools for communication can prevent or reduce most pest problems. Empowering all staff to identify as stewards in the care of collections is challenging but can be achieved with a variety of communication techniques that are accessible and insightful. Methods for socializing IPM at Auckland War Memorial Museum take the form of visually stimulating signage, engaging presentations, digital platforms and interactive educational tools. Varied strategies for spreading awareness have become increasingly necessary while the museum is undergoing major building transformations and since encountering an infestation of *Reesa vespulae*. By reconsidering traditional methods for communicating IPM and utilizing new and innovative techniques, staff interest and involvement has increased with a rise in the number of pest sightings being reported and pest considerations from non-collections staff. Soft skills such as positivity, creativity and good communication play a proven and integral role in the success of any IPM plan.

**Keywords:** Integrated pest management; *Reesa vespulae*; Dermestid beetle; communication; education; training; technology; creativity; infestation; preventive conservation; agents of deterioration
learning and apply this knowledge to the commu-
nication of IPM at Auckland Museum. Having
experienced how IPM is interpreted as a non-col-
lections staff member and now as a member of the
Collection Care team, I have attempted to imple-
ment new and innovative strategies to communi-
cate IPM, moving away from traditional modes of
communication. This paper will share an insight
into some of the strategies for socializing IPM at
Auckland Museum.

Introduction
An essential part of preventive conservation in
museums, galleries, libraries and other cultural
and heritage institutions is IPM. IPM focuses on
the prevention of pest infestations and the reduc-
tion of pesticide applications. Preventive measures
are easier to manage, more cost-effective and more
likely to ensure the longevity of collections for
future generations. For IPM to be effective, buy-in
from all staff within an institution is necessary,
this requires continual communication to inspire
staff to want to assist in pest prevention. There is
currently a considerable body of literature which
relates to pest identification and the implementa-
tion and maintenance of an IPM plan, however,
there is little written about practical approaches
and methods for communicating IPM policies and
procedures amongst museum employees. This is
surprising given that spreading awareness of IPM
is potentially the single most important factor for
reducing pest problems. Collection care staff gen-
erally have formal training which teaches, from a
scientific perspective, the importance of pest man-
agement and the damage that pests can cause to
collections. On the other hand, non-collection
staff often struggle to comprehend how their indi-
vidual actions can have negative impacts on col-
lections.

For IPM to be successful in preventing pests,
a museum-wide approach is fundamental. Unlike
traditional methods of pest treatments which
consisted of regular pesticide applications, IPM
requires a daily mind-set and assiduous practice
to remain effective. A museum-wide approach
involves having support and assistance from all
staff, not just those who have a direct role in col-
lection care. In large institutions such as Auckland
Museum, partnerships between the museums vari-
ous departments are crucial for ensuring the con-
sistent application of IPM strategies. Empowering
all staff to identify as stewards and stakeholders in
the care of collections and adapting their behav-
iours can often be a challenging and arduous pro-
cess; it requires good communication between the
staff responsible for IPM and the wider museum
staff. Communication that is irregular, unin-
formative and/or uninspiring can result in casual
attitudes and a lack of interest from staff; this is
dangerous when staff cooperation is essential for
ensuring the success of IPM. Communicating
IPM doesn't have to involve repetitive lectures or
a barrage of data. Instead, a variety of communi-
cation techniques can be applied that are focused,
accessible and insightful. Methods for socializing
IPM can take the form of visually stimulating sig-
itage, engaging presentations, digital platforms or
interactive educational tools.

Education
For staff members to be on board with IPM they
must have an understanding of why pests are dan-
ergous to collections, what to do if they find pests
in the building and how their actions can help
or hinder pest prevention. Therefore, regardless
of the size of your institution, training is funda-
mental for educating staff on the role they play in
the efficacy of their organisation's IPM plan. At
Auckland Museum there are over 300 full time
employees who work across five different direc-
torates. Like many other museums, we do not
have the time or resources to provide intensive
IPM training courses to all museum employees.
We do, however, provide thorough training to all
new staff that joins the Collections and Research
directorate with a full day induction. The induc-
tion is run by the Collection Managers in the Col-
lection Care team and is based on the Ten Agents
of Deterioration®, providing an insight into how
these factors are mitigated. This information is
presented by a number of speakers and in a vari-
ety of ways to ensure the presentations are memo-
rable and information is retained. As well as being
an introduction to the basics of Collection Care at
Auckland Museum, the induction is also intended
to foster a sense of shared responsibility in caring
for collections and to empower Collections staff
to set the example for best practice pest manage-
ment to non-collections staff. Training is also pro-
vided for contractors whose work has implications
for pest prevention including café staff, cleaners, event caterers and furniture hire companies. This training is carried out by the collection care IPM representative and encompasses pest identification and a detailed introduction to the practical appendices of our IPM plan, including our colour-coded floor plan indicating where food and drink can and cannot be consumed, approved commercial and catering food delivery routes (e.g. not through galleries or storerooms) and our incoming deliveries procedure.

Ambassadors
As it is not feasible to train every single museum staff member on the intricacies of pest management, Auckland Museum has in place a Pest Control Committee called the Bug Busters. Each team or office area has one staff member who is appointed as their resident Bug Buster and is the go-to person for pest related concerns. Each member of the committee wears a Bug Buster Identification tag on their staff lanyard and has their name listed on the IPM page on our staff intranet. The Bug Busters are Collection Care’s ‘eyes and ears’ across departments, reporting pest sightings and championing our food control methods. Quarterly meetings are held for the Bug Busters committee, which are an opportunity to offer further IPM training, discuss pest concerns and keep up to date on current pest activity. We also acknowledge the Bug Busters commitment to IPM with specialist activities including back of house tours of the entomology lab, presentations by guest speakers, tours of our pest treatment methods including the blast freezer and anoxic chamber and pest identification training. The committee has been successful in creating a museum-wide presence; the Bug Busters are avenues for distributing information and updates across departments, this means the reinforcement of key IPM messages doesn’t just come from Collections staff.

Monitoring
To further encourage cross-departmental communications and a sense of shared responsibility, some IPM tasks can be shared by several members of staff as opposed to solely the collection care department or IPM representative. Depending on the size of your institution, insect monitoring can be adopted by several members of staff. Auckland Museum’s monthly monitoring programme is spread across all collections departments; Human History, Natural Sciences, Documentary Heritage, Collection Readiness and Collection Care. Each team has 1-3 staff members who are on a rotating pest checking roster and are responsible for checking blunder and Dermestid bait traps placed in their particular collection areas. The monitoring programme was established by Collection Care and training on pest identification and record keeping was provided to each pest checker. As each department is discovering and identifying the pests themselves, they become invested in their particular collection area. For example, if the...
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• No hitch hikers: Consider what you bring into the museum. Check you have no pesty hitch hikers coming in on the items you bring in or have delivered to the museum.

• Famous Five: Have you seen the Famous Five? Look out for and report any sightings of the following pests to Collection Care for us to keep track of pest populations in the museum; rodents, clothes moths, silverfish, borer beetles and dermestid beetles and larvae.

Strategically placing visual prompts can enable them to be better comprehended. The Fast Four stickers are made to the size of our standard tissue boxes and are applied to the boxes before they are distributed to employee’s desks. By having these guidelines visible on each staff member’s desk they function as a subtle prompt to keep IPM at the forefront of people’s minds, staff can also easily refer to the pictures of the Famous Five and know where to report any sightings to. Posters also showing the Fast Four guidelines are displayed at our main loading dock where all deliveries enter the museum, to target people who are bringing materials into the museum and remind them to check for ‘hitch hikers’.

Human History team find high numbers of silverfish one month, it will indicate to them that perhaps they should increase the cleaning in their collection storage areas. Sharing pest monitoring further enhances the notion of a collective responsibility for IPM and means that the pest checkers will communicate their pest findings and concerns back to their teams.

Visual Perception
Visual stimuli are another effective tool for communication. Studies show that it only takes about a quarter of a second for the human brain to process and attach meaning to a symbol (Thorpe, Fize, Marlot, 1996). In back of house areas at Auckland Museum, stickers and posters with alluring graphics and symbols are used to serve as visual reminders for staff to remember our ‘Fast Four’ guidelines to IPM:

• Food and drink: Only consume food and drink in approved areas. Limiting areas where we consume food and drink will limit what pests can live off too.

• Keep it clean: A clean and tidy museum will mean fewer places for pests to find homes in.

FIGURE 3 & 4. Auckland Museum’s Fast Four Guidelines sticker and tissue box.
Visual stimulation in the form of digital technology can be used as an engaging educational tool. For staff inductions and Bug Buster meetings we have often used quizzes as an icebreaker when introducing a topic or to break up formal talks. There are a number of online, game-based learning platforms that can be accessed for free on the internet. Creating online quizzes and games to test people’s knowledge of pests can create an interactive social and competitive learning environment, which brings energy and interest to topics such as pest management, which can often be perceived as dull.

Presentations

Presentations and speeches to staff are necessary for communicating IPM updates and information and often function as a ‘call to action’. The style and delivery of a presentation can greatly influence the engagement levels of the audience and determine what information is retained. Studies show that humans are far more receptive to what we see versus what we hear, with 90 percent of the information we take in coming to us through our eyes (Hyerle, 2009). Therefore, pairing talks with visual cues are more likely to leave a lasting impression on the viewers. A range of presentation programs can be accessed online, some take the traditional slide based format whereas others are intended to be used in a more conversational context, encouraging participation from the audience to create a collaborative and dynamic dialogue. Changing up delivery styles can be another method to generate interest and communicate information. For example, the Pecha Kucha format involves having 20 slides for 20 seconds each; creating a concise and fast-paced presentation that forces the speaker to stick to the key messages. ‘Buzz groups’ are another learning technique that involves the formation of small discussion groups with the objective of developing a specific task. For example, you could pose a question to each group such as: what are our current methods for deterring pests in the museum? How can the museum’s building envelope be better sealed? Or a scenario question such as “what is wrong with this image?” After discussing the question, each group then informs the others of their considerations, creating a communal and receptive teaching and learning environment.

Social Media

Utilizing your institution’s website and social media platforms can be a further tool for communicating IPM to staff and additionally, educating the public on pest management within heritage organisations. The Collection Care team at Auckland Museum are committed to increasing the visibility and appreciation of the department internally and externally by sharing blogs and information pages on our website; these are then promoted via social media. Some examples of our current blogs include ‘What’s Eating Auckland Museum?’ an introduction to the Famous Five, and, ‘Cleaning, but not as you know it’, a glimpse into the complicated, specialist cleaning that takes place in the conservation lab. Other blogs cover topics such as storage optimisation, light sensitivity and environmental control. Sharing these stories in an informal or conversational style such as a blog, via multiple social media platforms, diversifies the audiences that this content influences.

Data

When communicating to staff it is important to include evidence that supports the need for IPM. Evidence can take the form of statistics of pest activity, maps depicting areas of pest density and distribution, images illustrating pest damage to collections or violations of policy and so on. IPM requires frequent monitoring therefore museums amass large amounts of data on pest species and population numbers in various store rooms, galleries, work spaces and other locations. Arrang-
Museum’s galleries prompted further investigations. A live larva was collected by the museum’s entomology curator, after the larva matured into a beetle and reproduced, it was confirmed that the insect reproduced through parthenogenesis. This, paired with the fact the larvae are omnivorous and the adult beetles can fly, make *Reesa vespucae* a huge threat to collection objects containing organic material. To further investigate the insect’s behaviour, preferred environments, population numbers and possible attractants, a project was launched which involved 12 months of intensified monitoring using protein baits in addition to our regular sticky blunder trap monthly monitoring. Between September 2017 and August 2018, 43 beetles, 52 larvae and 18 casings were discovered in nine locations in the museum. Seven of these locations held collection objects, one was an office space and one was the staff lunch room. From our data we were able to prove the following trends:

- *Reesa vespucae* are attracted to areas where staff store and consume food,
- *Reesa vespucae* are attracted to dark, quiet collection spaces that are rarely accessed.

These trends reinforced the need for increased store checks and regular cleaning schedules for collection teams and heightened awareness and vigilance of food storage for all museum staff.

**Case Study: Reesa vespucae at Auckland Museum**

In September 2017, an infestation of the Dermestidae species *Reesa vespucae* (common name: Museum Nuisance Beetle) in one of Auckland Museum’s galleries prompted further investigations. A live larva was collected by the museum’s entomology curator, after the larva matured into a beetle and reproduced, it was confirmed that the insect reproduced through parthenogenesis. This, paired with the fact the larvae are omnivorous and the adult beetles can fly, make *Reesa vespucae* a huge threat to collection objects containing organic material. To further investigate the insect’s behaviour, preferred environments, population numbers and possible attractants, a project was launched which involved 12 months of intensified monitoring using protein baits in addition to our regular sticky blunder trap monthly monitoring. Between September 2017 and August 2018, 43 beetles, 52 larvae and 18 casings were discovered in nine locations in the museum. Seven of these locations held collection objects, one was an office space and one was the staff lunch room. From our data we were able to prove the following trends:

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- *Reesa vespucae* are attracted to dark, quiet collection spaces that are rarely accessed.

These trends reinforced the need for increased store checks and regular cleaning schedules for collection teams and heightened awareness and vigilance of food storage for all museum staff.
Currently Auckland Museum is undergoing a dramatic period of transformation and change, this involves refurbishing and revitalising galleries, adding more public space to showcase collections and improving wayfinding. Any kind of change or impending change within the workplace can cause anxiety which unsettles employees and can create a negative atmosphere. However, change can also open up lines of communication and be an opportunity to adjust behavioural habits and reinforce key messages. As part of the refurbishments, the staff lunch room where the Reesa vespulae had previously been discovered was going to be demolished and rebuilt. This became an opportunity for Collection Care to provide input into the development of the new staffroom and to share with museum staff evidence of the correlation between food that is consumed and stored in the museum by staff and pests which make their way into stores and galleries and damage collections.

Collection Care made recommendations such as using lino on the floor instead of carpet, removable and washable covers on the cushions, easy to wipe surfaces and regular fridge and cupboard cleanouts. With over 300 staff and 300 volunteers at Auckland Museum, it was important that we advocated for stronger messaging around food storage. We promoted that all food, especially fruit, must be stored in sealed containers and for all staff to follow the name and date system; using the provided stickers and pens to write their name and date on any food that is stored in the lunch room. This means any old and forgotten or unclaimed food can be disposed of during the monthly fridge clean out, decreasing the chance of attracting pests. We also encouraged staff to get in the habit of visiting the lunch room on their arrival to the museum and on their way home, to drop off and pick up their lunch boxes and discourage long term food storage. To persuade staff to get on board with pest prevention communication needed to be transparent, receptive and delivered in an engaging manner.

We were conscious of the fact that during this time of change, staff might be feeling fatigued by the number of announcements regarding building changes. It was important to sell the new lunch room as an exciting and attractive new space for staff to eat their lunch, host morning teas and socialize with other colleagues. Encouraging people to want to eat there meant they would be less likely to consume food in their office spaces, which are often in close proximity to collection stores and galleries. When introducing a new system or protocols it is vital that communication is clear and consistent from the outset so people feel well-informed and involved. To introduce the new staffroom and protocols to all museum employees, a presentation was made during an all-staff meeting. From an IPM perspective, our strategy was to make the presentation memorable and informative and to inspire all staff to want to do their bit towards pest prevention. We shared the evidence of pest activity from our previous lunch room with statistics, images of Reesa vespulae larva and beetles, and an image of a kiwi bird from our collection which had its feathers consumed by larvae from the Dermestidae family; a kiwi is a flightless bird which is native to New Zealand and highly endangered, a naked kiwi was sure to pull on some hearts strings. A strong call to action was made by detailing how members of staff could be of assistance to our IPM strategy. To add an element of memorability and humour, the Collection Care team members opted to dress up in symbolic outfits; a fruit fly and a bruised banana. The result was positive and enthusiastic. When communicating science there is room for creativity and there is no shame in combining science with fun.

Recognition
A significant aspect of communication is acknowledging and praising people’s efforts towards IPM. Recognising good work and showing appreciation and gratitude to staff members confirms that their work is valued by others. When people feel their efforts are appreciated they become motivated to uphold or improve their good work. Appreciation can be expressed personally through words of gratitude for simple tasks such as reporting a pest sighting. Even if the pest is not a threat to the collection, it is important to acknowledge the effort that’s gone into reporting it, failure to do this could result in people not bothering to report a more dangerous pest in the future. To avoid always sharing negative stories of pest damage and infestations, share positive instances of good behaviour and hold it up as an example to the institution. If there has been a decline in pest activity due to intensified cleaning or food control


efforts, acknowledge this commitment by sharing statistics of the decrease in pest numbers as a result of their hard work. Furthermore, this reinforces that the success of IPM is largely dependent on the actions of those within an institution.

Conclusion

Increased efforts to socialize IPM at Auckland Museum in recent years have had noticeable impacts on pest activity. Although hard to measure, the diversity of staff and volunteers reporting pest sightings to collection care has become more widespread with sightings coming from across all museum teams as opposed to just collections staff. Varied strategies for communication have helped to strengthen relationships across departments and build a sense of trust. The Museum’s café staff were taken on a behind the scenes tour of the subterranean collection stores to spark an interest in collections and their care, this rapport has opened the lines for honest communication. Pest-related enquiries are also on the rise with many staff in commercial or building works teams consulting...
with collection care about how their work can best adhere to the IPM principles. Our biggest and most notable victory is the decline in the number of pests being sighted. Since the IPM plan was launched between 2013 and 2015 and a focus on communication was implemented in recent years, the presence of rodents in the museum has been eliminated. Silverfish sightings, although still present, have also dramatically decreased.

TABLE 1. Number of rodent and silverfish sightings reported by staff at Auckland Museum

<table>
<thead>
<tr>
<th></th>
<th>No. of rodent sightings</th>
<th>No. of silverfish sightings</th>
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</thead>
<tbody>
<tr>
<td>2012</td>
<td>20</td>
<td>167</td>
</tr>
<tr>
<td>2018</td>
<td>0</td>
<td>31</td>
</tr>
</tbody>
</table>

IPM requires a museum wide approach to effectively mitigate pest damage to collections; therefore, spreading awareness of IPM is potentially the single most important factor for reducing pest problems. To empower museum employees to want to assist towards pest prevention and protecting collections, communication must be engaging, accessible and insightful. Reconsidering traditional methods for communicating IPM and utilizing new, innovative techniques could refresh and invigorate current staff attitudes towards IPM and inspire better behaviours. Strategies for socializing IPM at Auckland Museum have involved communicating key IPM messages through all available avenues and incorporating different technologies to do so. Visually engaging signage and presentations, interactive presenting styles and activities and digital platforms have had a proven impact on staff interest and involvement in IPM. Continuously evolving technologies means that communicative strategies can change and develop over time to maintain relevance and hold interest. In this era of climate change, globalisation and increased museum and gallery reformations, it is now more important than ever to ensure we are doing all we can to socialize IPM in cultural heritage institutions and ultimately ensure the perpetuity of collections for future generations.

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References

Endnotes
1 The Ten Agents of Deterioration include: physical forces, theft, fire, water, pests, pollutants, light, temperature, relative humidity and custodial neglect.
Day II:
IPM in the era of globalisation
Ctenolepisma longicaudata (grey silverfish): occurrence and behaviour in UK heritage organisations

Abstract
At the 3rd International IPM Conference in Museums, Archives, Libraries and Historic Buildings, Ctenolepisma longicaudata (grey silverfish) were reported from a UK heritage organisation, the Museum of London (MOL), for the first time. Silverfish data collected as part of MOL’s ongoing IPM programme (from 2013–2018) is presented, as well as data from three other UK heritage organisations also reporting C. longicaudata in their buildings. Grey silverfish are currently being reported from organisations based in urban locations, and it is observed that they are able to thrive in environments optimised for the long-term storage of collections. Grey silverfish are also capable of establishing large and widespread populations in buildings containing significant food sources, making containment and remediation challenging, and emphasising the importance of effective building maintenance programmes and quarantine procedures.

Keywords: Ctenolepisma longicaudata; Museum of London; Science Museum; London Library; Leeds University Library; IPM; paper; relative humidity; normalised count.

Introduction
At the 3rd International IPM Conference in Museums, Archives, Libraries and Historic Buildings several authors made reference to Ctenolepisma longicaudata (grey silverfish) as an emerging threat to collections. This insect pest was also reported from a UK heritage organisation, the Museum of London (MOL), for the first time (Querner and Hassler, 2016; Knoop, 2016; Pinniger et al., 2016).

C. longicaudata is now present in 25 locations (stores, galleries, laboratories) across two MOL sites, representing 79 percent of the museum’s total silverfish population. This paper will provide an analysis of silverfish data collected as part of MOL’s ongoing IPM programme since 2013, and report the first known C. longicaudata damage to collections in the UK. A simple method of normalising insect data has also been trialled to enable more objective comparison of insect counts collected from locations with greatly varying insect trap densities.

In addition, the publication of ‘A New Silverfish Threat in the UK and Europe’ in 2017 (Moore and Steer) led to at least five other UK heritage organisations identifying C. longicaudata in their buildings, and one identifying Ctenolepisma lineata, another species new to the UK. A number of these organisations have been working in collaboration with MOL, exchanging IPM data and information on buildings and operations. This paper will provide a summary and (where possible) an analysis of C. longicaudata data collected as part of each organisation’s ongoing IPM programme, and report any observed similarities and differences in the occurrence and behaviour of this new insect pest.

Ctenolepisma longicaudata
C. longicaudata (of the order Zygentoma, in the family Lepismatidae) is reported as a native species of both North America and South Africa, however being as C. longicaudata is a species that lives in
C. longicaudata are reproducing, presenting an additional risk to collections (Walker et al., 2013).

**C. longicaudata data from the Museum of London**

As part of MOL’s ongoing IPM programme, the Collection Care team has been monitoring insect pest activity and recording insect pest data in a centralised database since 2013. In 2017 ‘A New Silverfish Threat in the UK and Europe’ reported that grey silverfish were first recorded in MOL’s Dress and Textile Store (DTS) in March 2015 following a notable increase in insects caught on traps (Moore and Steer, 2017). MOL’s Collection Care team have continued to monitor and investigate the ongoing presence of this new insect pest, and can now evidence the occurrence of *C. longicaudata* prior to 2015. Evidence also suggests that *C. longicaudata* did not necessarily originate from, or were confined to, the DTS. A video of *C. longicaudata* in the DTS was received by the Collection Care team’s ‘Pest Desk’ email inbox in April 2014. Additional reports of ‘large silverfish’ in the DTS, but also in the museum van (whilst transporting archive items from MOL to an off-site storage facility), were received between August 2011 and April 2012. Further reports from 2011–2014 document ‘silverfish’ activity in other areas of the building.

Between 2013 and 2018 the approach to insect pest data collection at MOL has varied in line with resources and collection risk. For the purposes of analysis, the IPM data documenting silverfish activity between 2013 and 2018 is therefore separated into three datasets to reflect three different data collection methods used. The datasets are described in Table 1.

### Table 1. Silverfish data from the Museum of London 2013–2018.

<table>
<thead>
<tr>
<th>Dataset number</th>
<th>Period covered</th>
<th>Data description</th>
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<tbody>
<tr>
<td>1</td>
<td>January 2013–June 2016</td>
<td>Dataset covers all MOL sites excluding the DTS1. <em>L. saccharina</em> and <em>C. longicaudata</em> are both recorded as <em>L. saccharina</em>.</td>
</tr>
<tr>
<td>2</td>
<td>September 2016–September 2018</td>
<td>Dataset covers all MOL sites excluding the DTS2. Following the identification of <em>C. longicaudata, L. saccharina</em> and <em>C. longicaudata</em> are recorded separately.</td>
</tr>
<tr>
<td>3</td>
<td>September 2016–September 2017 and January 2018–September 2018</td>
<td>Dataset covers all MOL sites including the DTS3. <em>L. saccharina</em> and <em>C. longicaudata</em> are recorded separately.</td>
</tr>
</tbody>
</table>

As terrestrial insects, most silverfish species from the order Zygentoma have evolved to reproduce by transferring sperm using silk. *Lepisma saccharina* (species of silverfish commonly found in UK Museums, Libraries, Archives and Historic Houses) and *C. longicaudata* are exceptions as they carry out a choreographed courtship behaviour consisting of antennae tapping and repetitive movements, with male insects using their silk as a tactile cue. They create patterns that are detected by females, inducing the uptake of a sperm droplet deposited by the male nearby. Since silverfish silk is not required for a structural purpose, it rapidly becomes dry and brittle. Silk fibres (up to 20 cm long and 0.3–1 µm in diameter) and shed scales are therefore likely to be present on surfaces where silverfish are reproducing, presenting an additional risk to collections (Walker et al., 2013).
1. The DTS is excluded from this dataset, instead the DTS corridor is used as an indicator of activity in this area. During this time the DTS IPM programme was moth focused in line with collection risk. Silverfish had been sighted but largely attributed to localised damp from an adjacent plant room, the Facilities team responded by deploying their own insect traps. Conversely, the number and location of insect traps in the DTS corridor has remained unchanged since 2013, and traps have been checked quarterly. The DTS corridor houses a representative portion of the collection and leads into the DTS.

2. The DTS is excluded from this dataset, instead the DTS corridor is used as an indicator of activity in this area. During this time the DTS trapping frequency was increased to an eight week rotation compared to a twelve week rotation for all other locations. It is therefore difficult to directly compare DTS insect counts to insect counts from all other locations.

3. The DTS is included in this dataset. For these select periods it is possible to produce a total count per twelve week period for every location.

The footprint of the 25 locations where *C. longicaudata* has been recorded at MOL varies from 5 to 2,405 m² and the number of insect traps per location varies from 1 to 49. All locations house collections so are covered by the same policies for access, security and collection care. All 25 locations undergo regular housekeeping activities and maintain an environment of 40–65 %RH and 18–22 °C. In each location insect traps are positioned according to best practice principles for catching insects.

However, insect traps at MOL are not deployed in regular grid patterns and do not achieve a consistent trap density (number of traps per m²) across locations. The higher the trap density, the higher the probability of catching insects, resulting in an increased count (Pinniger, 2015). Without a consistent trap density, it is therefore difficult to compare populations from different locations.

To enable more objective analysis of IPM data collected from locations with very variable trap densities, a simple method for normalising the actual insect count has been trialled. The trap density for each location has been calculated by dividing the number of insect traps by the footprint of the location. The actual insect count is divided by the trap density to produce the normalised count. This method has not yet been validated with the use of statistical analysis, but has proved useful in helping to take into account variations in trap density when analysing insect pest data.

For example, IPM data collected at MOL between September 2016 and September 2018 (dataset 2), shows that the actual count of *C. longicaudata* in two locations (the Lower Galleries and Photography Studio) is comparable. However, the trap density in the Photography Studio is four times greater than that in the Lower Galleries. The normalised count helps to highlight this, indicating that if the same number of traps per m² were deployed in the Lower Galleries, it’s likely that a larger grey silverfish population would be observed (Figure 1). Where indicated, this method has been used to aid analysis of IPM data presented below.

Figure 2 presents the actual count of *L. saccharina* and *C. longicaudata* per quarter from 2013–2018 (datasets 1 and 2), and the actual count of *C. longicaudata* per quarter from 2016–2018 (dataset 3).

It can be observed that the total population of silverfish at MOL has increased from 2013 to 2018, with the largest count recorded in September 2016. However, the *C. longicaudata* count has not significantly increased or decreased from 2016 to 2018.

The normalised count for datasets 1 and 2 reveals that the five largest silverfish populations are consistently reported from the same seven locations: Lower Galleries, DTS corridor (as an indicator of the DTS), Transit Store, Paintings Store, Paper Conservation Studio, Photography Studio and Upper Galleries (Figure 3).

This is consistent with reports of silverfish activity received by the museum’s Pest Desk email inbox, with the addition of the Applied Arts Conservation Laboratory.

The normalised count for dataset 3 also shows that the areas with the most activity are the Lower Galleries, DTS, DTS corridor, Upper Galleries, Transit Store, Photography Studio and Paper Conservation Studio (Figure 4).

The normalised count of both silverfish species for the period September 2016–September
With reference to Groups A and B, it can be inferred that *C. longicaudata* have entered/are entering the museum from the external urban environment via weaknesses in the building fabric and/or with visitors and objects. It is observed that *C. longicaudata* are able to locate food sources and harbourage sites within a building and establish populations in close proximity to them. Damage has been observed to papers, particularly those with high or added cellulose, starch or protein content. Large populations of *C. longicaudata* are also observed in close proximity to areas with significant human activity. Adults do not require elevated RH to thrive and therefore seem to be capable of straying throughout a building, rapidly establishing a large and widespread population. At MOL *C. longicaudata* is currently observed in up to 20 separate locations per quarter, compared to only six locations in September 2016 (Sellenschlo, 2007, Meineke et al., 2014; Landsberger and Querner, 2017; Chowdhury, 2006; Machida et al., 1996).

In 2018 *C. longicaudata* were observed in three bays (housing mixed material collections) at MOL's storage facility, Mortimer Wheeler House (MWH). Significantly fewer insects are counted at MWH compared to MOL and they have not been observed in a bay housing a large paper archive. Again, the lower temperature at MWH could be contributing to the lack of growth and migration of the population in this building.

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**C. longicaudata** elsewhere in the UK

**Science Museum, London**

The Science Museum IPM team have reported two *C. longicaudata* at their main site. One insect was observed in April 2017 in the basement, and another trapped in January 2018 in a third floor gallery.

FIGURE 6. Examples of *C. longicaudata* damage.
Left to right: damage to a watercolour painting concentrated around a methyl cellulose repair.
Damage to second watercolour painting.
Damage to a board covered with blotting paper adhered with wheat starch paste.
Copyright Museum of London.

The London Library, London

The London Library IPM team have reported *C. longicaudata* in five locations across their basement floor. *C. longicaudata* and *L. saccharina* have been recorded separately since August 2018, however conservators suspect *C. longicaudata* to have been present since 2016 when silverfish counts started to increase (Figure 7).

*C. longicaudata* has been regularly reported in three collection areas containing between 439–1,226 meters of books, and two adjacent non-collection areas. The ambient conditions in these locations ranges from 21–29 °C and 13–52 %RH. Trap density is variable, so a normalised count for the period August–September 2018 suggests a larger population in the side front basement when compared to the lift lobby and rolling cases, and the toilets and lobby (adjacent to the side front basement). The side front basement contains approximately double the amount of books than the lift lobby and rolling cases (Figure 8). The London Library also reports a seasonal increase in silverfish count from March–September for the last three years (2016–2018).

Leeds University Library, Special Collections and Galleries

Leeds University Library Special Collections and Galleries IPM team have reported *C. longicaudata* in 14 locations across five sites in central Leeds. *C. longicaudata* were first identified in May 2017 at the Cemetery Road Store (which houses books, paper archives and a museum collection), and Special Collections within the Brotherton Library building, in a room housing books and artworks. By October 2017, *C. longicaudata* were observed in The Treasures of the Brotherton Gallery, The Stanley and Audrey Burton Art Gallery (both Parkinson Building), and the Western Campus Store housing printed books. By April 2018 *C. longicaudata* were present in the University (books and paper) Archive (Figure 9).
The ambient environment in all 14 locations is not damp, only occasionally reaching a maximum of 65 %RH. The Collection Care team have reported populations of *L. saccharina* from a number of insect traps indicating areas of localised elevated relative humidity, *C. longicaudata* are not reported from these locations.

The largest and most established population of *C. longicaudata* is reported from the Parkinson Building. This building houses objects from Special Collections on temporary display in two galleries, including books, paper archives, photographic material, artworks, textiles and objects. There are a number of store rooms for non-collection material such as display cases and book mounts, and the building also houses the Art Gallery Store containing paintings, sculpture, works of art on paper, textiles and a library. There is a number of store rooms for non-collection material such as display cases and book mounts, and the building also houses the Art Gallery Store containing paintings, sculpture, works of art on paper, textiles and a library. IPM data shows that the *C. longicaudata* population in this building has increased since they were first reported in June 2017, and that the population has moved from one location to three in approximately four months.

The Parkinson Building houses the least amount of paper and books when compared to the other four sites, however the Treasures of the Brotherton Gallery (where the majority of the *C. longicaudata* have been observed) was refurbished in 2015. Similar to the Group A spaces at MOL, this gallery is an area with significant human activity, an entry point for visitors, and there are also cavities under and behind display cases providing harbourage sites.

Special Collections (Brotherton Library building) has the second largest population and *C. longicaudata* have been recorded regularly in this building since their first occurrence in May 2017. This building houses the most archive material and books when compared to the other sites. The population has not increased since May 2017, but has been recorded in eight separate locations in 16 months.

*C. longicaudata* populations at the three remaining sites are smaller (only one insect has been reported from the Cemetery Road Store) and occurrence is much more sporadic. These buildings house fewer archive materials when compared to Special Collections.

**Discussion of *C. longicaudata* data from the Science Museum, the London Library and Leeds University Library, Special Collections and Galleries**

The aforementioned UK heritage organisations reporting *C. longicaudata* in their buildings are based in urban locations. It is also observed that the occurrence of this agile insect is sustained and widespread in buildings with significant food sources, and appears capable of locating in close proximity to food sources (Sellenschlo, 2007). This is demonstrated with reference to the side front basement at the London Library, the Brotherston Library and Special Collections building in Leeds, and the Group B locations at MOL. Damage caused by *C. longicaudata* to paper has been observed, particularly papers with high cellulose and starch content. *C. longicaudata* is also capable of seeking out areas of high cellulose and starch content across single items. *C. longicaudata* has also been observed locating and thriving in areas with significant human activity (particularly those with harbourage opportunities), this is demonstrated with reference to the Parkinson Building, Leeds University Library, and Group A locations at MOL.

Populations of *C. longicaudata* are reported to thrive in buildings with significant food sources, mature insects live for two to ten years, with females producing 50 eggs per year (Landsberger and Querner, 2017; Meineke et al., 2014, Sellenschlo, 2007). At MOL this is despite the application of desiccant dust in a number of locations. University of Leeds Special Collections have reported a decrease in population size after the application of Constrain (permethrin) pesticide to the perimeter of two rooms. With reference to MWH and the Science Museum, in buildings with lower temperatures and fewer food sources, occurrence of *C. longicaudata* seems more sporadic, with population growth slowed.

The observations reported indicate that there is no link between elevated relative humidity and the occurrence of *C. longicaudata*, and that low temperatures could also be limiting population growth in the PPD Store at the MOL (despite its significant food source), and MWH.
Conclusion

The observations and IPM data reported indicates that in the UK, buildings containing paper-based collections located in urban areas are at greatest risk of *C. longicaudata* infestation and damage. Since *C. longicaudata* thrive in environments optimised for the long-term storage of collections, they cannot be controlled by improving the environment (i.e. identifying and remediating areas with elevated relative humidity) and therefore they pose a greater risk to collections than *L. saccharina* (Landsberger and Querner, 2017).

If the environment is favourable *C. longicaudata* populations are capable of becoming large and widespread, making containment and remediation of this insect pest particularly challenging. Grey silverfish have caused damage to conservation materials and collections, however as they are very mobile and have not been found living in/on the food source, object-by-object treatment has not been pursued as an effective remediation measure at MOL (Landsberger and Querner, 2017). This, coupled with the limited success of desiccant dust application (at MOL), has highlighted the importance of investment in programmes of building maintenance and robust pest-proofing measures, particularly for stores housing paper-based collections, objects and materials in transit, or collections stored with large quantities of acid-free tissue paper. For the management of this insect pest, preventative measures are proving critical. Building maintenance activities include vacuuming and sealing of wall-floor junctions, and pest-proofing measures include well-fitted and sealed doors and windows, seamless floors, sealed entry points for service pipes/cabling and ducted air, high efficiency filters in air conditioning systems and double-sided tape at thresholds (Landsberger and Querner, 2017).

The *C. longicaudata* population in the Transit Store highlights the need for museums to implement robust quarantine procedures; a dedicated quarantine facility is currently under construction at MOL. It is possible that *C. longicaudata* arrived at MWH from MOL via an internal transfer. Where feasible, large organisations with multiple sites should consider quarantining internal as well as external transfers.

The importance of housekeeping in operational areas of museum buildings has also been highlighted. The Paper Conservation Studio and Photography Studio at MOL currently has limited provision of pest-proof storage and disposal solutions for vulnerable conservation and photography materials, particularly those that have a requirement to be stored in the dark rendering them even more attractive to grey silverfish (Landsberger and Querner, 2017). Improved housekeeping measures are being implemented at MOL to prevent population growth.

A method of normalising insect counts in order to more objectively compare populations in buildings with variable trap densities has been trialled. Normalising insect counts is a possible solution to periods of variable data collection, as opposed to a methodology museums should adopt over the actual deployment of traps to a consistent density. The Collection Care team at MOL will be reviewing the placement of insect traps with a view to establishing a consistent trap density. Where this is not possible (i.e. for stores and galleries which vary greatly in size), a normalisation method will be developed further and introduced to the IPM database.

Through collaborative working and data analysis, the Collection Care team at MOL have a much deeper understanding of the occurrence and behaviour of *C. longicaudata*. As a result, priority areas for building maintenance, improved housekeeping and the implementation of pest-proofing measures have been identified, and resources more effectively targeted.

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Knoop, L., 2016. There is more to the Zygentoma. Poster at the 3rd International IPM Confer-


Remote Sensor Technology for Rodent Surveillance in Museums: Trial Program at the American Museum of Natural History

Abstract
As all those involved in collection care know, mice and rats pose significant threats to artifacts and biological specimens in museums. Remote rodent monitoring technology (RRMT) developed in the last 15 years provides early detection of rodent pests and many associated advantages for museum integrated pest management (IPM) programs. These products are now available from numerous manufacturers, including large scientific corporations as well as smaller entrepreneurs.

The American Museum of Natural History (AMNH) in New York City is among the first museums to evaluate this new technology in a large, structurally complex, functionally diverse institution. Outcomes of the AMNH trials provide insights into key criteria for assessing these systems and demonstrate the role of early detection alerts in better protecting museum artifacts from pest attacks. We observed increases in efficiency of routine trapping, opportunities for strategically investigating known or suspected activity, and a shift toward more environmentally sensitive trapping methods.

Keywords: remote pest monitors; electronic rodent sensors; vertebrate pest management

Remote rodent monitoring technology
Rodent pests that invade our cities and buildings tend to be both secretive by nature and most active when people are inactive (i.e., nighttime), often allowing them to escape attention. By the time we are aware that a rodent invasion has occurred, damage is already taking place. For museums and other highly sensitive facilities, any tardiness in detecting these destructive pests can be expensive and even disastrous.

Remote rodent sensor technology was invented in 1999, and in 2002 the Liphatech Corporation patented the Electronic Pest Management System and Method. These early sensors were designed to provide detection of rodent activity without the presence of monitoring staff. Advances in remote sensor technology and applications for biology and wildlife emerged over the next 15 years or so (e.g., Baharudin and Yan, 2016; Handcock et al., 2009; Kim et al., 2010; Mochizuki and Murakami, 2014; Ropert-Coudert and Wilson, 2005). Now in 2019, it continues to evolve in its use for rodent pest management applications (Corrigan, 2018). Herein, this technology is referred to as Remote Rodent Monitoring Technology (RRMT).¹

RRMT is similar in design and operation to systems developed for home security. Occurrences of rodents in or around a structure are monitored remotely, and notifications are issued in the same way that security break-in alerts are issued to the local police station. Since the first prototypes, RRMT has evolved to include multiple manufacturers offering varied capabilities depending upon the level of sophistication needed by a client.

Generally speaking, most remote monitors employ one or more sensors that detect rodents
through their movement, their touch, or their activation of a trap. Upon being triggered by a rodent, the sensor transmits an alert to a remote cloud server via either a property's WiFi system or a cellular data connection (with or without an intermediate network of cellular gateway hubs). By mid-2019, some manufacturers will be releasing technology that uses Bluetooth to send alerts to a designated smart phone. Alert data can be gathered and summarized according to each monitor's location, facilitating data compilation across rooms, floors, or an entire building.

Applications of rodent remote monitors in museum collections

For museums and other cultural heritage institutions, rodents present a danger to human health as carriers of disease, and to collections of objects that may be damaged by gnawing, consumed as nutrition, shredded for nesting materials, or stained with urine (Corrigan, 2011). Furthermore, the carcass of a dead rodent, whether in a neglected trap or a wall void, becomes an attractant and a food source for insect pests that can quickly destroy nearby collections (Bruesch, 2011). The advent of RRMT is a “game changer” because it can be configured to provide enhanced protection for virtually any kind of collection within a museum of any level of complexity and size.

Remote rodent monitoring enables around-the-clock, proactive monitoring throughout a facility, with particular value in

• artifact/object storage spaces where rodents can move into cabinets, boxes, crates, and other housings;
• hard-to-reach but highly vulnerable interior spaces such as ceilings, wall and floor voids, utility chase risers and basement tunnels;
• outdoor landscaping and exterior perimeter walls where, for example, rodents are often drawn to refuse staging and delivery doors.

The economic benefit of proactive remote monitoring cannot be overstated. Currently, without the use of RRMT, many hours are inefficiently spent performing routine checks of rodent traps. By most industry estimates, upwards of 95 percent of that time is spent servicing rarely-visited (i.e. empty) traps. Improved efficiency makes more time available to complete inspections and other IPM efforts elsewhere.

Further, RRMT provides immediate notification of any new rodent infiltration into a monitored space. Once an alert has been issued, communication with all IPM partners can be quickly enacted (e.g., pest professionals, custodial, maintenance personnel, administrators, etc.). They can then make a more detailed investigation and plan for a resolution. Rodent carcasses can be removed promptly, which reduces the risk of secondary insect invaders further threatening collections (Bruesch, 2011).

Remote monitoring can also assist in profiling overlooked or unknown structural faults and disrepairs that require rodent-proofing to prevent ongoing infestations. Operational issues requiring management intervention (e.g., doors being left open at night, sloppy use of refuse containers drawing rodents to the property, clutter providing harborage for mice, etc.) can promptly be detected and rectified.

When RRMT is interfaced with an IPM or pest control data management solution, integrated data tracking is possible. Such integration can further boost efficiency because pest control managers, contractors, facility personnel, and others may be provided with convenient summary reports of progress, hot spots, and evaluations of possible causal conditions. This information can aid in setting priorities and allocating resources.

Remote rodent monitor trial program at the American Museum of Natural History

Between 2017 and 2019, the American Museum of Natural History (AMNH) in New York City tested a selection of remote rodent monitor (RRM) devices. The goals of this trial program were to identify criteria that are important for assessing and selecting RRMT for a particular trapping environment and to qualitatively evaluate these criteria against the challenges of a museum like the AMNH, i.e. a large, complex institution with an assortment of use patterns.

The AMNH comprises 1.8 million square feet and is composed of 27 interconnected structures, built over 140 years. It includes 20,000 square feet of kitchen and restaurant space, a butterfly vivarium, classrooms, high-traffic areas where pest traps are regularly disturbed, low-activity areas
where pests may go unnoticed, and exhibit halls where refreshments accompany special events. Drop ceilings, false walls, platform floors and hidden voids are abundant throughout. These areas are difficult to access and are not routinely monitored or inspected.

The museum is situated within Theodore Roosevelt Park, an urban landscape that harbors house mice and Norway rats. Numerous perimeter doors present potential points of entry. The Park is owned by the City of New York, requiring the AMNH to partner with the Department of Parks and Recreation to manage pests beyond the zone immediately surrounding the museum.

The AMNH employs one full-time pest control manager responsible for control of insect and vertebrate pests. Though the museum is fortunate to have this expertise on staff, the fact remains that it is a huge area for one person to cover. With approximately 500 rodent trap locations across the facility, the time-cost to checking traps is very high. Upgrades that increase the efficiency of routine trapping and expedite investigations of known or suspected activity also allow more resources to be devoted to preventive activities.

The AMNH trial program included six different models of RRM devices currently on the market (Table 1, Figures. 1–6). Other manufacturers offer monitors that we were not able to include. Remote monitors were deployed in approximately 200 locations with a history of rodent activity and tested for periods of six to 24 months.

### Wireless network compatibility and ease of installation

Several modes of network connectivity were represented by the assortment of devices trialed, including WiFi and cellular data (the latter with and without a dedicated network of gateway hubs set up onsite). Monitors that connected directly to existing cellular data or WiFi infrastructure could quickly be deployed in a stand-alone fashion anywhere that sufficient signal strength existed. These systems could then be extended on an ad hoc basis where network coverage was available. RATMO, a cellular device, was deployed with minimal configuration. While in the past we have found that security settings on our institutional WiFi network can complicate the connection of stand-alone devices (such as environmental dataloggers), the EZ Square WiFi monitors were also deployed with ease. However, WiFi network settings are input to these monitors during activation, so in the event that later changes require the settings to

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**TABLE 1. Remote rodent monitors represented in the AMNH trial program.**

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Model</th>
<th>Network</th>
<th>Hub / Stand-alone</th>
<th>Trap/Station Compatibility (as tested)</th>
<th>Target Animal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arctic Systems</td>
<td>RATMO (Fig. 1)</td>
<td>Cellular</td>
<td>Stand-alone</td>
<td>Snap, bait station</td>
<td>Rat</td>
</tr>
<tr>
<td>Bayer Environmental Science</td>
<td>Rodent Monitoring System (Fig. 2.1 and 2.2)</td>
<td>Cellular</td>
<td>Hub</td>
<td>Multi-catch (snap trap retrofits were not trialed)</td>
<td>Mouse</td>
</tr>
<tr>
<td>Corteva Agriscience</td>
<td>ActiveSense NC1 (Fig. 3)</td>
<td>Cellular</td>
<td>Hub</td>
<td>Snap, bait station</td>
<td>Rat/Mouse</td>
</tr>
<tr>
<td>Corteva Agriscience</td>
<td>ActiveSense A1R1 Beta (Fig. 4.1 and 4.2)</td>
<td>Cellular</td>
<td>Hub</td>
<td>Multi-catch, snap, bait station, runways (no trap)</td>
<td>Rat/Mouse</td>
</tr>
<tr>
<td>VM Products</td>
<td>EZ Square Mouse (Fig. 5)</td>
<td>WiFi</td>
<td>Stand-alone</td>
<td>Snap</td>
<td>Mouse</td>
</tr>
<tr>
<td>VM Products</td>
<td>EZ Square Rat (Fig. 6)</td>
<td>WiFi</td>
<td>Stand-alone</td>
<td>Snap, bait station</td>
<td>Rat</td>
</tr>
</tbody>
</table>
FIGURE 1. RATMO, manufactured by Arctic Systems and provided by Insects Limited Inc. Photo: Julia Sybalsky.

FIGURE 2.1 & 2.2. Rodent Monitoring System, manufactured and provided by Bayer Environmental Science. Photo: Julia Sybalsky.

FIGURE 3. ActiveSense NCs, manufactured and provided by Corteva Agriscience. Photo: Julia Sybalsky.

FIGURE 4.1 & 4.2. ActiveSense AIR1 Beta, manufactured and provided by Corteva Agriscience. Photo: Julia Sybalsky.
be updated manually, it would take a long time to visit each monitor in a large and widely distributed array like ours.

It was found that due to the thick masonry and steel construction of the AMNH, the building envelope presents formidable limitations to the widespread use of any device that is dependent on a wireless network of any kind. Cellular data and WiFi coverage are inconsistent and do not extend to all of the areas in which rodent traps are used. Where these signals were weak, stand-alone monitors could not communicate reliably.

ActiveSense and Bayer RMS hub systems successfully addressed these drawbacks, but at the expense of setup time. Both relied on a network of cellular gateways installed prior to trap deployment. The time investment required to setup and troubleshoot a gateway network is proportional to the complexity of the site and should not be underestimated. The payoff for this effort was a dedicated network that provided coverage everywhere it was needed and could be extended going forward. Once that network was in place, monitor deployment was simple and efficient.

Because hub systems required an initial site assessment process and at least one subsequent site visit to establish network coverage, technical representatives from Corteva and Bayer were actively engaged in product installation and troubleshooting. Open and ongoing communication and collaboration between the pest control manager, museum staff and technical support were essential for the operation of these systems at the AMNH. The manufacturers of the stand-alone devices that we evaluated provided adequate documentation for us to deploy monitors on our own, and customer service was available if needed.

Compatibility of RRMs to various uses and environments

The AMNH pest management program relies on a range of snap traps, multi-catch live mouse traps (MCTs), and exterior bait stations to control rodent pests. None of the RRMs trialed were compatible with all of these traps. Most were compatible with standard snap traps and trap placements for mice or rats. These monitors were clipped, zip-tied, or otherwise attached to the trap, and were triggered by vibration, movement, or a change in position of the trap.

In high-traffic areas, rodent trap covers or trap stations were often needed to protect traps from human disturbances (i.e. a broom, a kick, etc.) that could trigger a false alert. The compatibility of each RRM with different covers sometimes impacted its suitability for a particular space. For
example, in a busy operational corridor, we found that remote-monitored snap traps were being triggered daily when inadvertently bumped by working staff. However, the slim-profiled trap cover supplied with the EZ Square Mouse solved this problem: it was narrow enough to fit into a gap behind a row of stanchions, protecting it from disturbance and significantly reducing the number of human-generated false alerts.

Bayer’s RMS and Corteva’s ActiveSense AIR1 Beta are both designed specifically for MCTs. MCTs vary in size and shape, but all of them incorporate a mechanism that confines successive mice in a chamber after they pass through a narrow entry point. Because they can capture a dozen or more mice at any particular deployment, MCTs offer high efficiency for a pest professional’s time, particularly in large facilities like the AMNH. The monitors we trialed fit into or onto the MCT. Bayer’s RMS was compatible with one particular style of MCT, while the AIR1 had near-universal compatibility. Both incorporate an ability to distinguish between human disturbance and true rodent capture, which successfully reduced false positive alerts being generated. Combining MCTs with remote monitors naturally leads to a situation in which a pest professional who responds promptly to a capture alert may come upon one or more live mice that will try to escape when the trap is opened. In our trials, we followed the pest industry’s standard practice of deploying flat glueboards (not glue trays) inside the MCTs, rendering any MCT with captures much easier to service.

Snap traps can also be configured for efficiency (but to a much lesser degree) by setting up several snap traps under a single trap cover. The ActiveSense NC1 and EZ Square Mouse were compatible with this technique and could each be coupled with two traps simultaneously. However, we observed that in most cases, the force of the first snap trap capture sprang the second snap trap, negating the multi-catch functionality.

In an incrementally built facility like the AMNH, it is important to monitor hidden voids when looking for the source of a problem or after taking action to exclude rodents. We trialed both ActiveSense models in these constricted, inaccessible spaces, and found that they provided a significant time savings benefit. The AIR1 Beta can be deployed without a trap or enclosure for monitoring rodent trails and runways in out-of-the-way places, but utilizing this capability required a precise understanding of where activity was located because the sensor detects movement at close range. Coupling RRM with a motion-activated IR wildlife camera in these spaces provided video confirmation and valuable detailed information about the nature of activity.

On the exterior of the museum, the AMNH employs rodent bait stations and rodenticide baits to reduce rodent populations, protect the perimeter of the facility, and locate concentrations of activity (Corrigan, 2001). Due in part to resident birds of prey that feed on urban rodents, there is a strong push to move away from rodenticidal baits towards non-toxic approaches. To this end, we were able to replace the rodenticide bait in many of our exterior stations with remote-monitored snap traps. Most of the devices we trialed were designed for indoor/outdoor use and could be deployed in this way. Snapped traps could be promptly emptied and reset, repositioned, or added in areas of concern. A reduction in bait used outside the museum means fewer poisoned rodents dying inside the museum and improves the health of the park and the urban ecosystem.

Data management, visualization and analysis

Data associated with the RRMT systems we trialed was accessed and manipulated through an internet browser or mobile device application. These digital platforms supported the deployment and maintenance of monitors but provided limited support for analyzing and/or reporting capture data. This shortfall reflects the fact that RRM manufacturers are under pressure to design products that interface with existing third-party software (e.g. PestPac, Briostak) commonly used in the commercial pest management sector rather than to develop comprehensive stand-alone data solutions.

Integrated pest management requires analyzing trends in data from one or more locations over time (Sawyer and Casagrande, 1983; Parsons et al., 2019). Nearly all of the digital platforms we trialed included basic capabilities for visualizing data, though they lacked advanced filtering tools (i.e. captures by department, floor, etc.). While these applications could record technician service notes such as the number, species, sex, and age of
RRMT is naturally aligned with the internet of things (IoT) and Smart City initiatives that use information from various networked data collection devices to manage resources for maximum operational efficiency in urban environments.

Conclusions and recommendations

Remote rodent monitoring systems offer exciting benefits, but vary in their network connectivity, ease of installation, trap and cover compatibility, and in the functionality of their respective data platforms. Some of the systems we trialed were a better fit for the AMNH than others, but the needs of other institutions will differ, and should be considered systematically when evaluating RRMT for possible use. Be sure to consider the following:

• What type of rodent(s) are you targeting? Choose monitors for rats, mice, or both.
• What kind of wireless network coverage is available in your trapping areas? If existing WiFi or cellular signal strength is good, stand-alone monitors are simple to set up. Hub systems provide consistent coverage where it is needed but require more time to install.
• How many monitors do you need? The effort of installing a hub system may not be justified if only a few monitors are needed.
• What type of traps and enclosures are suitable for your facility, and where are they used? Systems vary widely in their compatibility. Realizing the benefits of greater versatility requires greater engagement with the system on the part of the pest control operator.
• How important are mapping tools to keeping track of your trap inventory, and for communicating trap locations to affiliated pest professionals? Mapping to digitized floorplans is important for discriminating trap locations in large multi-level facilities.
• How do you organize and analyze capture data? Digital platforms provide limited integrated functionality for analyzing and reporting data, but some systems chart trends or allow users to export datasets in standard formats that can be manipulated in other applications or archived. Location hierarchies used by different RRMT platforms may suit some approaches to data organization better than others.
Presently, many pest management professionals still have very limited familiarity with RRMT. Whether or not a museum administers an in-house pest management program or contracts it out, remote rodent monitoring will be most successful with committed on-site staff who are engaged, have a stake in the success of the system, and are readily available for troubleshooting. Because timesaving is perhaps the single greatest benefit of RRMT, the implementation of any RRM system should reflect an institution's goals for taking the greatest possible advantage of those savings.

**Materials**

ActiveSense AIR1 Beta, Corteva Agriscience, a division of DowDuPont
ActiveSense NC1, Corteva Agriscience, a division of DowDuPont
EZ Square Mouse, VM Products
EZ Square Rat, VM Products
RATMO, Arctic Systems
Rodent Monitoring System, Bayer Environmental Science

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**References**


**Endnotes**

1 Various terms and acronyms continue to emerge for Remote Rodent Monitoring Technology (RRMT) including remote rodent monitors (RRMs), remote rodent sensors (RRS), electronic rodent sensors (ERS), electronic remote monitor devices (ERMDs), remote pest monitors, and others. Most of the terms however are synonymous and may simply depend on the particular manufacturer’s terms for the devices. In general, the term “remote pest monitors” will likely be the universally employed terms for this technology since their use is quickly being developed for a wide range of insect, rodent, bird and wildlife pests.
Long Lasting Insecticidal Netting as a Potential Form of Museum Pest Control: Effectiveness and Safety of Alphacypermethrin Impregnated Polyethylene Mosquito Netting for Pest Management of Clothes Moths (*Tineidae*) and Carpet Beetles (*Dermestidae*)

**Abstract**

Long Lasting Insecticidal Netting (LLIN) has been used successfully as a barrier against pest migration in museum and art storage settings (Nicosia et al., 2016, p. 46). This interdisciplinary research project aimed to further characterize the efficacy, safety, and feasibility of using alphacypermethrin LLIN in a museum IPM program. Laboratory testing was completed on webbing clothes moths (*Tineola bisselliella*) and cabinet beetle (*Trogoderma inclusum*). LLIN proved to be lethal to adult and larval stages of these museum pests on wool encased with LLIN and on wool interleaved with LLIN. Materials analysis of three brands of LLIN was completed through Oddy testing and gas-chromatography-mass spectroscopy (GCMS). Results suggested the netting may be safely used in proximity to museum collections on a temporary basis. Field studies were performed to evaluate the use of LLIN in the practical settings of a collections storage facility and at a historic house museum site. The field studies showed an interruption of the movement of adult webbing clothes moths and carpet beetle larvae after deployment of LLIN in areas of documented infestation.

**Keywords:** webbing clothes moth, *Tineola bisselliella*, varied carpet beetle, *Anthrenus verbasci*, cabinet beetle, moth, beetle, alphacypermethrin, cypermethrin, pyrethroid, insect net, long-lasting insecticidal net, LLIN, museum storage, museum collections, historic house museum, integrated pest management, IPM, Oddy Testing, GCMS volatiles analysis

**Introduction**

Protein eating insects common to the north-east region of the United States such as webbing clothes moths (*Tineola bisselliella*) and varied carpet beetles (*Anthrenus verbasci*) present significant challenges to museums (Pinniger, 2015). Integrated Pest Management (IPM) programs within museums often encompass active and passive methods of control, including monitoring, cleaning, quarantine, and de-infestation of collections objects by multiple methods, although use of pesticides is done with great caution (Pinniger and Myer, 2015 pp. 18, 27).

Long Lasting Insecticidal Net (LLIN) is manufactured and sold for the control of malaria transmission by mosquitoes (WHO, 2014). This net has been tested successfully as protective packaging of non-infested museum objects (Nicosia et al., 2016, p. 46), and permethrin insecticides like those used in LLIN have been investigated to control pests in museum contexts (Pinniger, Morgan, Child and Langford, 1994, p. 24). However, there has not
been an in-depth investigation into using LLIN to control active pest infestations on a large scale as part of a holistic IPM strategy in museums.

This paper presents the interdisciplinary research undertaken to determine the feasibility, efficacy, and safety of LLIN in museum settings. Entomological efficacy of LLIN at controlling specific species known to damage common museum objects was completed. Materials analysis was performed to determine the safety of using LLIN in proximity or contact with museum collections. Field studies were carried out to explore the logistics of deploying LLIN as part of a wider IPM strategy in a museum context.

**Laboratory Testing**

**Materials**

*Long-Lasting Insecticidal Net (LLIN)*

LLIN is used widely for the control of insectborne illness on a global scale. The production of LLIN is tightly controlled by the World Health Organization (WHO) and must be made of 100 percent polyethylene-fiber net manufactured with the insecticide permethrin (WHO, 2014). LLIN is effective only through direct contact with insects. The following brands of LLIN were evaluated: Duranet®, Pramex™, and Royal Sentry®. Exploratory surface pH testing of the three LLIN with Fisherbrand™ color-fast pH strips showed a neutral pH (Tse, 2007), indicating suitability for further testing.

*High-Density Polyethylene (HDPE)*

LLIN is produced with high-density polyethylene (HDPE) (WHO, 2014), a thermoplastic hydrocarbon (\((C_2H_4)_n\)) polymer in the class of polyolefin plastics. The polymer is known for high tensile strength and resistance to acids, bases, and oxidizing agents, and appears in its pure state as a translucent-to-white plastic (Waentig, 2008, pp. 291–301).

**Alphacypermethrin**

Alphacypermethrin (\(C_{21}H_{20}Cl_2NO_3\)) is a specific molecular formation of permethrin insecticides that are a commonly used to control an array of domestic and agricultural insects. For LLIN, alphacypermethrin is mixed with the polyethylene before spinning into fiber, so the insecticide is not located solely on the exterior of the net but is also contained within the polymer matrix. This allows it to move to the surface over a period of years to maintain efficacy (WHO, 2014). Alphacypermethrin is toxic to insects, causing mortality through direct physical contact with the insecticide. It has low toxicity for humans and other mammals, although it has higher toxicity for aquatic life (Pyrethroids Resource Center, 2018). Human toxicity exposure comes through direct skin contact, so it is recommended that safety-data-sheets of specific products are understood to assess handling hazards.

**Insect mortality testing**

To test the mortality efficacy of the netting on museum insects, three species of insects during mobile life stages were introduced in close proximity to all three brands of LLIN, and checked for survival over time. Adults and larvae of the species cigarette beetle (*Lasioderma serricorne*), webbing clothes moth (*Tineola bisselliella*), and the dermestid warehouse beetle (*Trogoderma variabile*) were introduced into an enclosed space containing a sample of 18 cm X 12 cm X 0.2 cm, processed, 100 percent wool from a sweater purchased at a thrift shop, wrapped in LLIN. The LLIN was cut to 38 cm X 14 cm X 0.1 cm and completely covered the wool sample.

Ten live insects of each species were used in the individual studies. The larvae of each species ranged from early to late molting-stages of development. Live insects were applied directly onto the wool and the LLIN was placed over the sample using a gloved hand. The wool and netting materials were placed into resealable, Ziploc®-style plastic bags that were 17.5 cm X 31 cm for the duration of the study (Figure 1). Control tests of the three insect species and wool samples, without LLIN, were also carried out (Figure 2). Insect mortality counts were made daily based on complete lack of insect movement. All tests were performed over a one-month period at a temperature of 20–23 °C and 30–45 % relative humidity (RH).

**Oddy Testing**

Oddy testing of all three brands of LLIN was completed at the Metropolitan Museum of Art (The Met). Tests were run in duplicate with duplicate controls for comparison using The Met’s Oddy testing and interpretation protocol version.
pest breeding and movement in the region with temperatures between 20–35 °C (Child, 2007). Sticky traps baited with webbing clothes moth pheromone and dermestid food lures were used to determine efficacy of the net at containing the movement of the insect species.

Collections storage testing
The first test site was within the Historic New England’s Haverhill storage facility. Occupied as a storage facility since 1988, the 1912 eight-story poured-concrete building has been retrofitted with modern environmental systems, insulation, and weatherproofing. The environmental conditions are modified and monitored throughout the building with some seasonal fluctuations. Pest monitoring is undertaken using sticky traps baited with pheromone and food lures.

An area of collections storage, with known webbing clothes moth activity, was chosen as a testing zone. This area contained dense storage of wool, feather, and silk textiles. Prior to testing, six moths were counted in the sticky trap near the test zone over a period of two months.

LLIN was deployed to entirely encapsulate the shelving units, using 804 m² of net to cover standard pallet rack system with 1.2 m x 2.4 m shelves occupying a 663 m² footprint. A new, refreshed pheromone trap was placed outside of the LLIN testing area and was monitored weekly for another two months from August through September.

Gas Chromatography Mass Spectrometry (GCMS)
Volatile analysis was performed using solid-phase micro-extraction GCMS using a LEAP RTC-PAL auto-sampling arm for heating, sampling, and injection into an Agilent 7890B/5977 GCMS system fitted with an Agilent HP-5MS-UI and cryotrap. A 1.1 mm diameter Carbon WR/PDMS SPME Arrow was exposed for 20 minutes at 60 °C to the headspace of a sealed 20 mL GCMS vial with 0.3 g of netting that had been pre-heated for 20 minutes at 60 °C. The fiber was injected and allowed to desorb for 2 minutes at 350 °C onto a -15 °C cryotrap. Oven method: 40 °C for 3 min, ramped to 250 °C at 10 °C/min, held at 250 °C for 5 min. Mass Spectrometer: scanned 12-475 mass units. Data analyzed using Agilent’s MassHunter Qualitative Analysis software vs. B.07.00 SP2 and the NIST 2017 electron ionization mass spectral library.

Feasibility Study of LLIN in Museum Setting
Historic New England deployed LLIN as a containment method for museum storage shelving units infested by webbing clothes moths, and one individual object infested with varied carpet beetles in a historic property. These tests were run at two different sites between the months of June and September, which represent the height of active pest breeding and movement in the region with temperatures between 20–35 °C (Child, 2007). Sticky traps baited with webbing clothes moth pheromone and dermestid food lures were used to determine efficacy of the net at containing the movement of the insect species.

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Single object containment

The single object containment test was conducted at Historic New England’s Beauport, the Sleeper-McAnn House, built in 1907. Beauport is open in the summer, with limited environmental controls. The average 2018 summer-season was 24 °C and 65 percent RH. The house is furnished with a large collection of textiles and upholstered furniture. The property has had significant, complex IPM issues involving several species over the years. Weekly monitoring and data collection of sticky traps for pest activity is routinely done throughout the spring, summer, and fall.

In Beauport Blue Willow room, a sticky trap baited with beetle pheromone and food presented 11 dermestid beetle larvae in one week. The trap was located between a wool upholstered chair, and a bed. The bed had no visibly active infestation with no recorded previous infestation history, however it did contain a feather pillow as a potential new infestation site. The chair had a known history of infestation, treatment and re-infestation, and dermestid beetle larvae were visible on the chair after inspection.

LLIN bed netting with stitched seams was draped over the chair in direct contact with the fabric and tucked under to completely encapsulate the object. A new sticky trap baited with pheromone and food lure was placed between the chair and the bed and monitored weekly for two months.

Results and Discussion

Laboratory insect mortality testing

The results in the following tables are based on a daily visual check of insect mortality over a 1-month exposure period.

All exposed adults and larvae of the webbing clothes moth died within one week of direct-contact exposure to LLIN. Cigarette beetles survived longer than the clothes moths in general. Cigarette beetles ingest tobacco products (Mahroof and Phillips, 2008) and are likely tolerant to some insecticides. Warehouse beetle adults all died within a week of being exposed to LLIN, however some of warehouse beetle larvae lived for more than two weeks after exposure. The larvae of *Trogoderma* species have dense hairs on their bodies (Ahmedani et al., 2007), which could possibly be preventing the insect larvae from having direct dermal contact with the pesticide netting that is needed for toxicity.

In general, the insects on the control wool survived longer than their counterparts in the LLIN tests. The warehouse beetle larvae and the webbing clothes moth larvae had survivors on the non-insecticide control test at the completion of the trial. The mortality numbers from this study suggested that tested brands of LLIN are effective at killing museum insects that come in direct contact with it.

Materials analysis of LLIN

Oddy test results combined with GCMS volatiles analysis allowed for a comparison of the suitability of the three brands of LLIN for suitability of use around art objects. The Oddy test overall results for all three brands of LLIN were similar, with all three brands rated as ‘temporary for use.’ The GCMS volatiles analysis was used to further understand what compounds in each net might be responsible for the corrosion or films produced on the Oddy coupons.

Oddy Testing

Oddy test coupons were used to detect volatile compounds released from materials to determine a material’s suitability for use around museum objects. Copper coupons are used to detect acids, aldehydes, chlorides, and sulfides. Silver is used primarily to detect sulfides and chlorides, and lead for detection of acids and aldehydes (Thickett, 2004).

The corrosion or film observed and rated according to The Met Oddy protocol are outlined in the table and images below (Table 2 and Figure 3). The ratings refer only to the hanging coupons, where all copper and lead coupons were ‘temporary for use’ (T). The silver coupons, despite having film growth were rated ‘permanent for use’ (P). No coupons were given an ‘unsuitable’ (U) rating. The in-contact coupons showed similar or slightly worse corrosion than the hanging coupons in all cases.

Previous investigation at The Met showed that a beige or white film on silver coupons can be attributed to a contaminant found on the silver from the manufacturer (Fine Metals Inc.). These films were not corrosion products which are typically yellow, purple, or black, and films were seen
TABLE 1. Graphic representation of insect mortality on three species of museum pests exposed to LLIN versus mortality on experimental controls.
TABLE 2. Corrosion and film descriptions with Oddy ratings for each brand of LLIN.

<table>
<thead>
<tr>
<th>LLIN</th>
<th>Copper</th>
<th>Silver</th>
<th>Lead</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duranet®</td>
<td>Red tarnish, diffuse light haze (T)</td>
<td>Haze from white film (P)</td>
<td>Darkening, white compacted corrosion at lower edges (T)</td>
</tr>
<tr>
<td>Pramex™</td>
<td>Rainbow tarnish and red tarnish (T)</td>
<td>Beige haze producing crystals (P)</td>
<td>Heavy darkening (T)</td>
</tr>
<tr>
<td>Royal Sentry®</td>
<td>Red tarnish, small areas of light haze (T)</td>
<td>White compacted film, thicker at lower edge (P)</td>
<td>Darkening, blue tarnish at edges (T)</td>
</tr>
</tbody>
</table>


Royal Sentry® Hanging coupons
Diffuse lighting: Glancing angle lighting:

In contact coupons – contact side in view:
containing compounds, which have the potential to tarnish silver during Oddy testing. The lack of silver tarnish on the Oddy test coupons for all three materials indicates that those compounds are unreactive and not of great concern.

Alphacypermethrin and its acid hydrolysis products were not observed. Only one very small signal in the Pramex™ sample was likely a di-chloro-alkene, which is also a component of alphacypermethrin, however, positive identification of the compound’s structure was not possible.

The differences between levels of acids, aldehydes, and esters for the three brands of LLIN were not significant. The similarities were borne out in the Oddy test, where the copper and lead coupons showed similar levels and types of corrosion for all three brands.

None of the acids found in the GCMS correlate to alphacypermethrin degradation products (Jones, 1999). GCMS experiments were run in small sealed vials, so access to water and oxygen were minimal and the length of exposure at 60 °C was minimal (≤ 1 hour). Alphacypermethrin degrades in the presence of water and oxygen (Jones, 1999), so more acids would be expected in the Oddy test (28 days at 60° C) and some atmospheric conditions. Acidic, oxygen-rich and humid environments increase the likelihood of damage only when enough acids and other reactive compounds are present, as confirmed by lack of visible film on control samples.

The films from on silver showed trace cyano compounds that did not match the known carbon-nitrogen triple-bond component of alphacypermethrin for Duranet® and Royal Sentry®, but not Pramex® (Jubert, et al., 2007, pp. 1208–21). This suggests that the volatile compound observed to be either depositing on the silver or absorbing in the contaminant film were not alphacypermethrin but were possibly a degradation product or bi-product from pesticide production for Duranet® and Royal Sentry®.

GCMS testing

The main chemical classes of concern for museum object safety are acids, sulfides, chlorides, aldehydes, amines, esters, and plasticizers. GCMS volatiles analysis identified acids, aldehydes, chlorinated organics, and esters in all three materials with aldehydes and esters generating the most signal in each (Table 3). Acids and chlorinated organics accounted for much less of the GCMS chromatogram and appeared in similar quantities across the three brands. Alphacypermethrin contains a dichloro-alkene compound, and GCMS data for each LLIN shows the presence of chlorine-containing compounds, which have the potential to tarnish silver during Oddy testing. The lack of silver tarnish on the Oddy test coupons for all three materials indicates that those compounds are unreactive and not of great concern.

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<table>
<thead>
<tr>
<th>Compounds</th>
<th>Duranet® Total Peak Area</th>
<th>Number of Compounds</th>
<th>Pramex™ Total Peak Area</th>
<th>Number of Compounds</th>
<th>Royal Sentry® Total Peak Area</th>
<th>Number of Compounds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acid</td>
<td>888,476</td>
<td>3</td>
<td>612,084</td>
<td>2</td>
<td>1,421,198</td>
<td>4</td>
</tr>
<tr>
<td>Aldehydes</td>
<td>29,855,357</td>
<td>12</td>
<td>34,126,189</td>
<td>9</td>
<td>27,432,216</td>
<td>7</td>
</tr>
<tr>
<td>Organic chlorides</td>
<td>851,522</td>
<td>4</td>
<td>2,614,499</td>
<td>5</td>
<td>1,367,550</td>
<td>4</td>
</tr>
<tr>
<td>Esters</td>
<td>11,359,583</td>
<td>10</td>
<td>11,881,635</td>
<td>7</td>
<td>7,740,612</td>
<td>8</td>
</tr>
<tr>
<td>Plasticizers</td>
<td>2,306,360</td>
<td>2</td>
<td>229,018</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
FIGURE 4. The Haverhill collections facility test, showing LLIN draped over shelving units known to be infested with webbing clothes moths. Photo: Adam Osgood, 2018.

FIGURE 5. The Beauport test site, using LLIN draped over a single object known to be infested with dermestid carpet beetles. Photo: Megan Creamer, 2018.
through acid hydrolysis of many museum objects that are also attractive to pests, such as fur, silk, feathers, leather, as well as cotton, woody fibers, and other materials (Timár-Balázs and Eastop, 1998, pp. 19–56).

The presence of phthalate plasticizers was most evident in Duranet®. Pramex™ showed minimal evidence for volatile plasticizers, and Royal Sentry® showed no GCMS signal for plasticizers. In the case of LLIN, it is likely that not only is the pesticide meant to migrate to the surface over time, but plasticizers and other small molecules within the HDPE net may also migrate to the surface of the fiber and possibly transfer to museum objects.

Field Testing
Supplied on a roll, or as pre-stitched bed drapes, LLIN was ready to use and quickly covered shelving units or individual objects. Cost and access to LLIN was a limiting factor in field testing, resulting in testing of only two brands. Duranet® was not marketed in the USA, but was available to be purchased in significant quantities through online auction at reasonable prices. Royal Sentry® was available for purchase in bulk at cost for this study, shipped directly from the manufacturer in China. Pramex™ was available as a consumer product in the USA at significantly higher costs.

In terms of feasibility for long-term or high-volume usage, Pramex™ was thought to be out of price range and was not pursued for testing. Total cost of Duranet® and Royal Sentry® used for the two tests was under 300 USD.

Sticky traps placed outside of the LLIN testing zone in the Haverhill storage facility showed zero pests trapped outside of infested shelving units or objects after containment with LLIN (Figure 4). A new webbing clothes moth pheromone trap attracted zero moths for the months of August through October after deploying LLIN compared to a count of six just prior to deployment. At Beauport, a new beetle pheromone and food lure trap was placed between the chair and the bed for continued monitoring after encapsulation of the chair in LLIN (Figure 5). In the subsequent weekly monitoring of the trap, zero beetle larvae or adults were seen for the next two months. Without deployment of LLIN these known infestations would have been expected to spread to other adjacent collection objects. The LLIN appeared to provide a quick and easy containment method for several months during the most active breeding cycles of the pests studied.

Risk to collections and staff
The results of testing at the Haverhill storage facility and Beauport were positive. The deployment of LLIN over large shelving units of mixed-material objects, presented very low risk to the collection, given the multiple barriers of acid-free storage materials and space between objects and LLIN. No microclimate effects or visible changes to objects were detected. For the single object in direct contact with LLIN, there was risk of exposure to the volatiles seen in Oddy and GCMS testing. No visual changes to the textile or wood components of the object were noted during weekly monitoring after several months. The use of LLIN as part of a temporary quarantine method is felt to be justified against the risks of active, damaging pest infestation.

While the manufacturer’s intended usage for the prevention of malaria is considered low-risk, some users in this study experienced mild skin reaction after cutting or handling the material. Personal protective equipment implemented during this study included nitrile gloves, long sleeves, and hand-washing after handling net, as well as particle masks and eye shields when cutting the net. Labels can be used to identify the LLIN in storage, with hazard warnings to ensure all staff are aware of the use of pesticide.

Conclusions
Entomological testing confirmed that LLIN was lethal to moth species and beetle species that damage museum collections. Materials testing by Oddy test resulted in a rating for ‘temporary use’ for all three brands tested. The copper and lead coupons in all tests were affected, and correlation with GCMS volatiles analysis indicated a possible cause was the presence of acids, aldehydes, and esters. Given the ‘temporary for use’ ratings, caution should be used in implementing the nettings near museum objects for more than six months, and more caution is advised when considering direct contact usage.

Field testing showed that LLIN was a cost-effective, low-tech, and easy to implement tool in settings common in many types of museums
across the world. Royal Sentry® had the highest ease of access to product direct from the manufacturer and lowest cost, but access and cost to brands of LLIN will vary internationally. In some scenarios, the risk of damage from uncontained, active pest infestations may be significantly higher than potential risk from LLIN. The use of LLIN provides fast, inexpensive containment before further IPM measures are implemented.

Future Research
There are still questions to be answered regarding the safety of LLIN in close proximity or direct contact with museum collections. Certain steps could be taken to mitigate the LLIN exposure risk that were not tested in this study such as barrier layers of Tyvek® or fabric to prevent direct contact with surfaces, or pre-washing the netting to remove readily soluble or volatile organic compounds. Further study of mortality against other museum pests such as powderpost and furniture beetles or silverfish is recommended, as are longer-term studies to identify potential issues with museum pest resistance to LLIN.

Materials
Duranet® is manufactured by:
Shobikaa Impex Private Limited
Plot No. 34 Sannathi Street
Vennamalai Post
Karur - 639 006
Tamil Nadu, India
+91-96777-22931
http://duranetllin.com/

Pramex™ is manufactured by:
MGK® Insect Control
880 Tenth Avenue North
Minneapolis, MN 55427
+1-800-645-6466
http://pramexnet.com

Royal Sentry® is manufactured by:
Disease Control Technologies, LLC
419 The Parkway, #120,
Greer SC 29650
+1-864-901-0107
http://www.diseasecontroltechnologies.com

Sticky traps, pheromone and food lures manufactured by:
Insects Limited
16950 Westfield Park Road
Westfield, IN 46074 USA
+1-317-896-9300
https://www.insectslimited.com

Oddy test coupons supplied by:
Fine Metals Inc.
P.O. Box 1055
Ashland, VA 23005
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References


Management of an infestation at the National Library of France: the role of the IPM team

Abstract
In October 2017, a Lyctus infestation was discovered in the framing workshop of National Library of France. An alert was triggered, and the infestation management process began immediately, under the supervision of the conservation department through its Integrated Pest Management (IPM) coordinator (IPM coordinator). The main goal of the IPM team was to evaluate the risk of the infestation spreading, and to develop an appropriate remedial and preventive action plan. Meetings were organized by the IPM coordinator to reassure the collections manager and curators of the low risk of spreading, and to present the action plans to all the stakeholders. The main challenge was coordinating the communication between all the stakeholders and determining the decision-making process, in order to implement curative actions without interrupting the activities of the different services involved in the management of exhibitions. This infestation was an opportunity to implement preventive procedures and actions previously not considered necessary, such as reinforced insect trapping, reinforced training sessions, and reorganization of spaces, including fitting out a quarantine zone on the Richelieu site.

Keywords: IPM coordination; decision process making; risk assessment; Lyctus infestation; biocides; non-chemical treatment; monitoring; prevention.

Introduction
The foremost missions of National Library of France (Bibliothèque nationale de France, BnF) are the preservation of collections for present and future generations, and the valorization of these collections through communication to readers and exhibitions for the public. The BnF holds more than 30 million printed books, manuscripts, and graphic and audiovisual documents, as well as coins and medals, furniture, theatre costumes, and archaeological objects. Each year, several thousands of documents or objects are exhibited in the BnF galleries or are loaned to other cultural heritage institutions. Because of the importance of these exhibitions, two specific services are dedicated to the framing of graphic documents: one under the supervision of the conservation department, and the other under the photographs and prints department.

In October 2017, an insect infestation was discovered during the dismantling of photographs that had been loaned to the exhibition Les Rencontres de la photographie in Arles (south of France). The IPM coordinator of the BnF was alerted. The infestation management process was immediately undertaken to develop a remedial action plan. This paper will discuss the risk assessment performed by the IPM team, and the implemented corrective and preventive actions. It will also discuss the challenges and how they were met, and the lessons that were learned about how to effectively manage this kind of infestation.

Risk assessment
The IPM section of the BnF is one of the three sections of the scientific laboratory and belongs to the conservation department. The IPM team is com-
exhibitions department released an office to use as quarantine. Once isolated, the five photographs were taken out of the frames, to reduce the risk of damage and evaluate the impact on photographs, but also to find evidence to confirm the Lyctus infestation. This first step was performed by the framing service staff. In addition to the dead adult insect, frass was identified in two other frames. One photograph was affected; the damage was a small hole in the photograph corresponding to the exit hole. The photographs and prints restoration service took responsibility for this photograph, and pictures were taken before sending the frames to the IPM laboratory. Unfortunately, because this was an emergency and normal procedure was not followed, they didn’t send the dead adult Lyctus directly to the laboratory and this sample was lost. Therefore, the exact Lyctus species has not been identified.

An analysis of the frames was carried out by the IPM team within the laboratory to confirm the presence of insects. This examination also allowed us to determine that only the frame spacers made of ramin wood, which serve to raise the glass from the photographs, were infested (Figure 1). Live larvae were found in these frame spacers (Figure 2), but the rough oak frames were not yet infested. The Lyctus infestation was confirmed by its typical frass, the size of emergence hole, and the shape and size of the larvae. Lyctus are dangerous xylophage coleoptera of the family Bostrichidae. They develop in the sapwood of broad-leaved trees, which contain a high amount of starch (such as

FIGURE 1. Infested frame spacers stored in storage room: vessels of the ramin wood and exit hole of 1.5 mm of diameter (Digital microscope Hirox KH-8700, x320). Photo: Caroline Laffont, BnF.

FIGURE 2. Live Lyctus larva found in a frame spacer stored in storage room (Digital microscope Hirox KH-8700, x120). Photo: Caroline Laffont, BnF.
this infestation was detected, the framing service had already framed almost two hundred works of art with the infested ramin wood. These artworks were framed for an important exhibition of photographs at the BnF (Paysages français – Une aventure photographique, 1984–2017), which was being installed for its opening at the end of that same month (October 2017). Moreover, these frames had already been dispatched several weeks earlier to all premises dedicated to exhibitions, and some of them were already hung in the exhibition gallery. Fortunately, the framed works of art loaned to other heritage institutions during this period were not framed with this type of framing and so were not at risk.

First, the assessment was conducted in the storage room of the framing workshop where the majority of frames were stored. This evaluation included:

- visual inspection for insect and frass sampling
- insect trapping
- identification at the laboratory
- climatic condition records (temperature and relative humidity)

oak, chestnut, mahogany, ramin) and whose vessels are more than 0.05 mm in diameter (Lyctus do not attack softwoods). The size of the adult is from 4 to 6.5 mm long, and they are a brown to reddish brown, with an elongate shape. They have eleven-articled antennae, antennal clubs formed of 2 articles; and the antennae about the same length as the pronotum. The length of the elytra is 2.5 times the width. Larvae dig circular galleries parallel to the woods vessels, filled with frass. Larvae measure 4 mm to 8.5 mm long at their final development stage, and have a curved shape. Their bodies are entirely greyish white with a reddish head. The emergence holes are circular and about 1 to 2 mm in diameter. The frass is typically very fine and looks like flour. Adults emerge from April to October, and the entire life cycle lasts about a year in normal conditions but there can be two or three generations per year in heated places.

Following identification, the most important step was to undertake a broad assessment of premises and works of art, in order to identify the source(s) and magnitude of the infestation, and the risks of spreading and then to create and implement remedial and preventive action plan (Brokerhof, 2013; AFNOR, 2016). Indeed, when...
• frame conservation evaluation (e.g. packaging, dust levels)
• evaluation of the environmental cleanliness.

In this room, Lyctus frass and remains were found in a highly localized place on rough oak frames (Figure 3). The climatic conditions were suitable for Lyctus development.

The same control was applied in the framing workshop where the installation for the mounting frame takes place. Frass was found in this room, where the infested ramin frame spacers had been stored. Two sources of infestation were then defined: rough oak frame from the storage room, and ramin raising sticks.

Subsequently, all premises at risk of infestation have had the same evaluation. No sign of Lyctus infestation were discovered, except in one deposit room where some frass was found and where moths (Tineola bisselliella) were found on the existing traps.

Simultaneously to the evaluation described above, all 200 works of art were examined by staff of the exhibitions department. The IPM coordinator described indications for the recognition of infestation signs. Frass were found in two rough oak and ramin-framed photographs. The IPM team also found live larvae in these frame spacers.

These assessments, from risk identification to risk estimation, were performed in less than one week. Knowledge of the life cycle of Lyctus, and the vulnerability of the materials, enabled the IPM action team to develop plans with prioritized actions concerning the framed works of art, the frames and the premises.

Remedial action plan

Communication and planning

The IPM coordinator convened a large meeting, where she presented the assessment results and the action plans to all the involved stakeholders. The action plans were divided into emergency and short-term measures, and a preventive plan. This meeting was also the occasion to define the decision-making process. The goal was to work together to find the best and safest way to get back to a satisfactory situation as quickly as possible. Key issues were human and financial resource planning. Another issue was the planning of corrective actions in order to avoid interrupting library activities – especially for the exhibitions and the framing services.

The challenge consisted in reassuring the collections manager and curators that the risk of the infestation spreading was low. Contrary to what they feared, it was not necessary to repatriate the works of art lent to cultural heritage institutions, because they had not been framed with infested materials. The head of the exhibitions department also decided not to inform these institutions. Another challenge was gaining acceptance of the fire safety and security services, the health, safety and environment service, and the building maintenance services, for fumigation of the premises.

Emergency conservation actions

Concerning the frames made for the exhibition being installed, it was decided to only un-frame the artwork that had been framed with ramin spacers or with wood likely to be infested by Lyctus, such as rough oak or mahogany. They were re-framed with resinous wood frames, because Lyctus doesn't feed on resinous wood. For extra precaution, these frames were not stored in the two infested rooms. Inert polypropylene frame spacers were purchased to re-frame them, and it was decided as a long-term preventive measure that only this material will be used from now on.

Furthermore, during the entire period of the exhibition, the BnF galleries were inspected every week, with particular care, by the exhibition department. A protocol for this examination, and a description of what to do in case of signs of infestation, was written by the IPM team. Once a month, the IPM team conducted this examination, as we are more trained to recognize signs of pests. And it was also the opportunity to recover the climatic data from the dataloggers.

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As it was not possible to fumigate the frame storage room, it was totally emptied and decontaminated with a liquid insecticide proposed by the BnF external provider, Saniterpen DK choc®. This insecticide contains deltamethrin (0.2 g/l), pyrethrins and pyrethroids (0.038 g/l). The other premises were thoroughly vacuum cleaned. The remaining frames (around twenty cubic meters) were sent to the Hygiene Office for anoxia a few weeks later. The dynamic anoxia treatment is performed in a chamber for three weeks at 25 °C and 50 % relative humidity with residual oxygen level lower than 900 ppm. A certificate is established after the treatment.

**Preventive action plan**

The preventive action plan includes both specific interventions on the premises and mostly procedural improvements. It was designed to prevent a recurrence of any insects, and improve the preservation conditions.

Concerning the premises, to improve the insect detection, sticky UV-light traps (Flex-trap 45®, Abiotec) were installed. The number of sticky traps, both with and without pheromones, was also increased. This allows any kind of insects to be targeted (flying and non-flying, adult and also larvae). The pheromone traps are used to detect moths. The monitoring, recording, and replacement are done by the IPM team. No damaging insects have been detected since the treatments.

The climatic monitoring has been reinforced in some premises.

Sticky floor mats that keep dust out at the premise entrances were also installed. The air tightness and insulation of the framing workshop windows was improved. Floors are now cleaned by vacuuming, and shelves are vacuumed more often. As noted above, the framing is now routinely done with inert polypropylene frame spacers.

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**Short-term action plan**

Regarding the premises, the framing workshop and safety deposit room were treated by fumigation with Dobol®. This process enables disinfestation by diffusion of an insecticide that spreads quickly in the most inaccessible areas. The insecticide contained is the cyphenothrin of pyrethroids family at a concentration of 7.2 percent. It acts by contact, on the nervous system of insects that ingest it. It does not stain and leaves no residual deposit.

For the organization of fumigation (e.g. sealing, safety and security detection shut down), the IPM team coordinated meetings, with the pest control external provider of BnF, the building maintenance, the fire safety and health services, and the safety and environment services. Prevention plan documents were signed, as required by French regulations. As these two rooms are located near public areas it was necessary to avoid any risk of dispersion of fumigation products. Therefore, a mobile air purifier (RoomDopair®) was installed after treatment. This air purifier only uses particulate and chemical filtration.

2. Five cubic meters of artwork that had been framed without ramin frame spacers, but that had been stored close to infested frames in the framing workshop, were treated by the BnF anoxia unit. This unit uses the Velox® system where a compressor sends the atmospheric air through molecular filters that separate gasses, sending only the nitrogen into a heat-sealed gas-tight enclosure. The residual oxygen inside the enclosure is below of 1,000 ppm. Once this concentration is reached, works of art are kept for four weeks at 25 °C and 50 % of relative humidity. After the treatment they are vacuumed. A report of treatment is sent to collections manager.
of propagation of the infestation, or damages to artwork. The IPM coordinator had to convince the management to dedicate premises for urgent quarantine. This was done through the exchange of reports and meetings. As the lack of space is a major problem, it was hard to find an appropriate space. It still needs to be furnished, and the procedures in terms of staff accreditation, cleaning and maintenance, and alarm system still need to be established.

Discussion and conclusion

This case study points out the importance of having an IPM team in a large and complex cultural heritage institution like the BnF, and also having an IPM strategy as part of the preventive conservation policy. Having these things in place allows for quick action, and the avoidance of a widespread infestation.

Knowing the pests and their biology, the vulnerability of the collections, the possible remedial and preventive strategies relevant to the occurrence, and the estimated magnitude of the risk are key factors to define proper action plans. Another key point is the importance of familiarity with the organization of the institution, and the regulations concerning particularly biocides, and safety and security.

In the case of this infestation, the assessments, the decision-making process, its implementation, and taking corrective measures (reframing, premises treatments) all happened very quickly. All stakeholders were very responsive. They prioritised the remediation of this infestation. This infestation was also exceptional in terms of the number of frames, of framed works of art, as well as the number of premises susceptible to infestation. It is also very uncommon to use an external provider for treatments of works of art; however this was necessary because of the volume of frames that needed to be treated in a very short time (in order not to interrupt the framing services activities for more than a few days). Usually the BnF anoxia unit is more convenient in terms of insurance, human and financial resources.

The IPM coordinator was able to reassure stakeholders, especially the collection managers, the head of departments and the health, safety and environment service. This was done thanks to the written reports, the meetings and a visual presentation that showed the results of the assessments and needed action plan. This presentation is a way of communicating which is not usually necessary. The coordinator also convinced the management of the necessity of biocidal treatments for premises. Usually, biocides are avoided, both because they are toxic and especially because since the implementation of the preventive conservation strategy in the early eighties, they have not been necessary. In this case, however, it was a necessary action.

This infestation was also an opportunity to reinforce preventive insect detection and preservation conditions. Importantly, an additional quarantine room for emergency has been defined (this is still being installed and is not yet in use). Before the Lyctus infestation, this quarantine was not judged necessary as BnF already has a large quarantine facility. The collaborative process was also critical to the successful management of this infestation, from the early detection to the implementation of curative and preventive actions. This event was also the opportunity to strengthen the collaboration between the department of conservation and the building maintenance department and the health, safety and environment service. Thus, through a fast and collaborative response, the BnF was able to both avert a widespread infestation, and to improve the emergency response systems for such an event.

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References


Practical emergency plans in the case of pest infestations in museums

Abstract
This paper reports on sudden pest infestations in museum exhibitions and storage facilities, which may happen without warning. These infestations may be caused by a lack of lending routines, lack of quarantine or infested transport boxes and wrapping material. Practical experience from a consulting expert in museums helps to show solutions with different methods such as protecting storage rooms with tapes, using traps and quarantine. A description of methodology will be given along with recommendations based on personal experience to help avoid mistakes and failures by implementing IPM.

Keywords: Integrated Pest Management; pest infestation; museum; quarantine

Introduction
An acute pest attack of insects or rodents can happen suddenly in spite of an existing IPM-system, a preventive action plan and frequent monitoring. In such cases, it is important to react fast and safely to avoid the spreading of pests inside the building and avert further damage. Through frequent lending of collections and objects between museums, libraries and archives, there is also a high risk of pest attack, for example through packaging materials or transport boxes (Biebl, 2014; Biebl & Querner, 2016). Larvae and adult insects can also enter buildings with infested objects (Pinniger et al., 2016; Querner et al., 2013; DIN EN 16790). Not only can museum objects be irreversibly damaged, but there is also a financial challenge to eliminating a pest attack that has been introduced to a collection with a loan (Biebl & Lang, 2014; Hakanen, 2011). Due to the fact that many pests are well hidden and have a short development cycle, it can result in a fast spreading problem, resulting in severe damage (SiLK, 2019).

This paper describes the general emergency management and an overview of the common pests classified according to food sources. Furthermore, it will demonstrate exemplified emergency cases with different materials and workflows, which could be helpful in practical application.

Emergency planning
- The basic principles for emergency planning are the following:
  - avoid emergency situations;
  - minimize damage;
  - prevent losses;
  - rescue objects.

Emergency plans usually address cases of robbery, earthquake, extreme weather, vandalism, and fire and water damage (SiLK, 2019; Smithsonian Museum Conservation Institute, 2019; Getty Conservation Institute, 2019). Following the recommendations from the Conference of Archives Headers (KLA, 2019), there are only handling instructions for general pest attack regarding archives. There are recommendations for action in cases of acute mould infestation on registry and archival material (LWL, 2019; Neuheuser, 2006). However, there is very little information about emergency plans for pest attacks in the literature or online forums, such as museumpests.net. Nor
Detritus feeders, like *Gibbium psylloides* (Figure 2), are commonly found in debris underneath floors from historic houses. Construction work with associated vibration can lead to an infestation of spider beetles. During autumn in buildings that are not well insulated, wintering insects like flies (*Brachycera*), stink bugs (*Pentatomidae*) or ladybirds/ladybugs (*Coccinellidae*) could cause an acute infestation.

Regarding rodents, the house mouse (*Mus musculus*) and brown rat (*Rattus norvegicus*) belong to the most common pests with high damage potential in museums and historic houses. They are able to colonise museums and historic houses, which may lead to many serious problems like damage by gnawing electric cables (Pinniger, 2015).

is such information available in national guidelines, such as the guideline of cultural heritage from the Bundesamt für Bevölkerungsschutz und Katastrophenhilfe (federal office for civil protection and disaster relief, SiLK, 2019). The guidelines only describe general problems with infestation of pests and mould. For this purpose, there is a need for constant observation and a basic knowledge about the biology of relevant museum pests.

### Overview of common museum pests

Webbing clothes moths (*Tineola bisselliella*) (Figure 1), biscuit beetles (*Stegobium paniceum*) and different wood borers like powderpost beetles (*Lyctus spp.*) belong to the most common insect pests with high damage potential because of their development cycle and reproduction rate.

![FIGURE 1. Heavy insect pest attack with webbing cloth moths (*Tineola bisselliella*). Photo: Stephan Biebl.](image1)

![FIGURE 2. Spider beetles (*Gibbium psylloides*) on glue trap. Photo: Stephan Biebl.](image2)

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### TABLE 1. List of pests according to different food sources and examples.

<table>
<thead>
<tr>
<th>Types of food sources</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>keratin based material (e.g. fur, feathers, wool)</td>
<td>clothes moths and carpet beetles</td>
</tr>
<tr>
<td>wood (particular plywood)</td>
<td>wood boring beetles, dry wood termites</td>
</tr>
<tr>
<td>dried plants or food, seeds</td>
<td>cigarette beetle, drugstore beetle, ham beetle</td>
</tr>
<tr>
<td>cellulose based material</td>
<td>silverfish, firebrats, grey silverfish</td>
</tr>
<tr>
<td>moulds and fungi</td>
<td>booklice, fungus and plaster beetles</td>
</tr>
<tr>
<td>detritus</td>
<td>spider beetles</td>
</tr>
<tr>
<td>human food and waste</td>
<td>cockroaches, rodents, ants</td>
</tr>
</tbody>
</table>
Case stories of acute pest attack in museums

The difference between a normal pest infestation and an acute attack is based on the unscheduled situation with a high risk of damage to cultural heritage within a short time. Suitable conditions (high quality food source, humidity and elevated temperature) for certain insects or rodent species can allow them to multiply explosively and lead to emergencies.

Below are eight examples/case studies that demonstrate practical emergency situations from museums and collections and their implemented countermeasures.

**Wood pest infestation in exhibition decoration**
A large number of palm tree baskets from Egypt, to be used as props in an exhibition, were delivered on a Friday afternoon from an art transport company to the storage room of a museum. While unpacking the palm tree baskets, many crawling beetles were detected on the packaging material and exit holes were found on the baskets. There was a risk of infestation of the wooden floor of the storage room and/or spreading to the exhibition areas. As an emergency measure, the wood boring beetles (determined to be palm tree borer *Enneadesmus trispinosus*) were removed by vacuum cleaner and many insect traps were placed along the walls to monitor the situation. All the 70 palm tree baskets were quickly removed outside into the museum’s garden. After a risk- and cost assessment, the museum’s management decided to dispose of all the baskets at a local incineration plant. Insect traps for monitoring the storage were used for some weeks after to check for spread of the beetles.

**Wood pest infestation in exhibition objects (1)**
A long and estimated 600 kg heavy log boat, which was built as a historic reproduction from hardwood showed many exit holes and crawling beetles, determined to be the fan-bearing wood-borer (*Ptilinus pectinicornis*) shortly after the beginning of an exhibition. This beetle can infest felled trees and develop inside the hardwood during the processing period. Considering the costs and work for removing the log boat, the museum’s management decided to treat the wood. This involved surrounding the log boat with a liquid contact biocide and daily removing the crawling beetles. This treatment was kept up until all beetles had hatched. The reason why the log boat was kept in the museum was based on the knowledge that such beetles do not spread, but remain close to their food source.

**Wood pest infestation in exhibition objects (2)**
A historic wooden figure was preventively treated with anoxia and placed in a showcase in a special exhibition. Shortly after the opening of the well-attended exhibition, conservators detected wood dust heaps and crawling beetles inside the showcase. After consulting a wood pest expert, an infestation of the common furniture beetle (*Anobium punctatum*) was determined. It had been caused by an ineffective anoxia treatment, because the temperature during treatment was too low. After risk assessment, the hatched beetles were removed and a daily control routine was put in place. There was no danger of a new infestation with this place-bound food source species and a hermetical display case. A new treatment with anoxia followed immediately after the exhibition.

**Textile pest infestation in a storage room**
A severe infestation of webbing clothes moth (*Tineola bisselliella*) developed in a non-air-conditioned room during summer with high temperatures. The infestation was unexpected since the historic collection that they belonged to had been treated with biocides. As a first step, the museum staff sealed the cabinets with adhesive tape to isolate the infestation and placed pheromone lures to catch as many male moths as possible. After a risk assessment with the support of an external IPM-expert, a comprehensive treatment with anoxia could take place. All cabinets were sealed with an airtight foil, enabling the lethal oxygen level to be reached for four weeks at about 24 degrees Celsius.

**Stored product pest infestation in exhibition rooms (1)**
During a well-attended temporary exhibition, a heavy infestation of biscuit beetles (*Stegobium paniceum*) was detected by the staff. Some insect traps were filled with beetles, but no food source could be found inside the rooms. The reaction measures were reduced to vacuum cleaning, using a green light lamp (attracting insects without harm-
ful UV-light) and spreading diatomaceous earth behind the exhibition shelves. Without finding the source of the infestation, the exhibition continued as planned without any damage. After some time, the pest infestation slowly decreased.

**Stored product pest infestation in exhibition rooms (2)**

Shortly before the start of a temporary exhibition, beetles were found running inside a display case with contemporary art, made of animal bones. The beetles were identified as the red-legged ham beetle (*Necrobia rufipes*), which can feed on carrion and was brought in with the artwork. Short-term pest control (treatment) was not possible because of time restraints. The high summer temperatures led to a continuous development of the beetles on the art object. As an emergency measure, the display case was opened daily and the bugs were mechanically removed until the exhibition ended.

**Mould infestation on organic exhibits**

A large tree trunk with bark was exhibited in a museum. Before taking it into the museum, the freshly cut tree trunk was stored outdoors in front of the museum. The wood was still very wet over the cross-section. For organizational reasons, the tree trunk could only be treated in a heated chamber for a few days in order to pre-emptively fight existing insects, such as greenflies (*Aphididae*) on the wood. Shortly after the installation, residual moisture from the interior of the wood in the air-conditioned exhibition space led to significant mould growth on the surface. A siphoning off of the mould made no sense as long as the tree trunk was still releasing moisture. Thus, the tree trunk had to be removed from the exhibition as an emergency and further dried until mould growth was no longer possible.

**Summary of errors when applying emergency management**

As the case stories show, lack of IPM, experience and general knowledge about pests are key factors that may aggravate an attack. Lack of preparedness, creating non thought-through actions more or less in panic, is also a major factor. The following list summarizes the major errors from the case stories mentioned above:

- Lack of IPM.
- Lack of experience and knowledge about pests.
- Panic actions, such as:
  - internal transport of infested material without covering;
  - use of (incorrect) food moth lures to control webbing clothes moths;
  - use of insecticides with repellent effect (e.g. pyrethrum) resulting in spreading of insects to other areas inside the building;
  - treatment of transport boxes or objects caused by wrong identification of the pest insect.
  - use of rodenticides, resulting of dead bodies of mice in the collection, which leads to a webbing clothes moth infestation.
- Lack of quarantine or interim storage for infested objects.
- Lack of preventive measures or incorrect treatment parameters.
- Incorrect classification of pests (such as false comparison with images found online).
- Incorrect application of biocides by untrained staff.
- Neglected pest control management (such as rodent control in outdoor areas).

**Prevention of pest emergency situations**

IPM emergency response can learn from ordinary disaster preparedness (Kriese, 2018), as performed by museums in case of fire and flooding. Many actions are similar. The following points can be part of a museum’s or archive’s disaster plan:

- Set an in-house quarantine strategy, such as isolating objects in case of a suspicion of pests, restricting access.
- Form an emergency group and record name, telephone and address (head and deputy of conservation, emergency officer, unit manager, storage manager, technician, etc.). Keep rosters up-to-date and central (e.g. on the intranet).
- Create an emergency plan for treatments (listings for the nearest heating/anoxia chamber or freezer, contact details for an IPM specialist, etc.).
- Keep a map of where the quarantine or storage room is and what the safest and fastest way from the delivery zone is.
- Have a quarantine room available, or choose a room that is fairly easy to evacuate and to use to store infested objects.
- Create a routine for risk assessment and control of incoming/outgoing objects and material.
- Offer regular training and exercises for staff and IPM coordinators to update knowledge of emergency plans and measures.
- Provide regular maintenance of freezers and chambers for treatment (anoxia, heat).
- Keep an easily accessible emergency box (see Table 2 for contents) close to the quarantine room. Maintain regular control of the emergency box for completeness and durability (e.g. PE film can become brittle, pens dry, tape dries out).

**TABLE 2. Suggestions for the content of an emergency box.**

<table>
<thead>
<tr>
<th>Material</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Handouts with contact details</td>
<td>IPM coordinator, collections response team, specialist biologists</td>
</tr>
<tr>
<td>Literature</td>
<td>IPM manual book images of pests to aid identification</td>
</tr>
<tr>
<td>Investigative material</td>
<td>disposable gloves, flashlight, magnifying glass, insect tubes, notepad and pen</td>
</tr>
<tr>
<td>Insect determination</td>
<td>USB microscope camera or mobile phone</td>
</tr>
<tr>
<td>Cleaning agent</td>
<td>vacuum cleaner with pipe extension, electric cable</td>
</tr>
<tr>
<td>Isolation material</td>
<td>garbage bags, stacking boxes, foils, zip-bags, cover films, tape, double tape, insect netting, stapler, barrier band</td>
</tr>
<tr>
<td>Measurement equipment</td>
<td>moisture measuring device for wood</td>
</tr>
<tr>
<td>Tools</td>
<td>scissors, knives</td>
</tr>
<tr>
<td>Pest traps</td>
<td>glue traps for insects, rodent traps</td>
</tr>
</tbody>
</table>

- Have a quarantine room available, or choose a room that is fairly easy to evacuate and to use to store infested objects.
- Create a routine for risk assessment and control of incoming/outgoing objects and material.
- Offer regular training and exercises for staff and IPM coordinators to update knowledge of emergency plans and measures.
- Provide regular maintenance of freezers and chambers for treatment (anoxia, heat).
- Keep an easily accessible emergency box (see Table 2 for contents) close to the quarantine room. Maintain regular control of the emergency box for completeness and durability (e.g. PE film can become brittle, pens dry, tape dries out).

**FIGURE 3.** Quarantine of paper materials in archive to control the possible infestation of the grey silverfish. Photo: Volker Hingst.

**FIGURE 4.** Cultural heritage emergency container for quarantine and treatment with climate control. Photo: Maruchi Yoshida/Kurecon.
<table>
<thead>
<tr>
<th>Steps</th>
<th>Actions / Examples</th>
<th>Person</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Identification/Assessment of emergency</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 Informing responsible persons</td>
<td>Call</td>
<td>Emergency officer IPM-coordinator Conservator</td>
</tr>
<tr>
<td>3 Request for help</td>
<td>Call</td>
<td>IPM-specialist Pest Biologist Pest Control company</td>
</tr>
<tr>
<td>4 Instruction of actions</td>
<td>Oral</td>
<td>Emergency officer</td>
</tr>
<tr>
<td>5 Documentation of the damage</td>
<td>Take photographs of the damage, pest species and numbers, galleries, exit holes, etc.</td>
<td>Emergency officer IPM-coordinator Conservator</td>
</tr>
<tr>
<td>6 Determining the extent and nature</td>
<td>Of the damage collection of pest and excrements samples send photos to experts matching with existing data (object documentation, old damages)</td>
<td>Emergency officer IPM-coordinator Conservator</td>
</tr>
<tr>
<td>7 Provision of material and equipment</td>
<td>Emergency box disposables (tape, foil) traps for insects or rodents</td>
<td>Emergency officer</td>
</tr>
<tr>
<td>8 Isolate infested objects</td>
<td>Pack objects e.g. with stretch foil (Fig. 3) bring objects into the quarantine room or to a treatment chamber</td>
<td>Emergency officer Conservator</td>
</tr>
<tr>
<td>9 Secure infested spaces</td>
<td>Avoid spreading of pests (e.g. close windows, glue doors with tape, isolate hollow spaces, seal storage shelves or show cases)</td>
<td>Emergency officer</td>
</tr>
<tr>
<td>10 Disposing</td>
<td>Packaging or infested material (disposal must be outside the building)</td>
<td>Emergency officer</td>
</tr>
<tr>
<td>11 Clarification next steps</td>
<td>Decision of treatment notification of transport company or emergency container company (Fig. 4)</td>
<td>Pest Control Company Emergency container company</td>
</tr>
</tbody>
</table>
Emergency measures

First phase
After the assessment of an acute pest infestation, it is necessary to follow certain steps to avoid failures that could lead to damage and worsen the infestation. The following table is an example of emergency workflow (Table 3):

Second phase
After the first emergency measures have been carried out, more self-directed countermeasures could follow:

- Mechanical elimination (removal) of insects.
- Removal of pests by vacuum cleaning (important: freeze or dispose of vacuum cleaner bags).
- Check and control climate: cool down if possible to avoid mould growth and rapid development of insects.
- Dry humid objects and lower the relative humidity if too high (to reduce the risk of mould).
- Avoid spreading of the insects by keeping doors closed.
- Isolate infested spaces or showcases to avoid spreading (e.g. seal with tape).
- Mount mechanical barriers such as double sided or one-sided sticky tape (see Figure 5) under doors.
- Seal objects in cupboards with flexible insect netting (Hakanen, 2011).
- Dispose of food sources (e.g. old mice baits).
- Set up traps for interception of crawling insects, thereby reducing the infestation.
- Put up light traps to monitor and reduce the infestation.
- Use empty isolated chambers or climate-controlled containers (Kulturgutrettungs-container 2019) to store infested objects temporarily.
- Check light sources like windowsills or emergency lamp fittings.
- In the case of a structural pest infestation, external expert(s) should be consulted (Museumpests, 2019).

Conclusion
In the past, many museums have just reacted with treatments in the event of pest attacks and disregarded the implication of preventive measures such as strict quarantine or insect monitoring in storage rooms.

Emergency prevention means doing everything possible to reduce the likelihood of acute pest infestation and to minimize the potential for damage in a preventative way.

By construction or climatic arrangements, pests can be prevented or minimized in an emergency. Lack of quarantine and knowledge of the biology or behaviours of museum pests increases the risk of an unexpected pest infestation. Training or courses for staff is important to avoid panic actions in emergency situations.

If in doubt, IPM or museum pest specialists must be consulted in order to make the correct risk assessment and take the most effective measures. In most emergency situations, simple measures and equipment such as tapes or foils, are sufficient to avoid spreading of pests. Emergency plans and equipment should be reviewed regularly and adapted to new requirements. New or invasive pests may require their own or separate emer-
gency strategies, which cannot be handled with existing procedures or methods. Open communication between museums and conservators about case studies or new treatment technologies are required to avoid sudden pest infestations.

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References
Sniffer dogs in the detection of biscuit beetle (*Stegobium paniceum*) infestations in historic libraries

**Abstract**

Using sniffer dogs to detect the Asian longhorn beetle (*Anoplophora glabripennis*), an introduced quarantine pest from Asia, is already widely practiced in Europe. Infested wood packaging materials are investigated by sniffer dogs to prevent the spread of invasive pest beetles. The infested wood is mainly used in the transportation of stones imported from China and beetle outbreaks have occurred in many European countries (e.g. Austria, Germany, Switzerland, Italy and more). We started testing the capability of sniffer dogs to detect active biscuit beetle (*Stegobium paniceum*) infestations in historic libraries and museums in Austria. These libraries, often found in monasteries, hold thousands of books being stored in a single large room. Locating individual infested books is very time consuming, expensive and can often end without the source being found. A well-trained dog should be able to detect an infestation in a room, locate actively infested books and also be able to locate potential sources of beetles in the building (e.g. attic or ductwork). We trained a two year-old beagle dog with original biscuit beetle frass from historic books, living adult beetles and larvae. The ability of the dog to locate infested material was tested in three locations (two libraries and one storage depository of a museum) in 2018. Results are compared with other methods of monitoring like the use of sticky blunder, pheromone and UV light traps as part of an IPM program.

**Keywords:** detecting infestation, monitoring, biscuit beetle, sniffer dogs

**Introduction**

Integrated Pest Management (IPM) is an important part of preventive conservation in museums and aims to stop damage to museum objects and the spread of pests. In IPM, different measures such as physically excluding pests from a building, regulating the climate within a building, quarantine of incoming or suspect materials, detailed cleaning and housekeeping, training museum staff about IPM and monitoring, all help to reduce the risk of an infestation (Brokerhof, 2007; Pinniger, 2015; Pinniger & Lauder, 2018; Querner, 2015). Most museums try to reduce the application of pesticides in their collections and will use the pesticide-free techniques of freezing, controlled heat as well as anoxic treatment with nitrogen or CO₂ to kill all stages of pests (Querner and Kjerulff, 2013; Pinniger, 2015). Objects made out of wood and textiles as well as natural history collections, ethnographic materials, modern art objects, historic libraries, archives and historic buildings can become infested.

**Biscuit beetles in museums**

The biscuit beetle (*Stegobium paniceum*) is a common food and artefact pest with a cosmopolitan distribution and can be found in museums, historic libraries, food industry settings and in private homes. Along with other Anobiids (such as the tobacco beetle, *Lasioderma sericorne* or the furniture beetle, *Anobium punctatum*), the biscuit beetle is a key pest for museum environments (Pinniger, 2015; Pinniger & Lauder, 2018; Brokerhof et al., 2007; Querner, 2015; Florian, 1997; Querner...
et al., 2015). The larvae of the biscuit beetle feed primarily on plant materials and on goods in the food industry such as cereal, pasta, rice, biscuits or bread. In museums, the beetles can damage dried plant materials found in herbaria, historic books, paper, upholstery, different objects with starch glue, as well as textiles, mummies, animal mounts and insect collections (Museumpests.net., 2012). They can feed and survive on keratin-based material, but in most cases, they prefer plant material and especially starch-based glue. While feeding on books, the larvae feed mainly on the glue of the bookbinding, and in this process the first pages of the book, the leather book cover and occasionally the entire back of the book may be damaged as well (Hicken, 1992).

**Monitoring of biscuit beetles**

Simple sticky blunder traps and UV light traps work well to trap adult beetles emerging from infested objects (Child and Pinniger, 1993; Child, 2011; Querner, 2015; Querner et al., 2010; 2013; 2017). Since the discovery of the isolated biscuit beetle sex pheromone and subsequent commercial availability of pheromone traps, locating an infestation has become even easier (see for example Swindells & Harvey, 2017, Harvey et al., 2017). But after trapping the beetles, the infested objects still need to be located, and this can be time consuming and difficult in large storage repositories or historic libraries.

**Sniffing dogs**

Besides the widely known use for detection of people, cadavers, truffles, drugs or explosives, dogs have also been trained to detect various insects (Brooks et al., 2003; Pfiester et al., 2008; Lin et al., 2011; Suma et al., 2014) and wild animals (Engemann et al., 1998; Paula et al., 2011; Wasser et al. 2012). *Anoplophora glabripennis* for example is a wood boring beetle pest mainly introduced into foreign countries along with untreated or insufficiently treated wood packaging material from China. *Anoplophora chinensis*, a similar species, is mainly introduced into non-native countries along with live plants. Canine scent detection is possible because the nose of a trained dog is able to detect even minute traces of the target scent. *Anoplophora* detection dogs have been trained in Austria since 2009 (Hoyer-Tomiczek & Sauseng, 2009). The dogs can detect empty breeding galleries, exit holes and overgrown oviposition sites. This ability enables the dogs to detect the insects in standing trees in a forested outbreak area as well among imported plants and even in roots in the soil. Hoyer-Tomiczek et al. (2016) tested the sensitivity and selectivity of trained *A. glabripennis* detection dogs towards different scent sources of *A. glabripennis* (larvae, frass and wood shavings, infested wood) under controlled as well as realistic conditions and found an overall sensitivity of 75–88 percent.

**Training of the dog “Funny”**

**Dog training**

One dog (a two-year-old Beagle named Funny) was trained by the author for six months to pick up the scent and locate living adult biscuit beetles and larvae. The dog already had intensive scent training for paper currency (Euro, US Dollar and Swiss Franc) since the age of nine weeks. Biscuit beetle training for the dog was performed for six months every other day for 15–20 minutes. The scent of biscuit beetle frass (collected from the historic library in the Capuchin monastery) as well as the scent of live larvae and adults (collected from a cultivation on bread biscuits) (Figure 1a) was presented to the dog within different environmental situations. The scent training method for *Stegobium* detection uses the principle of positive reinforcement where the dog is rewarded by its handler immediately after a correct indication by the dog in order to combine the positive feeling of reward with the target scent (Rebmann et al., 2000; Braun, 2013). The trained response of this dog for indicating the target scent was the act of putting its nose on the most intensive point of the scent and freezing any further movement. This kind of indication is very often used by police dogs in dangerous target scent detection scenarios such as the presence of explosives, accelerants and narcotics. This type of response from the dog avoids any contact or damage to the indicated area.

Further, we introduced a special scent carrier into the dog training. Cigarette filters were covered with real “beetle odour” by putting live beetles and filters together in a glass jar for two days (Figure 1b). The filters trap the odour of the beetles. By using the filters as a training device, safe training without any infestation risk to objects
can be carried out in historic libraries or any other training sites. The dog responds to the filters with the odours in the same way as it would respond to living beetles or larvae.

After training for six months (Figure 2) we were confident enough to test the dogs search capacity in three realistic locations in Austria with and without an active biscuit beetle infestation.

**Test location I**

The Kaiserliche Wagenburg horse carriage museum in Vienna holds a large collection of horse harnesses in its attic. Biscuit beetles are known to have been active in this room for many years. The authors knew of individual infested objects, but the beetles were also entering the room from small cracks and spaces in the floor. On the 25th of September 2018, the dog searched the attic for 1.5 hours and found six spots with a scent of live biscuit beetles. Some were known as entry points of beetles from void spaces and others were the infested objects themselves.
Test location II

On the 25th of September 2018, the historic library in the Klosterneuburg monastery was visited. A few years prior, an active and strong infestation of *Stegobium paniceum* was discovered in this library. All books were treated with the toxic gas Sulfuryl fluoride in the spring of 2017 to eradicate the infestation. Because no active infestation was present in the library, we hid two half open glass jars with five live larvae of biscuit beetle inside each jar (Figure 3). The dog searched the central part of the library for 20 minutes to locate the live insects.

Test location III

On the 27th of November 2018, the historic library in the Capuchin monastery (Kapuzinerkloster) in Vienna was visited. We knew that there was a low, but active, infestation of *Stegobium paniceum* in this monastery. Some books were treated with anoxia in the past, but the infestation was not completely eradicated. The dog searched the library for 17 minutes (Figure 4) to locate infested areas and books. Following a break for the dog, 13 books were laid out on the floor on blankets and the dog searched again book by book to locate the infestation more closely.

All tests were carried out indoors. Any indication by the dog had to be clearly communicated to the dog handler by the dog. The handler immediately confirmed whether the indication was correct. In the case of correct positives, the dog handler rewarded the dog with its usual reward (typically food). Then the search was resumed until all samples had been examined. The dog handler abandoned the test run in few exceptional cases when the dog became too distracted to work.

Results and Discussion

Test location I

The dog clearly indicated the actively infested horse harnesses in the attic, some of which were placed on the floor and some were still hanging. It also indicated different infestation areas in the room located in cracks in the floor. Some of these were already known as entry points of live biscuit beetles into the storage depository (Figures 5 and 6). The beetles were entering the room from small cracks and spaces beneath in the floor. The dog also indicated a previously unknown area of
FIGURE 5 & 6. The dog Funny in the attic of the horse carriage museum indicating an active biscuit beetle infestation. Photo: Pascal Querner.

FIGURE 7. The dog searching in the historic library in the Klosterneuburg monastery without an infestation. Photo: Pascal Querner.

FIGURE 8, 9 & 10. The dog Funny searching infested books in the historic library in the Capuchin. Photo: Pascal Querner.
infestation where many dead beetles were found after visual inspection. The ultimate source of the biscuit beetle infestation is still unknown to the authors at this time. Some food source beneath the floor must be the host of the infestation. The identified objects (horse harnesses) have already been or will be treated with anoxia. We also plan to treat the gaps and seal them.

**Test location II**

The dog was not able to locate the live larvae (Figure 3) inside the glass jars hidden in the large room (Figure 7). However, when the search area was made much smaller, it managed to locate them. Probably the scent of the larvae was too weak to detect (it was placed only for five minutes before the dog searched the room, and the glass jars were half closed with a loose lid to prevent spread of the infestation. The monastery insisted on the lid to reduce any danger of a new infestation.

**Test location III**

The trial in the Capuchin monastery in Vienna was the most important test as actively infested objects were present. Within 17 minutes, seven areas with potentially active infestations were found (Figure 8). The dog clearly indicated this and repeated her reaction again and again. Out of the 13 books from two shelves laid out on the floor, the dog indicated four books as actively infested (Figures 9 and 10). Other books on the shelves were not interesting to the dog. Out of the 13,230 total books in the library (we counted only half as the dog searched only up to the height of 1 m = 6,500 books), 10–20 books with an infestation were located within the reasonable time of about 1–2 hours of work with the dog. This is much faster than a visual inspection of all of the books.

Hoyer-Tomiczek et al. (2016) showed that dogs of various breeds are able to detect *Anoplophora glabripennis* scents of different origin in both controlled as well as realistic test conditions. The mean percentage of correct positive indications (= sensitivity) was between 85.0 and 92.6 percent under controlled conditions and between 75.0 and 88.1 percent under realistic conditions. Placement of the scent at a height of 1.8 meter was no problem for the dogs, since the mean sensitivity from the outdoor scenario of the old orchard in their study did not differ from the search for frass on the ground. Experience from training and from surveys in outbreak areas shows that dogs are able to detect infestations in tree crowns at heights of six meters (Hoyer-Tomiczek & Sauseng, 2013). Dogs searching for scent material from red palm weevil, *Rhyynchophorus ferrugineus*, in potted palm trees gave correct positive indications in 78 percent of cases (Suma et al., 2014). Trained dogs were shown to be able to distinguish the scent of imported red fire ants from other ant species (Lin et al., 2011) or of bed bugs from other insects, such as ants, cockroaches or termites (Pfiester et al., 2008). Dogs trained to detect termite colonies did not detect wood infested with lyctine beetles in a test but they were 100 percent successful at detecting wood with termite colonies (Zahid et al., 2012).

Using sniffer dogs to detect the Asian longhorn beetle (*Anoplophora glabripennis*) is already widely used in Europe. Infested wood packaging materials from China are investigated by sniffer dogs in Austria, Germany, Switzerland, Italy and more. The success rate of dogs in standardized situations is very high with an overall sensitivity (the ability to detect an odour) of 85–93 percent and a specificity (the ability to differentiate different odours) of 79–94 percent (Hoyer-Tomiczek et al., 2016). The Museum of Fine Arts in Boston also made public that they will start to use a sniffer dog to detect infestations of insect pests in a museum environment (Artnet News, 2018; Smartnews, 2018). The museum acquired a Weimaraner puppy which will also receive training to detect case making and webbing clothes moths (Owen, 2018).

A well-trained dog should be able to detect an infestation in a room, locate individual actively infested books and objects and also potential sources of beetles in the building. Training and real searches must be carried out in such areas. Canine training normally is expected to take about up to two years to reach a required standard (Springer, 2016). It was reported that dogs can be trained to detect black tea within eight training sessions of only a few minutes each and reached a high sensitivity of 92.1 percent and a specificity of 97.4 percent (Johnen et al., 2013). This pilot project with the dog Funny, showed a very high suitability for accurate inspection in the short time of six months worth of work and training.

Compared with other methods of monitoring such as the use of sticky blunder traps, phero-
mone traps and UV light traps, searching for biscuit beetles with a dog has many advantages. It is less time consuming if the dog is well trained and can pinpoint the infestation to an individual object. Monitoring with traps also clearly shows the activity of pests in a room, museum storage depository or library, but the infested objects still need to be found. This can be a very time-consuming process, especially if the library hosts thousands of books of which only few are infested.

If this method of detection is found to be successful in further trials, we suggest to train dogs to smell and locate other museum pests like other Anobiidae (for example Anobium punctatum, Lasioderma serricorne, Ptinus fur), Lycus sp. beetles or other species of pests like the grey silverfish Ctenolepisma longicaudata. Further experience must be gained for the inspection of tall bookshelves and the use of staircases to reach books at upper levels.

Acknowledgments

We thank the three institutions (museum and libraries) that allowed us to work with the dog on this project and gave us this opportunity to test a new method for pest monitoring in museums. We also thank Bill Landsberger (Rathgen Research Laboratory, Berlin) for providing an endless supply of live biscuit beetles and the two reviewers for valuable comments on the manuscript.

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References


KILIAN ANHEUSER

Anoxic treatment or freezing?
Consider your options

Abstract
In objects conservation there are four generally accepted preventive or curative treatments for suspected insect infestations: deep freezing, anoxic treatment in a large air-tight chamber usually using nitrogen, anoxic treatment in small oxygen-barrier film bags with oxygen absorbers placed inside, and heating to c. 50–55 °C with strict humidity control. Each of these techniques has its specific advantages and drawbacks. An experimental study of relative humidity (RH) fluctuations is presented for the two types of anoxic treatment and for deep freezing.

Anoxic treatment in a nitrogen chamber requires some considerable investment into infrastructure and takes several weeks per treatment cycle but carries the lowest risk of damage to the object through RH and temperature variations. It is suitable for treating large objects such as furniture or large carpets.

Anoxic treatment in bags with oxygen absorbers requires little capital investment but is limited to smaller objects.

Freezing to -25 to -35 °C has become popular as a rapid, inexpensive and convenient technique. The treatment only takes a few days and a suitably large freezer is affordable also to institutions on small budgets. However, RH fluctuations during treatment are significant. When the object is cooled to sub-zero temperatures, RH drops to very low levels as water is removed from the system by being frozen out. At the end of the treatment there is a risk of condensation on the cold object as the temperature of the environment increases. For polymers (glues, varnishes, natural resins, binding media) cooling below the glass transition temperature creates a risk of brittleness and associated damage.

The effect of placing bags of silica gel (ProSorb™) with the objects to mitigate RH fluctuations was also investigated.

The paper concludes with recommendations for best practice in choosing the most appropriate technique for a given situation. All techniques have their rightful place in conservation but should have different areas of application.

Keywords: insect pest treatment; anoxic treatment; nitrogen chamber; oxygen absorbers; freezing; relative humidity variations

Introduction
Since the late twentieth century institutions have made significant efforts to move away from the liberal preventive and curative use of insecticides towards non-toxic alternatives in order to manage insect pest related risks. The application of biocides to individual objects or globally by fumigation to groups of objects or even to entire buildings has been replaced by intelligent integrated pest management strategies with a strong emphasis on monitoring and on prevention through appropriate physical and administrative measures. Excellent introductions to modern insect pest management principles and procedures are for example Brokerhof et al., 2007 and Pinniger, 2015.

Where preventive and curative treatments remain necessary they will ideally be effective without causing damage or alterations to the often already degraded and delicate materials most likely to be attacked by insects (feathers, silk and wool,
and wood in all its different uses). These materials may also be dyed or carry polychrome surfaces.

Effectiveness and the absence of risks to the object are not the only relevant criteria for choosing the most appropriate treatment technique. In a real world there are also considerations of time- and cost-efficiency especially when large numbers of objects are to be treated, and versatility to apply a given technique to a great variety of objects, the size of which may range from the small and easily portable to architectural elements and other immobile structures which have to be treated in situ.

An overview of current preventive and curative insect treatment practices and research in museums can be found in recent conference proceedings such as Winsor et al., 2011 and Lochot, 2017. More specific references for the different treatment techniques are given below. The following alternatives to insecticide treatments are today generally accepted by the conservation community:

- Freezing at around -30 °C for a few days. Recommendations are usually based on the literature review by Strang (1992). The duration of the treatment must be adapted to ensure that the core temperature of large objects reaches equilibrium. For small to medium size objects a chest freezer may be used whereas larger objects such as carpets or furniture can be accommodated by walk-in freezer units.

- Anoxic treatment, usually using nitrogen. Occasionally carbon dioxide is also used despite its disadvantages, in particular its density higher than air (Selwitz & Maekawa, 1998). Regulation (EU) no. 528/2012 of 22 May 2012 adopted by the European parliament and the Council of the European Union now requires treatment operators to hold a specific licence for the use of nitrogen and carbon dioxide for anoxic treatments since it classifies these gases as biocidal active substances. This currently rules out its legal use for most institutions bound by EU legislation. Large objects are treated inside a hermetically sealed chamber or a bubble of the required size, equipped with a RH-controlled nitrogen generator, which takes the nitrogen from the surrounding air. Small to medium size objects can also be treated in hermetically sealed bags made of oxygen-barrier film with an appropriate quantity of oxygen absorbers placed inside. Either treatment is carried out at a minimum temperature of about 20 °C and takes about six to eight weeks.

- Heating to 50–55 °C in a RH-controlled chamber or bubble, a treatment option now internationally commercialized by Thermo Lignum Ltd. (Xavier-Rowe et al., 2000; Tscherne et al., 2016). The technique can be adapted to large-scale treatments such as the wrapping and heating of entire buildings. A low-cost variant with less stringent control over temperature and RH has also been proposed in the form of placing objects in a solar tent even though this is not a technique commonly used in temperate climates (Brokerhof, 2002).

Previous research and aim of this study

Much of the conservation research into non-toxic insect pest treatment techniques has in the past focussed on assuring and optimizing the effect of the treatment (Strang, 1992; Berzolla et al., 2011). How long do we need to freeze objects at a given temperature to ensure 100 percent mortality of all relevant insects in all stages of their development? How long do we need to go with the oxygen concentration in an anoxic treatment, and how does the minimum duration of the treatment depend on the temperature of the environment? What is the minimum length and temperature for heat treatment to be effective? Suitable freezer units, anoxic bubbles and heat chambers have been developed and are now commercially available for purchase or as a service.

Delicate materials commonly found in museum objects have been tested at length with all three methods to prove to the conservation community that they do not put at risk the objects they are meant to save and protect. This research has often looked at the physical effects of changes in temperature to which objects are subjected during heat treatment or freezing, especially brittleness of polymers below the glass transition temperature, and at dimensional changes (Strang, 1995; Mecklenburg, 2007). The physical impact of RH fluctuations on wood and on paintings has also been researched in considerable detail (Mecklenburg, 2007; Bratasz, 2013 and 2016) even though this
work is primarily focussed at defining tolerable temperature and RH variations in storage and display environments. In insect pest treatment studies RH fluctuations have generally received relatively little attention, with the exception of the Thermo Lignum® heat treatment for wood (Tscherne et al., 2016 with further references therein), where mechanical stress in the objects is reduced to a minimum through sophisticated control of the equilibrium moisture content of the wood.

In this paper we present RH recordings measured during freezing and the two types of anoxic treatments, with and without placing silica gel next to the object in order to stabilize RH levels during treatment. The purpose is to provide conservators with RH data to make an informed choice regarding which method to use depending on the nature of the objects to be treated.

Experimental setup and results

In all experiments temperature and RH curves were recorded using Elpro Hamster EHTi data loggers, which were placed on or immediately next to the objects to be treated. The data logger calibration was verified before the experiments by comparison of the readings with an identical reference data logger, factory-calibrated less than 12 months before.

Experimental setup and results

In all experiments temperature and RH curves were recorded using Elpro Hamster EHTi data loggers, which were placed on or immediately next to the objects to be treated. The data logger calibration was verified before the experiments by comparison of the readings with an identical reference data logger, factory-calibrated less than 12 months before.

a) Freezing

Experiments were carried out using the Liebherr BGPv 8420 ProfiLine freezer unit owned by the Musée d’ethnographie de Genève. This bakery-norm professional freezer offers one of the largest available interior spaces for stand-alone units. The freezer was cooled down to and maintained at its minimum temperature of -35°C. It is regularly used by the museum for preventive and curative treatments of objects from its collections.
In accordance with our routine procedure the objects to be treated, in this case a group of wooden household items, were sealed inside bags of polyethylene sheet and placed inside the pre-cooled freezer (Figure 1). To determine the possible stabilizing effect of a humidity buffer one group of objects was frozen with two bags of Prosorb™ silica gel granules (total net weight approx. 1,200 g conditioned at 45 percent RH) inside the polyethylene bags, the other without silica gel.

b) Anoxic chamber

Temperature and RH curves were measured during the anoxic treatment of an object from the European collection of the Musée d’ethnographie de Genève, a harvest festival bouquet made of cereal crop stems, after discovery of an active infestation by webbing clothes moths *Tineola bisselliella*. We used the 3 x 2 x 2 m fixed walk-in anoxic chamber of the Musée d’art et d’histoire de Genève manufactured in 2002 by Bentert GmbH in Berlin, Germany, equipped with a Domnick Hunter laboratory nitrogen generator and a PC-controlled *Oxymin* humidification module designed by the chamber manufacturer and supplied with the chamber (Figure 4). Figure 5 shows the temperature and RH curves inside the anoxic chamber during treatment.

c) Anoxic treatment using oxygen absorbers

Two identical treatment bags measuring approximately 62 x 42 x 3 cm each were made from heat-sealed PET / aluminium / polyethylene oxygen-barrier film. Inside each treatment bag twenty-four ATCO FTM 1000 oxygen absorber packs and identical books as mock-up objects were placed. One of the two treatment bags also contained two bags of Prosorb™ silica gel granules (total net weight approx. 1,200 g conditioned at 50 percent RH) to evaluate the effect of a humidity buffer (Figure 6). Figures 7 and 8 show the temperature and RH curves inside the barrier film bags during treatment.

Discussion

a) Freezing

The temperature and RH curves for freezing (Figures 2 and 3) demonstrate that it took approximately four hours for the data logger inside the polyethylene bag to reach -35°C at the beginning of the treatment, and two to three hours for temperature and RH to return to ambient levels from the moment the freezer was opened at the end of the treatment. During treatment there were minor periodic variations of temperature and RH related to the functioning of the freezer. The temperature varied between -32 and -35°C which is perfectly acceptable for the efficiency of the treatment.

FIGURE 5. Temperature and RH curves for an anoxic treatment using RH stabilized nitrogen.

The presence or absence of Prosorb™ silica gel with the objects made a significant difference to RH fluctuations. Without silica gel, RH levels dropped sharply from c. 45 percent to 15–20 percent and remained there for the duration of the treatment with minor periodic fluctuations matching those of the temperature inside the freezer. This is because humidity was frozen out of the system, with ice crystals forming on the inside of the treatment bag. The moment when the freezer was turned off and opened at the end of treatment, RH inside the treatment bags peaked at saturation point (100 percent RH) as the temperature increased beyond 0 °C and the water previously trapped in the form of ice was released. There was a risk of condensation on the objects, which are usually much slower to warm up than the surrounding plastic bag. For a brief period
of time, typically two to three hours, there was always liquid water on the inside of the plastic bags, originating from melting ice crystals. It is advisable not to touch or move the bags with the objects at this point in order to avoid contact of the objects with liquid water inside the bag as far as possible. Two to three hours after the opening of the freezer, temperature and RH had completely equilibrated with the room environment at c. 45 percent RH and c. 20 °C. The objects were nevertheless given 24 hours to warm up because larger items may require more than just a few hours to fully equilibrate.

In the presence of Prosorb™ silica gel the initial RH drop was from c. 45 percent to c. 25 percent rather than to 15 percent, and more importantly the brief peak at the end of the treatment only reached c. 65 percent RH rather than saturation point, eliminating the risk of the objects coming into contact with condensing water. For the ultimate RH minimum of c. 15 percent the presence or absence of silica gel made no difference, even though the minimum was reached more slowly in the presence of a silica gel buffer.

To what extent RH fluctuations in a situation of temperature change actually trigger significant dimensional changes in an object is a matter of discussion. Some research has been conducted on wood imitating panel paintings enclosed in microclimate packaging, i.e. small volumes with added silica gel (Kamba & Nishiura, 1993; Richard, 2007), arriving at different conclusions. However, this research sought to mirror typical shipping conditions and was therefore restricted to a temperature range of 10–40 °C. Actual dimensional changes of wood in the presence of silica gel at temperatures below 0 °C when humidity peaks during freezing treatments have to the best of our knowledge not yet been experimentally monitored. In the absence of scientific data common sense suggests that RH peaks to saturation point and condensation inside the freezing bag should best be avoided. In any case with the anoxic techniques we have a valid alternative for sensitive items.

In addition to RH variations and contact with liquid condensed water, freezing carries a significant risk associated with low temperatures and temperature variations. Most polymer materials such as glues, varnishes, natural resins and binding media in paint layers will be cooled below their glass transition temperature which renders them brittle and extremely delicate (Strang, 1995). Moreover, despite the fact that differences in linear coefficients of thermal expansion between for example wood and typical binding media are small there is a risk that thermal contraction in a cold environment may exceed the flexibility of a coating at low temperatures (Mecklenburg, 2007).

It is clear from the data that varnished or painted objects cannot be safely frozen.

Even though freezing must be considered unsuitable for certain sensitive objects we have in our ethnographic collection numerous other artefacts potentially at risk from insect infestation, for example plain wooden objects or simple items made of wool, where the benefits of rapid and simple freezing over a much longer anoxic treatment outweigh the added risk of damage. Most wooden objects in museum collections are already cracked or broken in places. Fissures in the material tend to act as expansion joints, avoiding situations of mechanical restraint and making the object more tolerant towards RH-induced mechanical stress (Mecklenburg, 2007). This is not always the case for freshly restored objects, which are potentially more sensitive towards RH variations.

b) Anoxic chamber

In the anoxic chamber the RH curve started with a slow decline from c. 52 percent to the set RH value of 45 percent. After approximately two weeks RH readings remained completely stable at 45 percent. The recorded RH peak reaching c. 63 percent immediately before the start of the treatment was due to transport conditions on the way to the anoxic chamber. It was not part of the actual treatment. When the nitrogen flow was stopped at the end of the treatment, RH levels inside the chamber remained stable with very small fluctuations until the moment when the chamber was reopened. The overall stability of RH and temperature was excellent as expected and deemed suitable even for the most delicate objects.

c) Anoxic treatment using oxygen absorbers

The use of oxygen absorbers for the anoxic treatment instead of a flow of humidified nitrogen led to similar results: excellent stability of RH readings for the entire duration of the treatment. There was a short peak at c. 60 percent RH and an
increase in temperature of 3–4 degrees for approximately the first four hours of the treatment which can be attributed to the chemical reaction of the iron powder in the oxygen absorber bags and the relatively small air volume inside the treatment bag. Later on there were no further significant variations.

For the duration of the treatment the temperature inside the treatment bags varied with room temperature as would be expected. No significant differences were measured for the RH peaks associated with the opening of the absorber bags, regardless of whether Prosorb™ silica gel was present or not. This is perhaps because unlike freezing with and without silica gel the momentary increase in RH caused by the oxygen absorbers was too brief for the silica gel to respond.

Anoxic treatment using oxygen absorbers can therefore be considered as suitable for delicate objects and does not benefit from any addition of silica gel.

Conclusions
The results show that either type of anoxic treatment, the anoxic chamber or the use of oxygen absorbers, guarantees highly stable RH levels, rendering the treatment suitable even for the most delicate objects. The disadvantage of the techniques lies in the long duration of the treatment, which at a temperature of 20 °C or slightly above takes about six to eight weeks from start to finish. Anoxic treatments also avoid the problem with brittleness of polymers associated with freezing.

The much faster freezing treatment, complete in just a few days, exposes the objects to a sharp drop in RH, from ambient humidity to c. 15 per cent, when at sub-zero temperatures most of the moisture in the remaining air is frozen out to form a thin coat of ice crystals on the inside of the treatment bag. This is in addition to the drop in temperature, which potentially creates brittleness problems depending on the composition of the objects.

The placing of silica gel inside the treatment bags attenuates the hygrometric shock significantly during the first 24 to 36 hours. Thereafter the objects are exposed to similar conditions as for a treatment without added silica gel.

At the end of the treatment the silica gel serves to reduce potential condensation of water on the cold object as the freezing bag returns to room temperature.

Based on these results we have adopted the following treatment policy:

- For sensitive items such as objects with degraded polychrome surfaces or delicate textiles, anoxic treatment is the preferred option even though this takes much longer and the associated cost is significantly higher (purchase of consumables such as oxygen absorbers and barrier film, extra working hours to take the objects to the anoxic chamber administered by another museum).
- Less sensitive objects like plain wooden agricultural tools are frozen. In this case a suitable quantity of silica gel is placed inside the treatment bag and the duration of the treatment is usually limited to three to four days for medium-sized objects.
- Unnecessary precautionary freezing is avoided, in particular if an object is clean and thorough visual inspection shows no evidence of an infestation.
- In order to avoid contact as far as possible between the objects and condensed water and ice on the inside of the treatment bags, we turn off and open the freezer at the end of the treatment without moving the objects until they have slowly warmed to room temperature. How long this actually takes depends on factors such as mass, thickness and thermal conductivity of the object. A period of 24 hours can generally be considered largely sufficient. We consider this good practice also because of the brittleness of some materials at low temperatures, which may render them particularly vulnerable to mechanical damage.

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Successful pest management in a museum is always the result of a team effort involving numerous colleagues at all hierarchical levels. The author would like to thank all of them for their continuous efforts and discipline to limit curative interventions to a minimum.

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Killing me softly … – Adaptive freezing as object-friendly and efficient pest control method

Abstract
Freeze treatment is a pest control method accepted and applied by museums and archives. This paper describes a technical approach to apply the freezing treatment in a multiplicable and scalable manner especially to support small and middle-sized museums and archives to prevent and control pest infestation. ISO-standardized, air-conditioned containers are to be equipped with supplementary technology in order to control the re-humidification in regard to the dew point line of the object surfaces and therefore avoid the use of plastic foils to cover the objects. Pre-tests in a climate chamber are run to simulate the freeze and thawing process in small scale. The first freezing test is run with paper material in different packaging types and a selection of common pest species e.g. the Grey Silverfish (*Ctenolepisma longicaudata*). The freeze treatment is operated in a usual manner and the temperature and relative humidity change is observed and documented in different places in the chamber, at the objects and inside the packaging. A preliminary evaluation and comparison of the climate progression in the sealed plastic bag and cardboard document box shows no significant difference. This leads to the assumption that the container box can be utilised as a “sealed bag” and therefore can substitute the plastic packaging. Further tests are carried out to control the de- and re-humidification process to reduce risk of damage to objects caused by extreme relative humidity values and condensation. Reference projects are started to create services in order to help affected institutions to adapt their IPM-system to specific conservational needs, their individual economic requirements and general ecological principles.

*Keywords:* low temperature treatment; adaptive freezing; humidity control

Introduction
The freeze treatment of museum and archival collections is a common pest management method. However, a range of sensitive artworks and cultural assets are regarded as not appropriate for extreme temperature exposure. Therefore, a large number of museums and archives, especially in Germany and also Austria, prefer anoxic treatment methods by using in-situ generated gaseous nitrogen (DMB, 2019). Since the new biocides regulation has become effective in September 2017 this common method of anoxic treatment is no longer applicable (European Union, 2012; Child, 2013). Museums and conservators associations are starting initiatives to proceed against the biocides directive – a resolution is still far off and the outcome is uncertain (ICOM Austria, 2019; ICOM Germany, 2019). Alternative solutions may be found in inventing new pest control methods, in rethinking IPM-strategies, and in re-considering existing methods like freezing in order to optimize its efficacy and efficiency.

The freezing method and its potential for an improved application
Freezing objects to control pests is a known and widely used method in museums and archives. Compared to nitrogen treatment freezing is much
Raphael, 1994; Strang, 1997; Pinniger & Winsor, 2004). Most damage to treated surfaces of wood and metals can frequently be observed within the temperature range of -31 to -45 °C. Causes of damage are not specified except for water damage resulting from condensation on unwrapped surfaces (Kjerulf, 2013).

A controlled freezing and thawing process with gradual heating and re-humidification of air has the potential to reduce physical load and avoid condensation on the surface of the objects. It could become an appropriate pest control method for a wider range of object types than currently assumed.

The challenge is to find optimal temperature curves adapted to properties of the different material composites of “common” artworks and targeted to particular pest organisms with different living conditions and resilience. For that, the following measures need to be taken:

Always chose the “warmest” lethal temperature for the targeted organism. This means that an exact identification of the pest present is necessary to define the lethal temperature. Experience, empiric studies, and experiments show that 100 percent mortality rate for certain species can be achieved with higher temperatures around -20 °C (Bergh & Jensen et al., 2006). In case of adult grey silverfish (*Ctenolepisma longicaudata*) infestation, the freezing temperature only needs to reach 0 °C to achieve lethal effect.

Define the physical “weak point” of an object and adjust the temperature drop accordingly. This means that competence in material science and historical art technology is needed to assess the physical weak point of a complex artwork.

Define the lowest dew point line of the object and adjust the temperature rise and re-humidification of air accordingly. This means that an appropriate technology must be made available.

The aim is to find a technical solution by modifying an industrial application in order to achieve effective and reliable pest control in an economically efficient, multipliable and scalable way, at the same time meeting the high requirements of the cultural artefacts and artworks. The development of technical devices for climate control with special regard to an intelligent measuring and control unit is therefore one of the main objectives.
shortly before ripening matures during trans-
port under controlled conditions. Pest pre-
vention is undertaken by running a pre-set cold treat-
ment program to sterilize insects known to affect
tropical fruit (Figure 1). There are also other mul-
tiple temperature set point programs available to
pre-define temperature changes in up to six steps.

Getting on track: technical approach

The starting product is a so-called reefer (refrig-
erated container), a climate-controlled container,
usually used as shipping container for perishable
food. They are available in three ISO-standard-
ized sizes: 3, 6 and 12 meter length. They have
proven to be highly efficient in an extremely com-
petitive global food trade market: Fruit harvested

Cold Treatment program, CT

FIGURE 1. Scheme of a pre-set Cold Treatment program of a reefer. Source: Maersk Container Industri.

FIGURE 2. Application examples of reefers as storage facilities for climate sensitive archaeological finds.
Photo: kurecon (left), Susanne Heimel (right).
FIGURE 3. Normal climate regulation curve in a container (red) vs. ideal curve (green) vs. dew point line for the object surface (light blue); blue hatch: humidifying, yellow hatch: de-humidifying. Source: kurecon/Streit.
air, the warming process should be adapted in a way that the heating is coupled with a controlled re-humidifying process alongside the dew point line of the coldest surface of the treated objects.

Pre-test configuration in a climate chamber
A pre-test was run in a climate chamber to simulate the “common” freeze treatment and to observe and document temperature and humidity progression in comparison between packed and unpacked objects in a small scale. So the freezing was operated without any additional humidity regulation. The chamber was loaded with archival materials in different forms: unpackaged; in a cardboard archive box and sealed in ESCAL™, an aluminium laminated polyester-polyethylene foil (12 µ Polyester/12 µ Aluminium/75 µ LDPE). Several high-precision sensors were installed within the chamber, at the object surfaces and within object packages and stacks (see Figure 4). Some insects, biscuit beetle (*Stegobium panicum*), larvae of house longhorn beetle (*Hylotrupes bajulus*), and grey silverfish (*Ctenolepisma longicaudata*) were also placed into the paper piles and packages. According to usually recommended temperature curves the target temperature was set at -30 °C for a duration of three days (Pinniger & Winsor, 2004; Strang, 2004).

Kurecon (a German company specialising in containers for cultural heritage storage and rescue) uses modified reefers to offer interim storage for waterlogged archaeological objects or to provide quarantine storage for potentially contaminated collections. These climate containers operate in a range from -30 °C to +30 °C, enhanced with further air conditioning supplements, guaranteeing constant environmental conditions in both very dry and very humid climates. Adaptable and mobile storage systems make them suitable for a wide spectrum of objects and collections. The first use of such a container took place during an archaeological rescue excavation in Lübeck in 2013 to recover and secure a wooden medieval cellar. Another container is in use for waterlogged wood at an underwater archaeological expedition in Austria since 2015 (see Figure 2).

The reefers are able to hold a targeted climate value very precisely as it is needed for perishable food or climate sensitive goods. However, they are not intended to regulate different climatic levels except of the pre-set temperature programs. Cooling and heating will therefore follow the “shortest” way to reach the target temperature as is shown in the simplified graphic in Figure 3. While the cooling process can be pre-set along with dehumidification of
Transfer to climatized containers

Taking the climate value of the sealed bag as an “accepted benchmark” the whole container body can be made to function as an airtight sealed shell around the objects. In the cooling process the climate unit automatically dissipates the humidity in order to avoid condensation, and the relative humidity will drop accordingly. In the thawing process the climate unit blows warmed air into the container room over a range of up to six temperature and humidity set points. The re-humidification should start as soon as temperature reaches a level where humidity becomes a relevant value. The technical challenge is seen in controlling the humidification rate according to the lowest dew point line of the “coldest” object surface to avoid condensation on the original materials.

Regarding archival collections the hygroscopic paper material will re-humidify gradually until the equilibrium moisture content within the targeted relative humidity is reached. The thawing process of museum collections consisting of different material composites is more complex. However, good practices in museums and study results, where no chemical and physical alteration on gilded historic polychrome oil painted wood samples were stated (Beiner & Ogilvie, 2005) encourage further field experiments which will focus on...

1997; Raphael, 1994). The cooling speed could not be pre-set but 0 °C was expected to be reached within 4–6 hours to avoid acclimatisation reactions in the insect organisms (Bergh, et al., 2006).

The climate curves in Figure 5 show that according to the temperature drop relative humidity also decreases quickly. The humidity in the sealed bag is partly adsorbed by the paper material but has probably mostly been condensed on the inner surface of the foil as no silica gel or other desiccant was used. The relative humidity in the document box falls about 5% lower than in the sealed bag. The humidity is probably adsorbed by the cardboard and also exchanged by the drier air in the climate chamber. Detailed evaluation of all climate data, which will be incorporated into the technical development, is still ongoing.

The climate progressions of the pre-test in the chamber shown in figure 5 are not very surprising as such. However, one detail gives a hint towards the aim to dispense with plastic foil: the pre-test shows that the cardboard box is not significantly different to the sealed bag. That supports the usual practice that paper materials are freeze treated in cardboard boxes without additional plastic covering, and also conforms to the statement that paper objects show no damage from freezing cycles (Beiner & Ogilvie, 2005).

**FIGURE 5.** Temperature and relative humidity in the cardboard document box and sealed plastic bag. Source: Obkircher.

![Graph showing temperature and relative humidity](image-url)
The expected benefits of freeze treatment in the airtight and climate controlled container are

- adaptive control of relative humidity, which reduces the duration of the critical dry phase to the minimum,
- avoidance of plastics, and
- multipliable and scalable solution.
Application cases and service prototyping with reference customers

Besides the technical solution, test applications with reference customers are necessary to adjust the service to the specific needs and capacities of public institutions. Especially small and middle-sized institutions are identified as target groups as their financial and personal capacities are limited and storage conditions accordingly problematic.

Test applications of freeze treatments are embedded in the IPM-system, which is individually elaborated for the specific institutions. The first case is a municipal archive, which will centralize their collections from different locations in a new central archive. Regarding the present storage condition, infestation with insects or contamination with mould is very likely. The size of the collection and the shortage of time and staff do not allow a detailed assessment of infestation beforehand. Thus the archival collection will be treated completely – whether contaminated or not – before moving into the new building. Therefore every object passes the decontamination chain starting with the freeze treatment in the container, followed by a manual cleaning and disinfection in a working container, before entering the building (Figures 6 and 7).

Further case studies will take place in museums where mixed collections are scheduled for annual (prophylactic) pest control. This application will provide opportunities to test and compare different thawing and re-humidification techniques. After the first reference projects, the freeze treatment is intended for use within the start-up operation of a new collection centre used by four institutions (municipal museum and archive on the one side and diocesan museum and archive on the other side), a larger project than monitored thus far.

Even though every institution involved has its own IPM-concept, all of them agree on a common IPM-strategy, especially in the start-up phase when huge collections are scheduled to be moved into the storage rooms within a short period of time. The general IPM-policy of all four institutions is to store collections in the new building only with a “clean” and “decontaminated” status. Thus any piece of object that could bear any kind of infestation or contamination must be cleaned beforehand.

Regarding the large amount of heterogenic collections, limited time and space to occupy the entrance area of the collection centre, decontamination chains will be divided into a “fast lane” outside and a “slow lane” inside the building. The majority of both archival and museum collections are allocated to undergo a thermal treatment (warm air and freezing), cleaning and disinfection outside the building. A selected collection of delicate artworks and artefacts will be treated in anoxic atmosphere by using nitrogen cartridges inside the building (see Figure 8).

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One-size-fits-all not available: Dealing with limitations as part of IPM-strategy

Indeed, the adaptive freezing method will not cover all types of collections, but will potentially increase the range of objects that can be treated in this way. In fact, using in-situ generated nitrogen was not always the most economical and effective method, but it was nonetheless used as a universal method. Whenever time and money are important factors for deciding the "right" method, adaptive freezing will be a treatment to be taken into account and discussed in addition to other alternatives like using heat or nitrogen cartridges. Ultimately, decisions on pest control methods always require a case-by-case examination.

The IPM-system is a cycle of measures to avoid and prevent, to observe and determine, and to isolate and control pests. It is essentially a matter of identifying weaknesses in this cycle in a regular review process and to find ways to compensate them by suitable and feasible structural, technical and organisational measures that can be implemented in a short-, middle- and long-term perspective. Thus, the IPM cycle is understood as a continuous improvement management, to be implemented step by step as a bottom-up approach, by involving the whole museum staff in all levels of the IPM strategy. This participatory approach for implementing IPM in small and middle-sized museums is undertaken where normative concepts according to DIN EN 16790:2016 are not yet possible for structural and organizational reasons (DIN EN 16790, 2016). In the end, it is not the pest control itself but its integration into a functioning IPM system that is decisive for long-term absence of pests.

Conclusion and outlook

The adaptive freeze treatment is an appropriate pest control method that can be applied much more frequently and for a wider range of objects than previously assumed. Operational safety and reliability is achieved by modifying proven equipment and technology, which have been adopted from industry. The physical load on the object can be reduced by limiting the cold temperature degree according to the targeted species and by providing controlled re-humidification within the warming-up phase. A major advantage arises by controlling the warming process in order to avoid condensation on the object surface and to be able to dispense with plastic packaging in future applications.

Follow-up studies besides the reference applications are planned to develop special racks and palettes for an optimal loading geometry in terms of freezing speed and regular temperature and humidity distribution to enhance performance and energy efficiency of freeze treatments in the containers.

More detailed research and development projects are planned to adapt the climate technology to the specific freezing processes required by targeted organisms to be eradicated, and climate sensitive artworks with special regard to the thickness, density and thermal conductivity of the material in question.

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The challenge of combining contemporary art and IPM at Moderna Museet, Stockholm

**Abstract**

Contemporary art can present considerable challenges regarding integrated pest management (IPM). The collection of Moderna Museet is relatively new and the museum building is only a few decades old. The very nature of a modern and contemporary art museum involves exhibiting and collecting high-risk objects. Already in the re-inaugural exhibition at Moderna museet in 1998, the Conservation Department encountered many challenges, followed by more in the coming years. Through increased awareness and shared responsibility, the IPM routines at Moderna Museet have gradually evolved and expanded during the period the museum has been operating in a new building.

*Keywords:* contemporary art; integrated pest management

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**Introduction to Moderna Museet**

Moderna Museet is a Swedish state museum with the national responsibility for modern and contemporary art, founded in 1958 and housing a collection of artwork from circa 1900 until today. The number of registered artworks in the collection is approximately 70,000, comprising 4,500 paintings, 1,500 sculptures, 31,000 prints and drawings, 34,000 photographs and 450 time-based media works. The museum was originally located in the old naval facilities on the tiny island of Skeppsholmen, in the center of Stockholm on the Baltic Sea. In the beginning of the nineties, an architectural contest for a new museum building was announced since the existing one was no longer suitable for the activities of a modern museum of art. In February 1998 the new museum building designed by the Spanish architect Rafael Moneo opened to the public. Since 2009, the museum has an additional space in Malmö, in the south of Sweden. The yearly number of visitors in both locations combined is around 800,000.

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**Re-opening and the first years**

The re-inaugural exhibition in 1998, with the title *Wounds*, comprised artworks by 68 international and national artists. Artworks including living flies, stuffed dogs, fresh red meat, mashed pears, a wasp’s nest and eight zebra finches in cages, were exhibited. When unpacking the gigantic wasp’s nest in the installation *Passage Dangereux* by Louise Bourgeois, living insects were discovered and the nest was sent for a weeklong low temperature treatment to the Swedish Museum of Natural History (NRM).

Damien Hirst’s installation *A Hundred years* was a two-room aquarium measuring over 2 x 4 x 2 meters, housing flies hatched from maggots, fed with water and sugar cubes, and eventually killed by an electric lamp (Figure 1). The maggots to be used for restocking were kept in the carpentry workshop in plastic buckets with lids and yet they were found crawling out from the buckets. The escape was discovered in time, and the lids were fastened more securely. The refilling of the mag-
Hundreds of kilos of fresh red meat hanging on hooks, an untitled installation by Jannis Konnellis (Figure 4), did not cause any major alarm regarding insect infestation. Neither did a sculpture called, ‘Moi,... (Memento Pirum)’ with slowly oozing mashed fresh pears by Thierry de Cordier (Figure 5). Except for one escaped bird in Bustamante’s installation that had to be chased and captured, no other incidents occurred. Despite all these incoming artworks with a high pest risk, the measures taken by the Conservation Department prevented possible infestations. The Conservation Department is always alert to potential incoming loans with high risk content, although this process requires further standardization. All works are unpacked in a special area close to the transport entrance and they are inspected as soon as possible after arrival.

gots and the water every week caused the conservators some concern since the silicone seal around the little window in the aquarium wall needed to be cut open; the maggots were then poured into the aquarium through a tube. The little window was then quickly resealed without letting any flies escape.

Another perspective: reactions from the visitors

Other works that could have been problematic regarding IPM became an issue from another perspective. Two stuffed dogs by Maurizio Cattelan (Figure 2), and an installation by Jean Marc Bustamante with eight zebra finches, each one in an individual cage (Figure 3), caused strong reactions from animal rights activists, with newspaper debates and live manifestations outside the museum. On the other hand, the above-mentioned installation by Damien Hirst did not upset the visitors in the same way.
An unexpected discovery

An issue instead appeared from an unexpected source. Soon after the move to the new building, the problem of wooden freight pallets from the EU was encountered. The museum shop discovered xylophagous beetles (Anobiidae) in their storage facilities and an infested pallet was identified. All wooden freight pallets in the museum were at this point exchanged for plastic ones during a relatively short period of time. At this stage insect traps of a standard sticky detector variety had been placed, but only in the art storage areas and with sporadic inspections.

The following years

During the following years, there were a few further incidents with incoming loans that could have caused severe problems but were avoided thanks to attentive staff members and preventive measures. One example from the exhibition After the Wall, in 1999, is an artwork by Artur Klinov consisting of suitcases filled with various contents, such as jars of jam, pickled vegetables and loaves of bread. During unpacking it was discovered that the lids were rusty, and that the jars were leaking. Insects and mold were found on the base of the suitcases. The loaves of bread in one suitcase were infested with insects and eggs. Both artworks were sent to NRM and underwent high temperature treatment according to standard procedures (Figure 6). In this period no documentation of species determinations was made when an infestation was discovered. At the time this was not considered necessary and the main issue was to incapacitate the insects. Policies and recordkeeping have since improved.

Another example from the same exhibition was Old Legends Newly Tested, by Audrius Novickas, a sculpture with 14 used hats on a metal stand. The hats were dirty, had holes and traces of moth activity and therefore, as a precaution, underwent the same treatment with elevated temperature at NRM (Figure 7).

Christodoulos Panayioutou’s installation Days and Ages, a terracotta floor from Cyprus, arrived at the museum in 2013. Upon arrival, big black bees began flying around in the unpacking area even before unpacking (Figure 8). They were captured and sent to NRM for identification and fortunately found not to pose a risk in this case. The species is called Xylocopa violacea, violet carpenter bee, and nests in dead wood. Initially, the artist also wanted to exhibit some of the wooden crates on top of the floor. However, the final installation
solution was without the crates for several reasons, which included conservation concerns. All the tiles (circa 400 m²) and crates were treated with low temperature, -40 degrees Celsius during four days at the Nordiska museet.

**On the way to implementation**

In 2007, the limited number of insect traps began to be expanded to around 20. They were also more systematically organized, regarding placement and documentation, thus improving the work of insect monitoring. This active regular monitoring was combined with the daily housekeeping and conservation care in the permanent and temporary exhibition galleries.

Participation in the Swedish interest group PRE-MAL³ (Pest Research and Education – Museums, Archives and Libraries) and use of its publications contributed greatly to the increased awareness and the continuing implementation of IPM routines. The fact that potential infestations were discovered and prevented early on and the lack of crisis during the initial years in combination with the newly constructed building led to certain complacency and false sense of security. Consequently, it took a few years to expand the IPM framework. However, work continued with the attendance of one conservator at a one-day IPM course organized by NRM and PRE-MAL in the beginning of 2012. Discussions with colleagues from other museums during the course further increased awareness and it became clear that the museum had been very fortunate in the relatively low number of insects detected in the museum facilities as well as the lack of serious outbreaks. But how could the museum keep it that way? The number of traps was once more increased, now to 30 traps with regular inspections every third month. Cleaning personnel and the museum hosts were also informed and instructed to monitor the exhibition rooms.

After some years, the workload of inspecting the increasing number of traps became too much for one person and various sections of the Conservation Department became involved, each specialized conservator taking care of their studio and storage. There was, however, the wider museum building to consider as well. To engage more of the museum’s personnel, NRM was asked to conduct a custom-made workshop for conservators, storage-keepers, art handlers and technicians at Moderna Museet. Two of the museum hosts also participated. The training course was held in autumn 2017. It was fully attended and ignited

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IPM routines have evolved from an intermittent activity undertaken time permitting, to an important activity that is part of the regular duties for both the conservation and technical departments. The work, which initially seemed easy and manageable, progressed to an unreasonable, unshared workload, but with awareness and wider involvement, it has become manageable again.

The Future – it will continue and never end

The IPM work at Moderna Museet is now evolving with a broader, deeper and more focused scope. The museum’s IPM policy is being reworked and expanded by the Conservation Department and will be re-submitted to the management team. Useful guidelines and European standards in the IPM field were published 2016 and give support to continuing IPM work with statements such as: “The IPM policy shall be authorized by management and included in the institution’s policy documents” and “The overall responsibility for IPM shall rest with the senior level management of the organisation.”

The museum is a tenant of the building managed by the state-owned institution, National...
Conservation Department faced another challenge: a new acquisition to the collection made after the exhibition *La naissance de Stockholm...!/* The Birth of Stockholm...! with the artist Georges Adéagbo. Adéagbo creates complex site-specific installations, where news cuttings, posters, books, postcards, objects, clothes and his own handwritten texts are shown together with sculptures and paintings from Benin and the specific exhibition venue, in this case Stockholm. The complete installation contained over 700 objects. The Conservation Department was warned by the artist’s team that the incoming crates from Benin contained ethnographic objects of materials with potential hazards. During the unpacking, some dead insects were found, mostly spiders, and it was considered necessary to immediately send the objects for treatment as a preventive measure. The objects were vacuumed, sealed in plastic, re-packed and sent for low temperature treatment, for one week at -30 degrees Celsius. No insects were detected during the exhibition, and after the exhibition the objects were stored in closed packages and will be checked regularly for signs of insect activity, aided by an annual digital reminder from the museum database. In 2015, a similar case arrived with the exhibition *Fantasma* by Adrián Villar Rojas.

One of the artworks, *Los teatros de Saturno III*, consisted of a podium with 84 objects in a state of natural decay, e.g. bread, drying fruits and vegetables, crab claws and other specimens direct from nature. Another acquired artwork from the same exhibition was a then eight-year-old sponge cake, from the series *Pedazos de las personas que amamos* (Pieces of the People We Love), 2007 (Figure 10). Preventive treatments

As mentioned earlier, the very nature of exhibiting contemporary art requires that the museum brings high-risk objects into the museum building as the artists continue to test boundaries, and this will continue to be the case. A recent example is the artwork *Silberfischenhaus*, (1999) by Carsten Höller in the exhibition Livet självt/Life Itself, 2016 (Figure 9).

*Silberfischenhaus* is exactly what it sounds like, a house in the form of a rebuilt overhead projector with a light beam which is now and then aimed at the tenants, silverfish (*Lepisma saccharina*), disturbing them and causing commotion. This artwork caused much concern and stress for the conservators and an agreement was made to put a plexiglass roof on the “house” to minimize the escape risk of the silverfish. The silverfish were delivered and installed in the house not without a degree of trepidation. During the exhibition, they were to be fed with fish food powder and water-soaked blotting paper. However, it became clear during the exhibition that the problem was not silverfish escaping, but that it was hard to keep them alive in the dry environment and under the heat of the strong light.

All the above-mentioned examples were incoming temporary loans to the museum. In 2014 the Conservation Department faced another challenge: a new acquisition to the collection made after the exhibition *La naissance de Stockholm...!/* The Birth of Stockholm...! with the artist Georges Adéagbo. Adéagbo creates complex site-specific installations, where news cuttings, posters, books, postcards, objects, clothes and his own handwritten texts are shown together with sculptures and paintings from Benin and the specific exhibition venue, in this case Stockholm. The complete installation contained over 700 objects. The Conservation Department was warned by the artist’s team that the incoming crates from Benin contained ethnographic objects of materials with potential hazards. During the unpacking, some dead insects were found, mostly spiders, and it was considered necessary to immediately send the objects for treatment as a preventive measure. The objects were vacuumed, sealed in plastic, re-packed and sent for low temperature treatment, for one week at -30 degrees Celsius. No insects were detected during the exhibition, and after the exhibition the objects were stored in closed packages and will be checked regularly for signs of insect activity, aided by an annual digital reminder from the museum database. In 2015, a similar case arrived with the exhibition *Fantasma* by Adrián Villar Rojas.

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before the installation were undertaken and during the exhibition several outbreaks of living insects had to be addressed. Among them were beetles such as *Stegobium panicum*, *Dienerella filum* and *Corticaria serrata*. The acquisition of this artwork resulted in a study regarding the conservation of and the potential for anoxic storage of the artworks and has now become a research project together with the Swedish National Heritage Board, for one of the conservators at the museum.³

Many more examples could be mentioned. What is reassuring is that during the time period described here, the number of institutions that offer services for IPM treatments has increased substantially, as have the online resources.

A recent challenge is the acquisition of an aquarium with a complete biotope from the pond in Claude Monet’s garden in Giverny in France by Pierre Hughye, containing insects, fish and plants, including Monet’s famous water lilies. Among the insects there should be four different kinds of water-living beetles that all have a developmental stage where they evolve wings and potentially can start to fly (*Dypticus marginalis*, *Notonecta glauca*, *Hydrobius fuscipes* and *Nepa cinerea*). The artwork is on show inside the museum’s exhibition spaces without the possibility of sealing the aquarium. Consequently, these insects are not included in the installation, which is a significant intervention in the artwork.

In the future, the ambition is to work even more pro-actively, so that the IPM work consists not only in controlling traps and reporting findings. One or a couple of insects do not constitute a pest problem. The museum has never had any major infestations and in the long run we want to keep it that way.

**Summary and conclusions**

The risk of infestations may seem higher with incoming loans and acquisitions, but this is more manageable than the risk presented by insufficient housekeeping routines and vague areas of responsibility in a very large building with a great number of different activities. There are now active routines for the care and handling of incoming loans since the museum activities involves high-risk objects being deliberately brought in. The risk of an infestation is higher in the storage areas where there is low activity for extended periods.

The collecting and exhibiting activities of Moderna Museet will not change dramatically in the future and the high-risk projects will continue to turn up: the Conservation Department has adapted to this. One risk factor is the increased number of exhibitions and tighter installation schedules noticed in recent years. Sometimes there is not enough time for IPM treatments in the planned installation schedules.

The IPM work must be shared and involve the entire staff working in areas with artworks. It is only when performing the monitoring routines that their importance is realized. A broader collaboration and communication with other stakeholders, internal as well as external, is also of high importance.

The IPM issues need to reach the senior management level for increasing the awareness and support since IPM activities need time, financial resources and official support.

It takes time to implement a structured, cohesive IPM strategy unless there is an infestation or a disaster that suddenly causes top-down change. It is a highly organic process but the experience at Moderna Museet has shown that with perseverance and a framework, an organized integrated pest management can be implemented and improved step by step.

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**Endnotes**

1 PRE-MAL (Pest Research and Education – Museums, Archives and Libraries), the IPM-group of Swedish museums, archives and libraries started 1984 and consists of conservators, entomologists and experts occupational medicine. Originally administered by the Swedish Museum of Natural History, and since 2013 by the Swedish National Heritage Board.

2 SS EN 16790 Conservation of Cultural Heritage – Integrated Pest Management (IPM) for protection of cultural heritage.

3 Guest Colleague, the Heritage Laboratory, Swedish National Heritage Board.
Depending on the material of the objects to be treated and species of pests that occur, the treatment time and the required minimum concentration for nitrogen can be quite variable (Selwitz and Maekawa, 1998; Bergh et al., 2003). In this study, the economically most important material pests in their different stages of development were treated under controlled anoxic atmosphere. Dose-response parameters were generated under different climatic conditions. This project work was funded by Deutsche Bundesstiftung Umwelt (DBU).

Material and methods

Test chamber setup

A nitrogen generator (HPN2 5200C, Parker Hannifin Corporation) was used to produce high-purity nitrogen of 99.999% to supply a climate chamber (C -40/350, CTS Clima Temperatur Systeme).
The oxygen concentration in the chamber was monitored by a zirconia oxygen measuring system (Zirox GmbH) with a resolution of 10 vol. ppm to 21 vol. % oxygen installed in the air-conditioned test chamber. Oxygen measurements were randomly double-checked and verified using a second oxygen sensor (CheckPoint MOCON Inc.)

Insects
Insect species for testing were supplied by the stored-product protection group of Julius Kühn-Institute Berlin and the Division 4.1 Biodeterioration and Reference Organisms of Bundesanstalt für Materialforschung und -prüfung Berlin. These insects were then cultivated on their respective substrates. Table 1 gives an overview of used culture diets.

Test specimens
Museum collections may consist of a wide variety of materials. This can probably influence fumigation, as the material may block the diffusion of nitrogen and hence the displacement of the residual oxygen (Petty, 1973; Sorz and Hietz, 2006).
TABLE 1. Culture diet substrates

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<th>filter paper</th>
<th>pine sapwood</th>
<th>oak sapwood</th>
<th>Mungo beans</th>
<th>oats flakes</th>
<th>yeast</th>
<th>wheat bran</th>
<th>fish meal</th>
<th>dried beans</th>
<th>wool</th>
<th>feathers</th>
<th>papaver</th>
<th>maize</th>
<th>wheat grit (raw)</th>
<th>wheat grit (fine)</th>
<th>wheat flour</th>
<th>dog biscuit</th>
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The objects may also perform as oxygen reservoirs (Bwambok et al., 2014). In order to investigate and evaluate this influence, two different approaches were used to simulate the effect of surrounding material on nitrogen diffusion and treatment efficacy. Tested materials were softwood blocks, paper, textile and bubble wrap (Figure 2), representing characteristic matrices of museum objects or packaging material. The wooden blocks consisted of three aligned pieces of spruce wood, 30 cm x 20 cm x 4 cm. A rectangular gap was cut into the central block, into which the test insects could be inserted. The same sample size was used for paper from telephone directories. Blankets made of a 60:40 % cotton-synthetic blend were used as a textile sample. Furthermore, a similar sample size of bubble wrap was tested. A sample body made of blankets consisted of three blankets of 100 x 150 cm², each folded to size of 30 x 20 cm², with the insect samples being inserted into the middle cover. The sample of bubble wrap consisted of a total of 40 layers of 30 x 20 cm². After 20 sheets, the insect samples were inserted and overlaid with another 20 leaves. In all tested materials three larvae of the old house borer *Hylotrupes bajulus* were treated. Additionally, identical specimens were stored under the same climatic conditions in a normal atmosphere as control set-ups.

To simulate real pest infestation of museum objects and to minimize handling stress to test organisms, groups of pest insects were placed in test tubes made of Polyethylene terephthalate glycol-modified (100 ml Rotilabo®-wide neck container), so that they were able to acclimatize and multiply before and during the tests. During test series, PETG tubes were covered by gauze instead of tight lids. Larvae of wood decaying beetle species *Hylotrupes bajulus*, *Anobium punctatum* and *Lyctus brunneus* were carefully removed from their breeding substrate and transferred into prepared wood, ten days prior treatment (Figure 3). Preconditioning of all test insects lasted minimum 10 days before testing.

**Test series and treatment parameters**

To test pest insect tolerance to low oxygen conditions, test parameters of 20, 24, and 27 °C were selected at a constant relative humidity of 50 % and variable oxygen concentrations of 0.5 and 1.0 % for a period of 14, 21, or 28 days.
Data collection and evaluation of test results was carried out in two different ways: Species for which the number of individuals was known, i.e. wood boring species, were split out of the wood after the experiment and discriminated as live or dead (Figure 4). Individuals were considered as dead when their coloration had turned dark and there was no reaction when probed with pointed forceps. This was also done with those species visible as individuals in the substrate. Results were recorded 24 to 48 hours after the end of the experiment. Delayed effects were analysed no later than seven days after the end of the experiments.

This procedure was not applicable for species within the substrate, where individuals were hidden and not counted at the beginning of test. Absolute numbers were thus unknown and small larval stages and eggs could not have been detected in the heterogeneous breeding substrates. Therefore, these samples were qualitatively inspected for adults or larger larval stages. If no living insects were recorded, samples remained for further incubation in the climatised breeding room and were checked again after three months. The effect of treatment was compared to the development in untreated control samples.

Untreated controls were kept under similar conditions as the test assays under ambient atmospheric conditions outside the climate chamber (approx. 22 °C, 40 % RH). Table 2 gives an overview of the species tested and the parameters of the experiments carried out.

A comparison of the experimental results obtained in different published references is often simplified. Frequently, data were produced under non-standardized conditions and with very different sample formats. Table 3 compares published research results in detail.

Results and discussion

Table 2 gives an overview of the species tested during the experiments. Marked in red are experiments in which at least one insect survived. Numbers within the red highlight reflect the number of dead (first number) and surviving (second number) insects. At a 21-day treatment at 27 °C at both 0.5 % and 1.0 % residual oxygen, all tested insects were killed. At 24 °C, however, complete eradication of all insects was achieved only at 0.5 % residual oxygen. At 1.0 % residual oxygen and the same temperature, individuals of some species were no longer successfully controlled: In addition to the old house borer (Hylotrupes bajulus), which plays a minor role in museum pest control, also the tobacco beetle (Lasioderma serricorne), the dermestid Trogoderma parabile and the shiny spider beetle (Mezium affine) were not completely eradicated. This is an important finding, as a treatment success of museum objects, when target insect pests are unknown, is no longer given. It is therefore of particular importance to strictly observe the residual oxygen concentration and the temperature at any time and at any place in the treatment room, which can be quite difficult, especially with larger treatment chambers or tents. Also interesting are the results obtained at 20 °C. There, other relevant species, such as dry wood termites (Kalotermes flavicollis), common furniture beetle (Anobium punctatum) and brown powderpost beetle (Lyctus brunneus) as well as the Australian carpet beetle (Anthrenocerus australis) were found surviving. Less tolerance was observed with species from tested moths (Lepidoptera). In all experiments carried out, moth species, such as webbing clothes moth (Tineola bisselliella), case-bearing clothes moth (Tinea pellionella) and Indian meal moth (Plodia interpunctella) were completely eradicated. However, a shorter treatment time for these frequently occurring, low-tolerance species, such as the webbing clothes moth, is not recommended, because the Australian carpet beetle Anthrenocerus australis is a tolerant species that has a similar food spectrum. By choosing the shorter time the moths may be killed but not any carpet beetle present. The combat against keratin-consuming species should be based on the most tolerant species.

In overall summary of the results, some tolerant species are listed in Table 4, with respect to a treatment period of 21 days. From the data obtained the authors recommend anoxic treatments of museum objects similar to the those tested for a duration of at least 21 days at maximum 0.5 % residual oxygen content and at least 24 °C with no more than 50 % RH.

Corresponding author
Bill Landsberger,
b.landsberger@smb.spk-berlin.de
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- X: all dead after treatment
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Nicobium castaneum  
Reesa vespucae larvae  
Sitophilus granarius  
Stegobium panicum  
Stegobium panicum  
Thermobia domestica  
Tineola bisselliella larvae  
Tineola bisselliella  
Tribolium confusum  
Trogoderma angustum larvae  
Trogoderma includum  
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Xestobium rufovillosum  

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<td>Biebl and Lang 2014</td>
</tr>
<tr>
<td>Nicobium castaneum</td>
<td>20 °C</td>
<td>0.9</td>
<td>10</td>
<td>Rust and Kennedy 1993</td>
</tr>
<tr>
<td>Nicobium castaneum</td>
<td>20 °C</td>
<td>0.9</td>
<td>10</td>
<td>Rust and Kennedy 1993</td>
</tr>
<tr>
<td>Reesa vespucae larvae</td>
<td>20 °C</td>
<td>0.9</td>
<td>10</td>
<td>Bergh 2003</td>
</tr>
<tr>
<td>Sitophilus granarius</td>
<td>20 °C</td>
<td>0.9</td>
<td>10</td>
<td>Adler 1993</td>
</tr>
<tr>
<td>Stegobium panicum</td>
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<td>0.9</td>
<td>10</td>
<td>Gilberg 1991</td>
</tr>
<tr>
<td>Stegobium panicum</td>
<td>20 °C</td>
<td>0.9</td>
<td>10</td>
<td>Gilberg 1991</td>
</tr>
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<td>Stegobium panicum</td>
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<td>0.9</td>
<td>10</td>
<td>Gilberg 1991</td>
</tr>
<tr>
<td>Thermobia domestica</td>
<td>20 °C</td>
<td>0.9</td>
<td>10</td>
<td>Rust and Kennedy 1993</td>
</tr>
<tr>
<td>Tineola bisselliella</td>
<td>20 °C</td>
<td>0.9</td>
<td>10</td>
<td>Rust and Kennedy 1993</td>
</tr>
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<td>0.9</td>
<td>10</td>
<td>Rust and Kennedy 1993</td>
</tr>
<tr>
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<td>20 °C</td>
<td>0.9</td>
<td>10</td>
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</tr>
<tr>
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<td>20 °C</td>
<td>0.9</td>
<td>10</td>
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</tr>
<tr>
<td>Trogoderma includum</td>
<td>20 °C</td>
<td>0.9</td>
<td>10</td>
<td>Rust and Kennedy 1993</td>
</tr>
<tr>
<td>Xestobium rufovillosum</td>
<td>20 °C</td>
<td>0.9</td>
<td>10</td>
<td>Rust and Kennedy 1993</td>
</tr>
<tr>
<td>Xestobium rufovillosum</td>
<td>20 °C</td>
<td>0.9</td>
<td>10</td>
<td>Valentin 1993</td>
</tr>
</tbody>
</table>

TABLE 4. Tolerant species with single individuals surviving a treatment time of 21 days at 50 % RH

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Residual oxygen concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.0 %</td>
</tr>
<tr>
<td>20 °C</td>
<td>Anobium punctatum</td>
</tr>
<tr>
<td></td>
<td>Anthrenocerus australis</td>
</tr>
<tr>
<td></td>
<td>Hylotrupes bajulus</td>
</tr>
<tr>
<td></td>
<td>Mezium affine</td>
</tr>
<tr>
<td></td>
<td>Sitophilus granarius</td>
</tr>
<tr>
<td></td>
<td>Sitophilus zeamais</td>
</tr>
<tr>
<td></td>
<td>Thermobia domestica</td>
</tr>
<tr>
<td>24 °C</td>
<td>Hylotrupes bajulus</td>
</tr>
<tr>
<td></td>
<td>Lasioderma serricorne</td>
</tr>
<tr>
<td></td>
<td>Mezium affine</td>
</tr>
<tr>
<td>27 °C</td>
<td>none</td>
</tr>
</tbody>
</table>
References


Day III:
IPM in a changing climate
GUSTAF LEIJONHUFVUD & TOR BROSTRÖM

A call for systematic monitoring: exploring the link between monitoring and management of cultural heritage in times of climate change

Abstract
Climate change will give a warmer and more humid climate in Scandinavia, which will increase the risk of bio-deterioration of cultural heritage. Given the limited understanding of future risks, there is a need to adopt management strategies that are robust, adaptive, and that facilitate organizational learning. We therefore suggest that safeguarding cultural heritage from climate change impacts will require management practices that use feedback from long-term, systematic monitoring. In this paper we argue for the need of such monitoring, as well as discuss its conceptual foundations. Collected data can be used as feedback at different levels: to improve the scientific models of the system, to give early warning signs that require immediate management action and to improve long-term decision-making. Monitoring programmes cannot live a life on their own, decoupled from management. We advocate that monitoring and management should be set-up and work in tandem in a framework of adaptive management, where feedback from monitoring provides double-looped organizational learning.

Keywords: cultural heritage; climate change impact; risk assessment; monitoring

Introduction
The summer of 2018 was extremely warm and dry in Sweden. In August, the weather became more humid, and The Swedish Meteorological and Hydrological Institute recorded a temperature of 26 °C and a relative humidity of 93 % on the first of August 2018 near Karlskrona in southern Sweden. This corresponds to a dew point temperature of 24,8 °C which was one whole degree higher than the previous record (SMHI 2018). Later in the same month, on the Baltic island of Gotland, a period with warm and humid weather caused an unexpected outbreak of mould in Visby cathedral, leading to costly cleaning and a reconsideration of the indoor climate control strategy of the church (Figure 1). The unusually warm and humid weather might have been an effect of the natural variability of the climate, but anthropogenic climate change may very well be a contributing factor. We know that climate change will lead to a warmer and more humid climate with more extreme weather in Northern Europe (Kjellström et al., 2018, IPCC 2013), which brings new and increased risks for cultural heritage (Leissner et al., 2015). Local building traditions have evolved in response to stresses related to the local weather, both in terms of extreme events such as storms and in terms of average levels for temperature and humidity. Buildings built in traditional ways may therefore be more vulnerable to the impacts of a changing climate than modern buildings, and preventive adaptation will be necessary to avoid costly damage.

Regardless of the fact that predictions of climate change impacts will always remain highly uncertain (Dessai et al., 2009), it is apparent that the scope and the inevitability of the challenge with future climate change is extraordinary. Within the cultural heritage sector there is an awareness of climate change and a high level of ambition in
terms of adaptation (Fatorić and Seekamp, 2017; Sesana et al., 2018). Given the limited understanding of future risks, there is a need to adopt management strategies that are robust, adaptive, and that facilitate organizational learning. We therefore suggest that safeguarding cultural heritage from climate change impacts will require management practices that use feedback from long-term, systematic monitoring. In this paper we argue for the need of such monitoring, as well as discuss its conceptual foundations. Within the field of natural resource management there is ample experience from climate change impact monitoring. We draw on this literature to discuss ways in which the cultural heritage sector could implement monitoring activities as a part of an adaptive management of cultural heritage.

Projects and prospects
Long-term systematic monitoring requires long-term systematic management. The cultural heritage sector is by nature suitable for long-term management, but existing modes of governance are lacking and will have to be modified to successfully adapt cultural heritage to the impacts of climate change. A long-range planning horizon should be part and parcel of cultural heritage management. Traditionally, the sector has been dominated by state institutions with hierarchic and stable organizations, reliable funding and high inertia (Glendinning, 2013). There are pressures on governments to embrace new modes of governance over cultural institutions, where control is decentralized and cooperation with private sector actors is hailed (Coombe, 2012). As a result of the decentralization of decision making in the public sector, cultural organizations are developing strategies to secure funding and legitimacy by adopting private sector managerial rhetoric and practices (Lindkvist, 2012). In Sweden, we have seen a shift where built heritage organizations have become more independent from the state and are governed more like the private sector with a focus on cost-effectiveness (e.g. Statens fastighetsverk, 2009; Svenska kyrkan, 2015). In a parallel development, heritage conservation has become a highly professionalized enterprise during the 20th century (Barthel-Bouchier, 2013). A process of rationalization has followed upon this professionalization, with increasing demands on tangible results, responsible allocation of resources and transparency of decisions (Barthel-Bouchier, 2013). Jones and Yarrow (2013) discuss how new modes of governance, related to external pressures such as funding schemes and legal frameworks, have shaped conservation practice by demanding accountability, transparency and evidence-based decision making.

We live in a “project society” where projects, characterized by temporary organization and specified tasks, have become a dominating form for structuring work (Lundin et al., 2013). The cultural heritage sector has also become “projectified”, not least activities involving restoration and conservation. A major contributing factor is funding schemes. An obvious risk with the “projectifi-

• establish a baseline in terms of existing environmental conditions and the state of cultural heritage objects.
• assess long-term changes in the environment and in objects.
• improve the understanding of causal links between environmental changes and damage.
• guide management action in the short-term in the form of early warning signals.
• assess the consequences of different management interventions and in the long run improve the management strategy.

Risky risk assessments

Jonathan Ashley-Smith elaborated on risk assessment as the governing logic for conservators in the 1990s, and while he didn’t deliver ready-made answers, he evoked a transformation of the field (Ashley-Smith, 1999). The following three decades have seen a development of risk-based frameworks for collection care that has had major impact on both the discourses and practices of preventive conservation. Risk has become the lingua franca in training material, policies, and standards and guidelines. Standardization has moved from being rule- to risk-based, from a focus on outcomes to a focus on processes (Leijonhufvud and Broström, 2018).

Climate change impact assessments on cultural heritage also use the language of risk, although (the unknown but high) uncertainty is disguised in the deterministic top-down approaches applied so far (Leijonhufvud et al., 2013). Current state-of-the-art is based on materials research and the predictive power of computer modelling, ranging from simulations of crack propagation in wood to simulations of future indoor climates (Leijonhufvud, 2016). The top-down approaches now widely used in risk assessments of museum indoor climates (e.g. Martens, 2012), and climate change impact assessments in particular (e.g. Leissner et al., 2013) are necessary but not sufficient to inform adaptation decision-making. Complex causal links, stochastic deterioration processes and synergies between hazards (e.g. light, humidity, pollutants) complicate the use of damage functions and stress the need to monitor how actual objects endure in different environments (Leijonhufvud et al., 2013).
Still, thirty years after Ashley-Smith rhetorically asked for the frequency of damaging events to collections, we don’t have good answers. Long-term, systematic, monitoring can improve the statistical evidence needed to assess vulnerability to climate change in a bottom-up manner. It can be used to calibrate damage functions, improve the knowledge base for risk assessment, and correlate regional climate change impact projections with local and site-specific measurements.

**Models and monitoring**

All monitoring should be based on models of the system to be monitored, but not all monitoring data is useful for improving models. Monitoring in museums used for quality control is often useless for scientific purposes (Padfield, 2007). Temperature and relative humidity monitoring is a case in point. Handy data loggers have replaced the analogue thermohygrographs and we have become immersed by data. Lack of calibration, documentation and standard data formats make most monitoring activity useful only as a way of reactive quality control, where monitoring results can be checked against pre-set targets (Padfield, 2007). More often than desired, such monitoring has been performed as a kind of textbook ritual, at times encouraged by wishful thinking that monitoring in itself will improve the preservation of collections. Our experience is that the data (in the few cases where it is of high quality and well organized) seldom is used for thorough analysis that has resulted in improved climate control strategies. We suspect that this lack of analysis is partly due to the fact that the monitoring has been performed without a useful model in mind.

Models (or alternatively: theories) are the building blocks of science. A model is an abstraction of the real world, a set of ideas that describe a specific system. By testing hypotheses we can debunk or improve models. Models are needed both to plan what and how to monitor. How variables should be sampled in space and time is informed by models. As was apparent in the case discussed above, models are also needed in order to interpret and act upon collected data (Ims and Yoccoz, 2017). Monitoring can be performed as a scientific activity in itself if the monitoring is designed to answer a set of questions based on the models of the system (Ims and Yoccoz, 2017; Lindenmayer and Likens, 2009). Generally, confidence is increased in models that make accurate predictions, and confidence is decreased in models that give poor predictions of system performance (Williams, 2011).

**Adaptive management and adaptive monitoring**

Management strategies for preventive conservation are, at best, based on best practices and expert judgement. In the worst cases they are non-existent and management actions are ad hoc and reactive rather than proactive. Relying on expert judgement can be the best alternative if there is low uncertainty about which management alternatives are most resource efficient, if developing an effective monitoring programme is impossible, or if there is no feedback pathway between monitoring and strategic decision-making (Williams, 2011). In practice, such situations would be rare in the context of adapting cultural heritage to climate change impacts. We therefore need to look at management frameworks that take into account dynamic processes and feedback loops. In this section we will discuss the concepts of adaptive management and adaptive monitoring, and outline a framework for how monitoring can be integrated in cultural heritage management.

To fully exploit the benefits of monitoring, there is a need for integration with management programmes. Commencing monitoring programmes that have little or no connection to overarching management is a waste of resources. Experience from the monitoring of ecological systems tells us that the choice of indicators might be negatively affected by vague long-term goals of management programmes (Dale and Beyeler, 2001). Further, the integration of monitoring and management will not be possible with static management models, hence a call for monitoring is also a call for more dynamic management, which has the potential to link monitoring, risk assessment, adaptation and thereby both improve management actions and learning.

Adaptive management is a management framework developed for natural resource conservation, in which the feedback loop between learning and decision-making is the key component (Williams, 2011). The guiding principles of adaptive management are generic and by inference valid also for cultural heritage resources. Adaptive management is at
its core a version of rational choice theory, involving defining objectives, identifying alternative courses of action, assessing their consequences and making trade-offs. What is emphasized is the temporal dynamics of the system to be managed, and the learning process where improved understanding of the system derived from feedback is iteratively used to improve the management strategy.

The context in which adaptive management is useful is where a complex system changes over time and where the effects of management actions are difficult to predict (Council, 2004). According to Williams (2011) it is typically applied in the management of natural resources in situations where

1) the system to be managed is dynamic and responsive, over time, to both environmental change and management actions.
2) the system is only partially predictable due to inherent uncertainties, such as stochastic processes.
3) the system is subjected to periodic management actions that may vary over time. These actions may affect the system either directly or indirectly.
4) there exists uncertainty about which management actions are the most effective. By reducing this uncertainty, more resource efficient management is possible.

In this case, we illustrate the “system” to be managed with an historic building. Such a building consists of elements that are structurally linked, and where deterioration of one element might affect others. The various elements are vulnerable to environmental stressors depending on their material composition (Loli and Bertolin, 2018). Predictions of future damage will to some extent always be uncertain, as well as the effect of remedial actions. There are however epistemic uncertainties that can be reduced with improved knowledge of cause-effect relationships (Leijonhufvud et al., 2013). Preventive measures, maintenance and renovation work will prolong the life of individual elements, and such activity will vary with time. Other management aspects, such as the use of the building, have indirect effects on the state of preservation. Taken together, these characteristics illustrate a dynamic, partly unpredictable system where feedback loops can improve models and in the end decision-making and policy.

Adaptive management is implemented in two phases, one set-up phase and one iterative phase. A similar structure has been suggested for indoor climate management in historic buildings, which emphasizes the (often missing) link between the system level and the operational level (Figure 2). The set-up phase in adaptive management includes an orientation of the decision context and a framing of the overall problem (Williams, 2011). Setting objectives and stakeholder involvement are the important first steps. The iterative decision-making phase consists of decision-making, monitoring and assessment. The management actions in the iterative phase are based on objectives, resource status and understanding of the system. Data from monitoring is assessed and used to inform decision-making. This is the first learning-loop. The objectives and understanding of the problem identified in the set-up phase have to be revisited at periodic intervals, based on an improved understanding of how the system responds. This is the second learning-loop, taking place at a different time scale than the first loop.

An adaptive monitoring programme (Lindenmayer and Likens, 2009) can be an integral part of adaptive management. Design, data collection and analysis are the three activities that make up an adaptive management framework (Figure 3).

**Design monitoring programme**

In this first step, the questions that the monitoring should aim to answer are carefully formulated. Clear objectives and tractable questions are necessary to resolve conflicts about what and how to monitor. Posing good questions requires a robust model of the system to be monitored as well as a true partnership between stakeholders and experts (Lindenmayer and Likens, 2009). The design of the monitoring programme can in practice be coordinated with the set-up of the management programme, but they remain parallel activities at different time-scales. Monitoring programmes should aim to maintain long series of core data sets, while management programmes have shorter life span.
FIGURE 2. The two levels of management related to indoor climate control in historic buildings (Leijonhufvud, 2016).

FIGURE 3. A framework for the integration of systematic monitoring in cultural heritage management.
Choosing indicators

Choosing what to measure in a long-term monitoring programme can be a difficult task. Indicators (i.e. simple measures that reflect complex processes) are often used in the monitoring of ecosystems. According to Dale and Beyeler, indicators should be chosen that are: 1) easily measured, 2) sensitive to stresses on the system, and 3) reacting to such stresses in a predictable manner (Dale and Beyeler, 2001). As already noted, it is important that what is measured (i.e. the indicators) is relevant for management intervention (Lindenmayer and Likens, 2009). In order to understand how different local impacts are related to climate change, it is essential to also include monitoring of the local outdoor climate in the programme.

The selection process of indicators for a recently started climate change impact monitoring campaign in Norway, in which the authors of this paper were involved, is described by Haugen et al. (Haugen et al., 2018). The team developing the programme decided to use two simple criteria for selecting indicators: relevancy and practicality. Relevancy related to the ability of the indicator to indicate climate change impact, i.e. it should be possible to determine if a change in the indicator is due to a change in the climate, and not some other factor. Practicality meant the potential to use the indicator in practice, given the long time frame, limited available resources (financial and competence) and the availability of existing technologies. This was, in our experience, a simplistic but effective way of deciding between indicators. In the case of cultural heritage management, the problem is limited as the number of plausible indicators is not as many as in ecosystems, and most of the available indicators are directly relevant for the practical management. The key question revolves more around how monitoring programmes should be funded and organized, and which institutions should be accountable for their longevity.

Conclusions

The magnitude of risks related to the impacts of climate change makes it painfully obvious that we have to monitor the surrounding environments and the conditions of cultural heritage objects, buildings and sites in order to better understand the risk and to make informed decisions about adaptation measures.

In this paper we have argued that long-term, systematic monitoring is both a key to better decisions regarding management actions and an essential part of the scientific endeavour to calibrate and improve the risk models that underpin impact assessments. Monitoring programmes cannot live a life on their own, decoupled from management. We advocate that monitoring and management should be set-up and work in tandem in a framework of adaptive management, where feedback from monitoring provides double-looped organizational learning.

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References


Conservation heating (CH) is a common technology in northern European countries for lowering RH and has been extensively tested in practice (Broström et al., 2013). By using hygrostatic control instead of thermostatic control it is possible to keep a steady RH and also to reduce energy use (Broström and Leijonhufvud, 2008).

Dehumidification (DH) is achieved either by condensation or adsorption technology. Adsorption dehumidifiers are more effective at low temperatures and therefore favourable in unheated buildings during winter (Klenz Larsen and Broström, 2011).

Adaptive ventilation (AV) is a low-energy alternative for indoor climate control in historic buildings (Klenz Larsen et al., 2011; Klenz Larsen et al., 2014). A fan is activated when the absolute humidity indoors is higher than outdoors.

Introduction
Climate change is likely to increase the risk for mould growth in unheated historic buildings in northern Europe (Leissner et al., 2015). Historic buildings without proper climate control, which until now have had no, or at least manageable, problems with mould growth, might have to install active humidity control to avoid serious problems in the future. At the same time, there is a need to reduce the energy used by buildings to curb greenhouse gas emissions. Climate change thus calls for adaptation measures that are as energy efficient as possible.

In buildings with little or no demand for thermal comfort there are three principal technologies available for lowering relative humidity (RH) in order to eliminate mould growth: heating, dehumidification and adaptive ventilation.

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In addition to active control, the structural condition of the building should be considered, in order to minimise the intrusion of water through the building envelope.

The energy load to reduce RH, by any of three above mentioned technologies, is defined analogously to the heating load of buildings (EN 12831:2017). The load to reduce RH is characterised by the time of operation, indicating energy use, and the maximum capacity needed. This in turn determines running costs and investment costs for humidity control. In the following text, the load to reduce RH will be referred to as humidity load. The humidity load is determined by the actual level of relative humidity in relation to the desired level.

Energy efficient climate control is not only about technical solutions; it very much depends on the targets that are used. Conservative targets with a safety margin will inevitably result in higher energy use for climate control. A trade-off between “being safe or being sorry” is always involved in setting indoor climate targets with respect to preservation.

The present paper builds on a previously published technical cross-comparison of three different strategies for preventing mould growth in Skokloster Castle: conservation heating, dehumidification and adaptive ventilation (Wessberg et al., 2014; Eriksson, 2016; Justin Moll, 2016). Based on the results from this case study, the paper discusses the importance of understanding how the humidity load is affected by different control strategies and by the selection of safety margins in relation to commonly used mould growth limits.

**Case study: technical cross-comparison of three different strategies for preventing mould growth**

The case study was carried out at Skokloster Castle, a unique Baroque palace museum (Figure 1). The major part of the collection, which is dominated by objects from the 17th century, is still on display in its original historic setting. The castle is mainly open during the summer, but there are occasional guided tours also in winter. The upper floors of the castle have been unheated for centuries. A few rooms on the ground floor are permanently heated to provide thermal comfort for staff and visitors. An increase in problems with mould growth, especially in rooms facing north, has called for preventive indoor climate control.

The indoor climate of Skokloster is characterized by high thermal inertia and a high and unstable RH. Indoor temperature (T) has small short-term fluctuations and follows the average outdoor T with a time lag. Due to the relatively leaky building envelope there are large short term fluctuations in RH, driven by changes in the absolute humidity outdoors in combination with strong winds. The
Three rooms known to have mould growth were chosen as case study rooms. The active measures were rotated annually according to the schedule described in Table 1. Three similar rooms with no active climate control were used as reference. Rooms CS1, CS2, RF1 and RF2 were facing north-northeast and CS3 and RF3 were facing south-southwest. T and RH were monitored in all six rooms for all three years while energy use was monitored solely in the case study rooms.

Prior to the first year of the study all six rooms were draught proofed to improve air tightness. Conservation heating and dehumidification were controlled with hygrostats, with set points for T and RH set according to Sedlbauer’s Lowest Isopleth for Mould (LIM I) for susceptible building materials (Sedlbauer, 2002). This is a commonly used mould risk model for control pur-
poses. However, it should be pointed out that it does not reflect the full complexity of conditions for mould growth.

A safety margin of 3% in RH was used during the first year. In the second and third years a safety margin of 8% in RH was used. In the case of adaptive ventilation a fan was controlled by the ratio between indoor and outdoor water vapour partial pressure (Broström et al., 2011), running only when the ratio was larger than 1. The technical installations for the third year are shown in Figure 2.

Results from the case study

The results from the case study have been presented previously (Wessberg et al., 2014; Eriksson, 2016; Justin Moll, 2016). The following is a summary and short discussion laying the ground for the second part of the paper.

Draught proofing prior to the actual experiment reduced the risk for indoor mould damage and the need for humidity control much more than expected. Draught proofing appeared to have an effect equal to or better than that of active control. The room with the highest air exchange rate consistently had the highest risk for mould damage and the highest energy demand due to active climate control. Draught proofing also had a positive effect in terms of providing a more steady RH.

It should be noted that Skokloster Castle is a special building with none or very little internal moisture generation. In other buildings where moisture is added to the indoor climate from the construction and from visitors, draught proofing may not have equally positive effects. Either way, if active climate control is introduced, the building should be as airtight as possible.

Even though draught proofing had a significant effect, the reference rooms without active climate control, had an indoor climate with a significant risk of mould damage. This risk occurred during a limited number of short and well-defined time periods that were distributed throughout the year without any obvious seasonal pattern. Thus, the indoor climate at Skokloster is characterized by an intermittent and short-term humidity load in order to prevent the emergence of indoor mould growth.

Based on the above, it comes as no surprise that in the three rooms with active climate control, the time of operation was quite limited. Thus, energy use was low throughout the test years, regardless of measure, room or year varying between 32 to 443 kWh per year and room. Since the absolute numbers were so small, the cross comparison of the three different measures in terms of energy was not as conclusive as expected. However, dehumidification generally seemed to have the lowest energy demand. The total amount of energy used was so low though that the difference hardly could be important for the selection of control strategy in this particular case.

Given that the devices for dehumidification and conservation heating are designed with respect to the actual humidity load, both these solutions are sufficient to maintain a desired indoor climate. Adaptive ventilation will never be fully sufficient as its function depends on the weather, and thus an auxiliary solution is needed to cover extended time periods of humid outdoor climate.

The indoor climate in the rooms with climate control was kept within target range but only just below the mould damage risk limit. In spite of this, during the later stages of the case study mould growth was discovered in some of the rooms with climate control. Possible reasons for this could be:

- Microclimates in the rooms. Previous measurements with higher spatial resolution (Broström and Leijonhufvud, 2010) showed that there were none or very small T and RH gradients in the rooms. During the present study, the sensors were placed centrally in each room.
- Inaccurate sensors: The sensors were calibrated annually, but they have an inaccuracy of ±3%.
- Insufficient mould risk models.

Whatever the actual reason was, the solution could be to introduce a large enough safety margin. In the following part of the paper we will discuss this further.

Understanding the humidity load

To determine dehumidification load in residential buildings and offices there are established practices used by engineers (Winkler and Booten, 2016) but for buildings where preservation, rather than comfort is the main concern, there are no guidelines to follow. The present paper does not aim to present such guidelines but rather discusses and illustrates the need to understand the humidity load before deciding on solutions.
The humidity load depends on
- design conditions – what T and RH are we aiming for?
- T and RH of the outdoor air;
- air exchange rate in the building;
- moisture production from the building envelope, activities and people in the building;
- hygrothermal buffering of the building envelope.

The design conditions are not cast in stone as they are based on often complex negotiations (Winkler and Booten, 2016). In the following we will show examples of how different design conditions affect the load for humidity control.

**Load duration curves as a tool for understanding the load for humidity control**

A conventional time graph over RH, see Figure 3, gives a good chronological overview, but it is very difficult, if not impossible, to say anything about the humidity load. Load duration curves are commonly used for designing heating systems (Poulin, et al., 2008). A load duration curve is constructed by sorting all values of RH for one year, from the biggest to the smallest and plotting a curve, see Figure 3. The duration curve clearly shows the maximum value of RH and how long RH is above a certain threshold. In Figure 3 the maximum value of RH is 87% indicating the required capacity and investment cost. The time above a given RH level, for example, 1,000 hours above 80% indicates the time of operation for active climate control and thus the running cost.

**Humidity control strategies**

Often, humidity control is governed by a set point for RH. However, if avoiding mould growth is a main priority, indoor climate can be controlled in relation LIM 1 (Broström and Leijonhufvud, 2010), see Figure 4, where the risk for mould damage is defined in terms of both RH and T. As we will see, the control strategy will have an influence not only on the indoor climate but also on the energy use.

Duration curves can also be made to show the duration of mould damage risk. In this case we use the ratio between RH according to LIM 1 and measured RH to construct a mould damage risk index. Values of the index above 1 are above the LIM 1, and values below 1 are below LIM 1 (Figure 4).

Figure 5 shows duration curves for RH and mould damage risk index for one room in Skokloster castle without climate control. In relation to the mould damage risk curve, the indoor climate is above the threshold for around 300 hrs.
FIGURE 4. The lowest isopleth for Mould (LIM 1) growth on sensitive materials according to Sedlbauer (2002).

FIGURE 5. Duration curves for RH and mould damage risk.
If we instead use a set point for RH, for example 70%, the indoor climate will be above the threshold for 2,500 hours. Anytime the indoor climate reaches above the set point, climate control will be activated. Thus, this comparison would seem to indicate that using the mould damage risk curve would give a much lower energy use than using a fixed set point to control RH. However, control using LIM 1 leads to higher RH levels at low temperatures. This may cause hygroscopic moisture buffering in the building during winter which in turn may increase the humidity load during the summer season.

The difference between using the mould damage risk curve or a set point for RH was assessed by the use of whole building hygrothermal simulations on a church nearby Skokloster Castle (Håkansson and Thor, 2017). As can be seen from Figure 6, controlling the indoor climate by LIM 1 (with a 10% safety margin) reduces the humidity load during the winter, as compared to using a set value for RH. However, during the summer LIM 1 control results in a higher humidity load. In all, LIM 1 control would still have an annual duration of 5,000 hours as compared to around 6,000 hours using a set point for RH, but the difference is not as much as one would expect from looking at the duration curves only. This is probably due to seasonal moisture buffering.

**Safety margins**
As seen from the Skokloster case study safety margins may be needed with respect to the uncertainties involved. Duration curves, see Figure 5, can be used to assess the effect of introducing different safety margins. The duration curve for RH shows that RH is above 75% for around 2,500 hours. If introducing a safety margin by lowering the target to 70%, the indoor climate would be above the threshold for around 5,000 hours.

Depending on the shape of the duration curve, even a moderate safety margin may have a dramatic effect on the time of operation for humidity control.
The effects of climate change
Climate change in Northern Europe is expected to lead to a warmer and more humid climate resulting in higher RH levels and increased risk for mould growth inside buildings without climate control (Leissner, et al., 2015). Using duration curves, it can be shown that even small changes in the average level of RH may lead to dramatic effects on the humidity load. In the case of Skokloster Castle an increased indoor average level due climate change of for example 5 percentage points would have the same effect as lowering the present threshold by as much. The time of operation for humidity control would double in this case.

Discussion and conclusion
In Skokloster Castle, the results from the present investigation have been used to set a long-term strategy for prevention of mould growth. The first stage is draught proofing of all the windows in the castle, which will take some time given the size of the building. Even if weather stripping can be expected to have a significant positive effect on the indoor climate, the results from the reference rooms indicate there will still be a need for active climate control in order to prevent mould growth. In the present situation the need for active climate control is limited to short periods. However, even with relatively small long-term changes in the outdoor climate the time of operation for active climate control and thus energy demand can increase substantially.

More generally this paper points at the need for a method to define and understand the humidity load before deciding on a technical solution. A general strategy/approach is presented as follows:

1. Monitoring indoor climate and primary analysis: The objective here is to determine if there is a further need for improved climate control.
2. Expert analysis of existing mould growth, if any.
3. Improve air tightness: If the primary analysis shows a need for active climate control, the building should be made as air tight as possible.
4. Humidity load analysis using duration curves: A second monitoring period is necessary to determine the new humidity load following draught proofing.
5. Designing conditions: Choose control strategies and safety margins based on the calculations extracted from the duration curves indicating the consequences of different options.
6. Choose technical solution: Based on the above, choose technical solutions as described in this study for indoor RH control.

The choice of adapting a climate control strategy is important, both in terms of preservation and in energy use. The decision requires thorough analysis of the consequences following different alternatives. We have shown how small changes in the safety margin of indoor RH control or in the future outdoor climate can have major implications on energy use. In addition it is illustrated how load duration curves can be a simple yet effective tool to support decision-makers in making informed trade-offs between preservation and energy use.

For the future, the authors suggest three lines of research and development on climate control for mould growth prevention:

• Further development of methods to determine the design load for humidity control, i.e. the size of the equipment needed.
• Systematic investigations, in situ, of the effectiveness of different solutions for humidity control.
• The development and assessment of smarter control algorithms based on dynamic and more precise mould growth models.

Acknowledgement
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References


Ecclesiastical textiles and mould – strategies for prevention

Abstract
Textile conservators in Sweden have seen an increasing problem with mould growth on ecclesiastical textiles. This paper will describe how the mould infested ecclesiastical textiles are decontaminated and new out-breaks are prevented at Studio Västsvensk Konservering, a conservation studio in Gothenburg. Mould can be hazardous for the health and can damage ecclesiastical textiles. The Church of Sweden has a long tradition of using liturgical colours on ecclesiastical textiles and therefore our churches house a large number of valuable textiles.

An anonymized church, referred to here as Church A, with mould and dampness problems is used to illustrate the process of decontaminating the ecclesiastical textiles. On some of the textiles so called “sticky-tape tests” for spores and hyphens were taken and analysed by the Swedish research institute RISE.

The paper also describes that it is impossible to fight mould on ecclesiastical textiles if the climate in the vestry is not controlled and how good communication with the people involved in the care of the textiles in the church is key to obtain the desired results.

Keywords: mould; ecclesiastical textiles; churches; conservation

The Swedish tradition of church maintenance
There are approximately 3,400 churches in Sweden and they make up the largest collected cultural heritage in the country. Stone churches from the 12th century are still in use and it is important that the cultural and historic values are saved and looked after for the future. Although one of the most secular countries in the world, the church is still an important building and many people get married, baptize their children and finally have their funeral in a church and half of the concerts conducted take place in a church, this means that a church with mould and dampness can cause problems for visitors and staff.

Churches, their surroundings and the artefacts inside them are protected by the Cultural Heritage Act. The law governs the keeping of artefacts, such as ecclesiastical textiles, and only artefacts of a certain age and quality are covered. In fact, the law does not allow churches to independently deaccession artefacts, but rather demands that old artefacts taken out of service are kept in the church. The law states that the church is responsible for those artefacts detailed on their inventory list.

Since the year 2000 when the Church separated from the state, the state has given economic aid for the upkeep and preservation of church buildings, interiors and artefacts, through the Church Antiquarian Compensation Fund. In 2017, SEK 460 million was distributed. The amount given to each church or parish varies but is usually 60-85 percent of the cost for renovation and conservation.

This funding enables individual churches with smaller budgets to look after and conserve important objects. The parish to which the church belongs must apply for the financial compensation,
The use of liturgical textiles in Sweden

The use of liturgical colours is mentioned by the Pope Innocentius as early as 1198 AD. White, green, red, violet, blue and black are the standard liturgical colours. Black is no longer a compulsory liturgical colour but is still formally used on Good Friday and for some funerals. White and green are most commonly used and ecclesiastical textiles in white and green are consequently mostly exposed to stains and wear. Red and violet are only used a few times per year, blue is used more seldom. It is rather odd that a protestant nation has such a magnificent collection of ecclesiastical textiles. The Church of Sweden kept using liturgical textiles and their colours after the Reformation (Ridderstedt, 2008), when Sweden became a protestant country, simplified ceremonies and changed the use of artefacts in church service. During the 18th and 19th centuries, the use of several colours declined but in the mid-19th century, a deeper interest in the liturgical textiles increased leading to the reintroduction of the colours. Several studios made ecclesiastical textiles at this time and a lot of churches expanded their textile collections. The history of textile conservation in Sweden took its shape during the beginning of the 20th century with knowledgeable and gifted textile artists for example Agnes Branting with ateliers Handarbetets Vänner, Licium and Pietas among others, promoting high quality fabrication and care of ecclesiastical textiles, shaping the future and paving the way for textile conservators working today (Ridderstedt, 2008). Many of the newly produced objects were of good quality and of a very high artistic standard, the ateliers imported exclusive fabrics and materials. Even smaller churches in poorer areas would invest in high quality textiles such as those in the image (Figure 1), sometimes supported by donations from wealthy patrons. In the 1970s a trend towards simplicity in the production of ecclesiastical textiles could be noticed with more abstract motifs and often heavier hand-woven fabrics. Numerous church carpets of a very high standard were produced in this country and are still in use today. Many of the textiles are irreplaceable valuable pieces of art in their own right and should be given the best conditions possible to withstand the tests of time.

The use of liturgical colours is reviewed by the county administrative board in accordance with a certain protocol. The process can take a few years, which means in practice that conservators can detect mould-infested textiles and it can take another two years until the textiles will be treated.

FIGURE 1. Chasubles in a variety of liturgical colours and qualities at SVK. Photo: Rebecka Karlsdotter.
This treasure of ecclesiastical textiles calls for a high level of responsibility in care since most churches would never be able to replace a damaged silk chasuble with something similar of the same quality, the cost would simply be too high. Ecclesiastical textiles are often made from various high-quality fabrics and materials, some are made from the finest silk fabrics and silk-velvet is common in older types of chasubles. Sometimes the textiles are decorated with metal-threads, silk embroidery and applications. Historic ecclesiastical textiles taken out of service but kept in the church can sometimes cause a problem as they might need extra care and take up space.

Church/vestry interior
The climate in the vestry is very important, if it is too damp it can increase the risk of microbiological growth like mould attacking the ecclesiastical textiles. It is key to change the environment of the textiles placed in cupboards and wardrobes in the vestry, otherwise all the work put into the textiles is futile. Textiles hanging too close to each other, not allowing air to flow, is often a culprit but new furniture for the vestry can be designed to make a better environment for the textiles. As textiles absorb humidity from the human body it is advisable to hang chasubles on a standing hanger after use and let them dry before placing them in the wardrobe again. General maintenance like this can hugely improve the conditions for the textiles.

Mould
Mould is a biohazard. It can deteriorate fabric, cause allergies and asthmatic attacks. A mouldy building may smell, some describe it as a “musty cellar-smell”. Microorganisms exist everywhere where life is present and are an important part in the biodegradation process in nature (Edebo, 1999). Climate change, with an increase in precipitation and higher temperatures increases the risk of indoor microbiological growth. “Church mould” is often present in churches, especially in microclimates, even when RH is low in the larger

FIGURE 2. Lining of a very mould infested chalice-cover that has been framed behind glass trapping dampness and preventing the air movement. Photo: Lotti Benjaminsson.
problems with dampness and mould stains, making it more difficult to detect and also preventing movement of air. Research shows that certain mycotoxins may influence immune cells causing an increased risk for allergies and that extremely small doses (picograms) are enough to start the process. It has also been detected that mould fungi release very small hyphae fragments that never sediment. These particles are smaller than spores and are very effectively distributed in the lungs. In practice this mean that our exposure to mould can be many hundred times higher than previously estimated (Bloom, 2008). The actual risks or perceived risks of working in a mould infested church can be the same. Sometimes the symptoms cannot be measured and can very well be experienced by only one individual. However, it is important to recognize the symptoms. You can react to wearing a chasuble that is infected by microbiological growth and mould, the reaction can be rapid and acute or give milder symptoms such as itchy eyes, headaches and a runny nose. It can also cause an acute asthmatic attack (Bloom, 2008). Mould shows up well in UV-Flourescence, see figure 3. The microbiological damage can lead to deterioration of the textile fibers. Mould can also discoulour and stain lighter coloured fabrics leaving dark spots. Mould infested textiles like a chasuble worn close to the body or a chalice-cover close to the wine to be consumed in the mass is a definite health hazard.
Method

How ecclesiastical textiles are initially decontaminated at Studio Västsvensk konservering (SVK)

Initial inspection of a church. By wearing a protective mask when examining textiles in churches we avoid the risk of allergic shocks.

- Affected textiles are taken into the conservation studio for initial decontamination and investigation. Usually the church arranges the transportation of the textiles to us. We request that they are packed together wrapped in a cotton fabric and plastic wrapping.
- Textiles are frozen for at least seven days. Freezing will not kill fungi but as a safety measure we always freeze artefacts upon arrival at SVK as there can be other pests, like moths, present. Heat can be used as a way of “killing” mould but is not advisable as such high temperatures can lead to degradation of the textiles (Edebo, 1999)
- If sticky-tape samples are taken they are taken after the freezing.

- Basic photos are taken of the full textiles, front, back, insides and outsides before we start the decontamination. Details of affected areas or damages are also photographed. Work is carried out in a safe and organized manner to minimize any risks of harm or allergic reactions.
- Tyvek overalls, P3 masks and goggles together with protective disposable gloves are used for protection. The work takes place in a designated room that has a good extraction system and contaminated textiles are kept separate from other textiles, shown in Figure 4. A small mould-infested area on the outside of a chasuble can mean a larger damage/growth behind the lining!
- Visible mould is removed mechanically by using a vacuum cleaner with HEPA filter (High Efficiency Particulate Arresting filter). For a HEPA filter in a vacuum cleaner to be effective, the vacuum cleaner must be designed so that all the air drawn into the machine is expelled through the filter, with none of the air leaking past it.

Conservation, restoration and the future handling of the textiles

If mould is detected on several textiles, we try to treat all textiles as if they were affected. The textiles are always kept separate from other items and well covered when in the studio care (Bengtsson, 2012). Vacuum cleaning is followed up by washing the objects by hand, using water and a surfactant. We change linings that need and can be replaced if they are mouldy and carry out renovation and conservation as needed on the textiles. It can be argued that the quality of a good linen fabric from an older textile cannot be obtained these days. We go to great lengths trying to find proper fabrics if anything must be replaced and therefore, we sometimes must import fabric or dye existing stock. Ecclesiastical textiles in use may have to be repaired and conserved with a utilitarian mind and by relining a chasuble with new fabric, its lifespan can be prolonged, and the priest can wear it without experiencing any allergy symptoms. It is an on-going challenge to make these textiles useable in ceremony and let them withstand the test of time at the same time. Old fashioned chasubles can have linings stiffened with paper like old manuscripts or book pages that can hold humidity and there is always a risk of mould in hidden places such as hemlines and inside linings on textiles.

Church A

Upon a visit to a church built in 1914 a textile conservator reacted to the amount of mould infested textiles in the vestry. The church was still in regular use and the vestry itself had had problems with high humidity and a mouldy smell for some time. The textile cupboard, in the vestry of the church, was positioned by the outer wall with no air circulation resulting in a damp microclimate. During closer inspection active mould could be seen on some of the ecclesiastical textiles, even on some of fairly recently acquired textiles used regularly. There were 20 textiles in the vestry and mould was found on 11 of them. The chasubles were hanging in a very small wardrobe placed against an outer wall so close to each other that the air could not circulate between them. The chasubles being used the least hung in the back and were affected the most. The 11 ecclesiastical textiles with visible mould were examined. The textiles are described in Table 1. Sticky-tape tests were taken on six of them before the initial cleaning to measure the amount of mould present before and after decontamination, see Table 2.

Test by Research Institutes of Sweden AB (RISE)

Microbiological growth on the textiles was tested by RISE to see if one could measure the quantity of mould before and after the cleaning. The microbiological analysis was conducted by sticky-tape samples taken on the infested textiles (Urzi & De Leo, 2001). Affected areas were marked with tacking thread to know where the samples were taken on the object and the samples were sent to RISE for analysis. The method used is a quantitative analysis of micro fungi and actinomycetes using microscopical technique. The sticky-tape samples are transferred to glass slides, dyed and analysed in 400-1,000 times magnification under a microscope (Ekstrand-Tobin, 2018).

Table 2 shows the results of the sticky-tape samples reported by RISE. The points were marked on the textile with tacking thread to make it possible to take new tests after the initial cleaning. A number of the samples were not tested after the initial cleaning and are therefore not included in the table, since no conclusion regarding the effectiveness of cleaning can be reached.

Communication

Monitoring the climate in church buildings is vital and requires interest and skills. Usually the approach to problems with humidity in a church is professional but sometimes employees in the church trivialize the problem with mould and dampness, which has led to prolonged mould attacks on textiles. If the church-staff learn to be proactive problems could be detected early. Climate change is a challenge for the churches and so are new functions like toilets and kitchens that have been incorporated in the church building. How do we deal with wet rags, left-over flowers and the risk of water leakage in cleaning cupboards in churches from a conservation point of view (see Figure 5)?

The care of the textiles in the churches is often undertaken by church wardens or volunteers. Skills in textile-care that the church depends on and has counted on for many years are not always present nowadays and this fact needs to be acknowledged when planning for the care of the textiles in the
### Table 1. Examination of textiles from Church A before initial cleaning.

<table>
<thead>
<tr>
<th>Object</th>
<th>Mould</th>
<th>Foxing</th>
<th>Cleaned</th>
<th>Further treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Altarcloth, red</td>
<td>Large patches and smaller spots of mould on wool fabric</td>
<td>Not seen</td>
<td>Brushing and vacuum-cleaning</td>
<td>Cleaned with surfactant and water</td>
</tr>
<tr>
<td>Altarcloth, green</td>
<td>None on silk fabric. On lining and on tablecloth. Test 8</td>
<td>On lining and on tablecloth</td>
<td>Brushing and vacuum-cleaning</td>
<td>Cleaned tablecloth and lining replaced</td>
</tr>
<tr>
<td>Chasuble, red wool</td>
<td>Mouldy spots over larger areas on outer fabric. Test 3a, 3b</td>
<td>Not seen</td>
<td>Brushing and vacuum-cleaning</td>
<td>Cleaned with surfactant and water</td>
</tr>
<tr>
<td>Chasuble, green wool</td>
<td>Mouldy spots over larger areas on outer fabric. Test 5a, 5b</td>
<td>Not seen</td>
<td>Brushing and vacuum-cleaning</td>
<td>Cleaned with surfactant and water</td>
</tr>
<tr>
<td>Chasuble, velvet, violet</td>
<td>Mould on lining and outside-fabric. Test 6a, 6b</td>
<td>Not seen</td>
<td>Brushing and vacuum-cleaning</td>
<td>New placement</td>
</tr>
<tr>
<td>Chalice veil, older.</td>
<td>Mould covering the whole textile on both sides. Test 4a, 4b</td>
<td>Not seen</td>
<td>Brushing and vacuum-cleaning</td>
<td>New placement in acid-free cardboard box</td>
</tr>
<tr>
<td>Collection bag, red</td>
<td>Small mouldy areas on outer silk</td>
<td>Not seen</td>
<td>Brushing and vacuum-cleaning</td>
<td>Protection bags made, new placement</td>
</tr>
<tr>
<td>Collection bag, green</td>
<td>Small mouldy areas on outer silk</td>
<td>Not seen</td>
<td>Brushing and vacuum-cleaning</td>
<td>Protection bags made, new placement</td>
</tr>
<tr>
<td>Priests coat</td>
<td>Large attacked areas at hemline and lower part</td>
<td>Not seen</td>
<td>Brushing and vacuum-cleaning</td>
<td>Cleaned with surfactant and water</td>
</tr>
<tr>
<td>Stole, black, lining</td>
<td>Mould on lining</td>
<td>Not seen</td>
<td>Brushing and vacuum-cleaning</td>
<td>Lining replaced</td>
</tr>
<tr>
<td>Stole, violet, lining</td>
<td>Mould on lining</td>
<td>Not seen</td>
<td>Brushing and vacuum-cleaning</td>
<td>Lining replaced</td>
</tr>
</tbody>
</table>

### Table 2. Tests conducted by RISE.

<table>
<thead>
<tr>
<th>Point</th>
<th>Textile</th>
<th>Tested by RISE: Hyphens. Before initial cleaning</th>
<th>Tested by RISE: Spores. Before initial cleaning</th>
<th>Tested by RISE: Hyphens. After initial cleaning</th>
<th>Tested by RISE: Spores. After initial cleaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>1a, 1b</td>
<td>Black stole, lining.</td>
<td>Sparingly</td>
<td>Abundant</td>
<td>Sparingly</td>
<td>Sparingly</td>
</tr>
<tr>
<td>3a, 3b</td>
<td>Red chasuble</td>
<td>Abundant</td>
<td>Abundant</td>
<td>None</td>
<td>Sparingly</td>
</tr>
<tr>
<td>4b</td>
<td>Chalice Veil, black velvet</td>
<td>Abundant</td>
<td>Abundant</td>
<td>Not tested. The object will be kept separate in a box.</td>
<td>Not tested. The object will be kept separate in a box.</td>
</tr>
<tr>
<td>4c</td>
<td>Chalice Veil, black velvet, lining</td>
<td>Abundant</td>
<td>Abundant</td>
<td>Not tested. The object will be kept separate in a box.</td>
<td>Not tested. The object will be kept separate in a box.</td>
</tr>
<tr>
<td>5a, 5b</td>
<td>Green Chasuble</td>
<td>Abundant</td>
<td>Abundant</td>
<td>Abundant</td>
<td>Abundant</td>
</tr>
<tr>
<td>7a, 7b</td>
<td>Red altar cloth</td>
<td>Abundant</td>
<td>Abundant</td>
<td>Sparingly</td>
<td>Sparingly</td>
</tr>
<tr>
<td>8</td>
<td>Linen lining from green altar-cloth.</td>
<td>Abundant</td>
<td>Abundant</td>
<td>Not tested as linen fabric will be replaced</td>
<td>Not tested as linen fabric will be replaced</td>
</tr>
</tbody>
</table>
church. If there is a checklist it is recommended to ask the people actively working in the church about their routines and let them explain how they work towards the recommendations by scrutinizing their own answers. Finding solutions that work and rules that are easy to follow, for example fool proof written housekeeping rules together with a calendar, will open up for good routines in handling the ecclesiastical textiles over the liturgical year. The recommendations from the Swedish National Heritage Board are a valuable resource and can be used in combination with directions for the individual church.

After conservation and decontamination is carried out it is good idea to present what has been done and why to the church-staff. It is better to have a discussion in-situ rather than just write recommendations in a conservation report that might not be read by everybody handling the textiles. Doing this in the actual church opens for discussions and is also an opportunity to point out difficulties and their solutions on a positive note.

**Conclusion**

During the project with this specific church we came to some conclusions regarding the practical decontamination and future handling of the textiles.

Analyses of the mould type can be of interest but at is also a source for misunderstanding and false security as every sticky-tape sample only covers a small piece of the fabric, if taken in the wrong part of the textile it can be misleading. To analyse objects can be costly and takes time and is probably not doable on a regular basis. If mould is seen or if other signs of a visible mould outbreak are spotted there is probably a problem with the climate (or microclimate) in the church building.

Communication skills are important and clarity in communication with the people actively working in the church is vital, as is the ability to listen to information given by administrative personal, churchwardens and laymen. To learn about new research by attending conference and workshops is also crucial for conservators.

Good routines and proper monitoring of the climate and microclimate where the ecclesiastical textiles are kept will minimize the risk of new mould out-brakes. By being curious when entering a church for the first time fewer problems with damp and mould will go unnoticed. Use protective gear when working with mould infested textiles and always wear a mask if in doubt when entering a church that might have problems with mould. Climate change can make the problems with mould and dampness worse in a church and will affect the textiles. If the vestry has been rebuilt and renovated the storage for the textiles might have to be redesigned as well. Sometimes a textile conservator can give important input or even design the new storage to aid in the handling of the textiles for the future. The vestry in Church A is now being rebuilt with a free-standing cupboard and floor-heating to prevent the dampness problems in the future.

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**FIGURE 5. Cleaning cupboard in church, showing damp conditions and general untidiness. A perfect spot for mould growth!** Photo: Rebecka Karlsdotter.
References


Application of humidified warm-air treatment to entire historic wooden buildings at Nikko World Heritage site to control insect attack

Abstract
To control insect attack, mainly by beetles, in historic wooden buildings in Japan, a humidified heat treatment system for large-scale treatment was developed, and it was applied to two wooden Buddhist buildings in Nikko in Japan, in November 2017 and September 2018. The temperature of the airflow was increased from atmospheric up to 60 °C at a rate of 0.3 °C per hour and kept at 60 °C for three days. The humidity of the airflow was controlled so that the moisture content of the wooden parts was kept at initial air-dry level of about 15 %. In the process of cooling down, another unit was employed for generating cooler and dry airflow to avoid water condensation in the treatment system. It was confirmed that the air in a treatment volume of about 400 m³ can be controlled successfully by the developed system. The treatment ability was confirmed by the mortality of the test insects at several stages evaluated in a wooden sample. The strain both on the wooden surface and the Japanese lacquer surface finish was also evaluated using strain gages attached to the wooden members and test specimen. The strain was smaller in comparison with results obtained by a long term strain monitoring for the actual wooden members of the buildings in Nikko. No colour change on surface finish, crack generation or deformation of the wooden parts was detected as a result of the treatment.

Keywords: humidified warm-air treatment; wooden historical building

Introduction
Treatment using humidified warm air is known as one of the effective, safe and environmentally friendly methods to control insect attack in historical properties, and is increasingly popular mainly in European countries (Ertelt, 1993; Thomson, 1995; Kneppel, 1995; Leary, 2002; Beiner, 2005; Ackery, 2005; Tscherner, 2008; Tscherner, 2008). By increasing temperature to around 55 to 60 °C and maintaining it for a couple days, all the stages of the insects inhabiting the objects, egg, larva, pupa and adult will die. This method is applied to smaller objects in museums by placing them in a special chamber for the treatment. It is also applied to the entire or part of a building in some cases (Nordt, 2006; Rotberg, 2007). The key technical point when this method is applied to wooden objects is to humidify the objects during the heating process and to dehumidify during the cooling process, so that the moisture content of the wooden object is kept at a constant equilibrium level. Through this approach, no shrinkage or swelling is expected of the wooden objects, and as the result, we can minimize the risk of cracks, deformations or irreversible strain on the objects. The expansion or shrinkage that would be generated by the temperature change alone should be relatively small in comparison with those due to the moisture change.
Treatment unit. (Figure 1a).
Temperature / humidity sensor located at the center of the building. (Figure 1b+1c).
Steam generator with water softener in control unit. (Figure 1d).
Electric generator driven by diesel engine. (Figure 1e).
Dehumidifying control unit. (Figure 1f).
Dehumidifying ducts attached to thermal isolation covering. (Figure 1g).
This method is under development and before its application to the Japanese historical objects and buildings, we have to investigate not only the effect on our domestic wood attacking insects, but also the influence of the treatment on the objects, which are often finished with urushi (Japanese lacquer) or constructed with wooden post and beams of larger size.

We have started a series of research and development projects since 2013, starting with a survey and basic research on the related technologies, insect activity in Nikko area and some laboratory tests on efficiency and influence of the method. We have also invited researchers and engineers from abroad for further advice. Additionally, we have conducted a one-year continuous measurement of the surface strain of the buildings generated by the combination of temperature and relative humidity change by the local climate. Following this we developed a small treatment chamber of about 30 m³, powered by electricity, with a fan, a heater, a steam injector, a dehumidifying apparatus and a control unit. We have confirmed the performance of the chamber and developed another system for whole building treatment. After the repetition of the test treatment, we have developed a system for...
the treatment of full size building and applied it to two buildings in the Nikko area, in November 2017 and September 2018 respectively, as a verification test.

**System configuration**

The system consists of eight treatment units. Each unit consists of a heater, a fan and a steam injector. The hall was covered by a provisional roof and wall structure and it was thermally insulated and air-tightened. A water softening apparatus was employed to avoid the mineral deposits due to impurities in the steam generated from tap water. Apparatus powered by combustible gas such as propane is not allowed in Japan, thus the developed system was driven by electricity generated by the nearby diesel engine generator. The units are controlled by the temperature/humidity sensors located in the centre of the building. A dehumidifier was also employed to avoid water condensation in the cooling process (Figure 1). Strain sensors monitored the surface strain on the wooden members. Temperature/humidity sensors embedded in the test wood specimen of 30 cm³ were also used. Test plates finished with urushi and Japanese traditional painting were used for colour analysis before and after the treatment (Figure 2).

**First verification treatment “I-zen-do” in November 2017**

“I-zen-do” is a small hall that belongs to the Chuzenji temple and is located at the lakeside of the Chuzenji lake. It is about 7 meters high and 5 meters wide and deep, and with a statue on an altar in a prayer room. It is constructed by wooden post and beam method. Most of the wooden structures in- and outside of the building are finished with urushi. Heavy attacks by anobiid beetles are confirmed in the construction parts such as posts, beams, sill and rafters.

**Schedule of humidified warm-air treatment.**

The allocation of the units and other apparatus is shown in Figure 4. The schedule of the treatment was as follows: starting temperature/relative humidity 18 °C/73 %, increasing up to 60 °C/83 % taking three days, retention time of two days, decreasing down to 10 °C/73 % taking three days. This was based on the average moisture content at the seven posts and the regional equilibrium moisture content. The treatment was finished at the 9th day (Figure 5) The warm air was drawn along the peripheral walls and introduced slowly toward the inside of the building by the intake fan set in the hall floor.

**Results and discussion**

The change in temperature and absolute humidity in the treatment area measured at several representative points in the hall, under the floor and in the attic is shown in Figure 5. It can be confirmed the temperature and the relative humidity are controlled in line with the schedule explained above. As Figure 5 shows, the distributions in temperature/relative humidity measured by about 400 sensors in the treatment area was almost uniform at about 60 °C and 83 % during the retention time, respectively, no local large deviation in temperature and humidity was found.
As an indicator of the efficiency of the treatment, live powder post beetle *Lyctus africanus* of different stages were used. They were put into a hole in the air-dried wood specimen (*Zelkova serrata*) of 30 cm³ and the hole was sealed. The specimen was set in the treatment area and the mortality was evaluated. No adult generation was found from the specimen exposed to the treatment. Adult beetles were found in a control wood specimen.

Figure 6 shows the temperature distributions inside of test specimen measured by embedded or attached sensors over four days just before and during the retention time. At the beginning of the retention period, the temperature at the centre has not reached 60 °C (in blue lines), however, in four days the temperature distribution becomes uniform at the set temperature.
FIGURE 6. Temperature distributions inside of test specimen measured by embedded or attached sensor over four days just before and during the retention time.

FIGURE 7. Surface strain of the cubic specimens of 30 cm, made of solid wood and wood finished with urushi.
the treatment on the shaded side of the building remained for a long time. It is necessary to confirm, if these strains would cease over a longer period of time, and to clarify the mechanism.

Second verification treatment

"Sho-row" in September 2018

"Sho-row" in Chuzenji

Sho-row is the bell tower that belongs to the Chuzenji-temple located also at the lakeside of Chuzenji-lake. It is constructed by wooden post and beam method. Wooden walls surround the frame construction with the curvature covered by copper plate at its lower part. At the top of the building, a bell is hung from the main beam. In the upper part of the building, posts and beams are finished by urushi technique. The wooden roof is covered by copper plate. The building is about 15 meters high and 7 meters square. Heavy attack by anobiid beetles was detected in the previous survey.

Outlines of treatment

Based on the results of the first verification treatment, we have improved the treatment system and the second verification treatment was conducted in September 2018. The hardware of the system is

Figure 7 shows the change in surface strain during the treatment. The strains both for solid wood and wood finished with urushi show a similar tendency. In this process, the moisture content of wooden object should be kept at a constant level, so that no strain due to the change in the moisture content is generated (Takeguchi, 2017). The measured strain was due to the temperature increase and it was of about $1000 \times 10^{-6}$, and it reduced to zero after the treatment. The strain in the tangential direction is much larger than the one in the longitudinal direction. The anisotropy in the strain of urushi layer suggests it expands or shrinks in accordance with the changes in the wood. By taking the results from another experiment into consideration (Takeguchi, 2017), the strain change due to the change in moisture change was not detected. The strain was lower than that in wooden parts exposed to the local climate.

Figure 8 shows a long term strain monitoring on wooden members of the hall before, during and after the treatment. The strains measured by the sensors attached to the wooden parts on the sunny side of the building changed during the treatment and recovered to the initial values just after the treatment. However the strain generated during the treatment on the shaded side of the building remained for a long time. It is necessary to confirm, if these strains would cease over a longer period of time, and to clarify the mechanism.

Figure 8. Long term strain monitoring on wooden members of the hall before, during and after the treatment

“Sho-row” bell tower located at the lake side Chuzenji-ko. (Figure 9a)

“Sho-row” covered with thermal isolation scaffolding installed with treatment devices. (Figure 9b)

Roof part of the thermal isolating scaffolding. (Figure 9c)

Inside of the treatment area. (Figure 9d)

Ducts for air-pull-out near ground level. (Figure 9e)
the same as the first verification treatment, but we have strengthened the thermal isolation. Figure 9 shows the outline of the treatment. The treatment was conducted in the same manner as the first verification test, but with the change in the treatment schedule.

Summary
We have investigated humidified warm air treatment of two Japanese wooden buildings to control insect attack, and confirmed the feasibility of the methods, although there are still technical problems such as cost/efficiency optimization and a long-term influence evaluation of the treatment on the objects, etc. The treatment can be applied, for example, in combination with the normal restoration process, such as renovation of roof tiles. By this method, we can control insect attack to a zero level without any after effects. It is important to maintain inspection for insect activity as part of regular maintenance.

Acknowledgement
The authors express special thanks to Dr. Tom Strang, Senior Conservation Scientist, Canadian Conservation Institute, and Mr. Nikolaus Wilke and his colleagues, Thermo Lignum® GmbH for their kind and significant advice. The authors also express thanks to the Association for the Preservation of the Nikko World Heritage Site Shrines and Temples, Japan, for their kind support. This project was partly supported by JSPS KAKENHI Grant Number JP 15H01778.

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Literature


Introduction
The English Heritage Trust (EH) is a charitable body that looks after over 400 historic buildings, monuments and archaeological sites and their associated artefacts. As well as those displayed at sites, there are several collections stored in other buildings. Since 2015 EH has experienced outbreaks of furniture beetle (Anobium punctatum) in wooden pallets at two large stores. In both instances adult furniture beetles were first spotted emerging in autumn, which is at odds with the currently held view that the adults emerge during spring and early summer (Pinniger and Lauder, 2018). Whilst the infestations are currently in the pallets, there is a risk of spread to historic wooden objects in the stores as well as compromising the structural integrity of the wooden pallets themselves. In order to control these infestations effectively and to prevent further outbreaks, questions arose relating to why adult beetles are emerging in autumn and also what conditions A. punctatum need to develop and reproduce.

Emergence details
Helmsley Archaeological Store (HA Store) is a 5,000 m³ warehouse in Yorkshire housing over 1,300 pallets of objects from EH sites in the north of England, including architectural stonework and archaeological finds. There is no environmental control and minimal insulation, which is not a
risk to the majority of the stonework stored in this space. Wooden pallets are housed on a mixture of five-metre high static and mobile racking.

On 10th November 2015 (late autumn in the UK), hundreds of furniture beetle bodies were discovered on the floor of one of the aisles. This aisle had been cleaned 14 days earlier and no beetles were found. A full inspection of the store revealed over 400 pallets with flight holes and/or frass present, centring around one aisle. The concentration of affected pallets noticeably diminished when moving away from this aisle. The exact source remains uncertain but is assumed to be a pallet or pallets moved into the store.

In February 2016 numerous pallets previously identified as being sound, showed signs of furniture beetle activity. In November 2018 beetle emergence continued with numbers in the thousands – too many to count individually! The structural stability of pallets affected became a concern. On average, loads in excess of 250 kg are standard within the store and collapse of a pallet at the top of five-metre high racking could be catastrophic. There is also a fear that the small numbers of wooden objects within the store were being placed at risk with such widespread beetle activity in the building.

Wrest Park House and Gardens is a historic site in Bedfordshire. In 2011–2012 a 1950s industrial building on the site was refurbished to become the Wrest Park Collections Store (WPC Store) housing over 170,000 archaeological and architectural artefacts. The store is divided into several sections, of which Area 1 (6,060 m²) and Area 2 (2,600 m³) are both fitted with static racking and objects are stored on wooden pallets. Area 1 contains approximately 900 pallets of bulk archaeological finds, predominately stone and ceramic material and is well insulated with good passive environmental control. Area 2 contains approximately 400 pallets of large architectural pieces, many of which are constructed from wood. The environment is controlled by two Munters MCS 300 dehumidifiers with a set point of 75 % RH as the materials are robust (architectural fixtures and fittings) and conditions were predicted to rise to 75 %RH for 20 % of the time. (Xavier-Rowe et. al., 2014).

On 1st November 2017 in Area 2, pale powder was noticed on 19th century bell jacks. These are originally from a massive clock from a demolished
carried out every time the store is opened (usually several times a week) no one could be certain when the frass had appeared and so we can only narrow down the potential date of emergence to between 9th October and 1st November 2017.

A survey of all objects and pallets in Area 2 was undertaken during November 2017 and 290 furniture beetles were found. Upon visual inspection a pattern of infestation emerged: old pallets were affected whilst newer ones nearby, as well as wooden artefacts, didn’t show evidence of beetle activity. All new pallets had been heat treated before use in the store. A small number of large, heavy or awkwardly shaped objects were still on old pallets that they were stored on in a previous store. These pallets may be the source of the furniture beetle infestation.

On 29th November 2017, frass was also discovered on a pallet in Area 1. This pallet had been checked for other reasons on 28th November and no frass was present. Furniture beetles caught on traps and collected were recorded to help measure activity, see Table 1.

Review of the lifecycle of *Anobium punctatum*

*Anobium punctatum* has been associated with man and his dwellings for thousands of years (Child and Pinniger, 2014). Some of the earliest documented records in the UK are from the archaeological remains of wooden buildings in York (Kenward, building, in the form of larger-than-life-size tradesmen, carved from walnut and painted black. Closer inspection showed that it was frass that had dropped down from pallets above. The bell jacks are a feature of public tours and so close attention is paid to cleaning the surrounding area. A team of volunteers cleaned on 9th October 2017 and there was no frass present. Whilst checks are

![Figure 4. Frass on wooden bell jacks. Photo: English Heritage.](image)

**TABLE 1.** *Anobium punctatum* numbers at WPCS, both caught on sticky traps and collected up

<table>
<thead>
<tr>
<th>Date / Location</th>
<th>Total number of beetle bodies Area 1</th>
<th>Total number of beetle bodies Area 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Third quarter 2016</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>(July to September)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Third quarter 2017</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>(July to September)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fourth quarter 2017</td>
<td>0</td>
<td>290</td>
</tr>
<tr>
<td>(October to December)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>First quarter 2018</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>(January to March)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Third quarter 2018</td>
<td>9</td>
<td>17</td>
</tr>
<tr>
<td>(July to September)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>November 2018</td>
<td>33</td>
<td>74</td>
</tr>
</tbody>
</table>
Williams and Addyman, 1979). Its biology and behaviour have been researched by a number of authors, including Hickin (1975), Ridout (2000 and 2012), and Unger, Schniewind and Unger (2002). It is generally accepted that in Northern Europe the female beetles emerge from the wood and mate in spring. This is triggered by both temperature and length of daylight resulting in the main emergence occurring from March through to June, or even July. In some years a few individuals emerge outside this window, although the causes are not known. The furniture beetle was introduced into Australia in the 19th Century and is now well established in the South East coastal areas. The main emergence period is September to December, which means the beetle has adapted to emerge in the Australian spring and early summer (French, 1968).

The observations of the main emergence of *A. punctatum* in the autumn have, as far as the authors are aware, never been recorded before in the UK. It is possible that *A. punctatum* has adapted to a change in conditions caused by recent changes in climate, much as has been found in those residing in Australia (French, 1968). There could be the possibility of adaptations in the DNA of the beetle populations that have been found in the stores. This is a much understudied area and would need considerable research to make specific conclusions.

Knowing what environmental conditions (principally RH) will support *A. punctatum* infestation is critical to understanding how these conditions may be controlled to prevent infestations. Additionally, understanding whether parts of the life-cycle are particularly sensitive to parameters such as temperature and relative humidity, could provide a method for controlling and eliminating infestations. The female beetles lay up to 30 eggs in cracks or end grain of wood which, it has been suggested, needs to be above 10–12 % equilibrium moisture content (EMC) for the eggs to hatch and the larvae to burrow into the wood (Becker, 1942; Spiller, 1948; Bletchley, 1957; Williams, 1983; and Unger, Schniewind and Unger, 2001). Although it is difficult to study the development of an insect that lives inside wood, it is generally accepted that there may be up to six or seven larval stages before pupation. The length of this development period can vary enormously depending on the key factors of temperature, nutritional value and EMC. In ideal conditions (> 65–70 % RH and 21–24 °C

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**FIGURE 5.** Summary of data from literature on the effect of temperature and relative humidity on the development of *A. punctatum.*

Key: dark green – optimal conditions; light green – activity possible; yellow – activity significantly decreased; red – activity not supported. (Unger, Schniewind and Unger, 2001; Becker, 1942; Spiller 1948a; Bletchley, 1957).
Whilst there are no published studies showing at what point *A. punctatum* larvae would no longer survive, Williams (1983) studied a closely related Anobiid: *Xyletinus peltatus*. Williams found that at 25 °C the RH at which no young larvae survived was 59.1 ±2.6%, equating to an EMC of 11.6±0.7 %. Importantly though Williams found that an EMC of 11.9 ± 0.4 % or lower for 13 weeks after larvae had already reached three, six, or nine months old did not reduce survival. Therefore only three months of above 12 % EMC would allow for the Anobiid insects to lay eggs that could survive and proceed through the lifecycle stages to a point where EMC would not prevent activity. Williams (1983) suggests that if EMC remains below 12 % throughout the year Anobiid infestations would die out.

**Equilibrium Moisture Content of Wood**

The species, dimensions and age of wood can all influence its response to changes in environment (Bratasz, L. et al., 2008). Pine is the most frequently used wood for pallets, but even then the subspecies and extractive content (e.g. resins and phenolic compounds) affects the isotherm, the

(11, 21, 31, 41, 51, 61, 71)
FIGURE 7. Helmsley Archaeological Store 2017 temperature and relative humidity measurements plotted over the risk of *A. punctatum* activity as in Figure 5.

FIGURE 8. Wrest Park Collections Store 2017 temperature and relative humidity measurements plotted over the risk of *A. punctatum* activity as in Figure 5.
way in which it absorbs and desorbs moisture. In order to determine the relationship between RH and EMC isotherms were measured gravimetrically for five unused pallets from WPC Store.

The samples were dried at 110 °C for seven days, cooled in 0 % RH conditions and weighed. They were deemed dry when three consistent weights were recorded. Replicate samples were then exposed to 5 % RH intervals from 35 % to 85 % in sealed glass Mason jars above glycerol solutions. Other replicates were equilibrated at 85 % RH before being exposed to lower RH environments. The calculated values were confirmed using a NAMAS traceable calibrated Rotronic probe. The pallet samples were weighed until equilibrium was reached and three consistent measurements were recorded. Gravimetry is considered the most accurate measure of EMC and used as a reference to calibrate other methods (BS EN 16682, 2017).

The experimentally determined desorption isotherm for the pallets are shown in Figures 6. These show that the wood used for the pallet slats has less variation in EMC than that of the supporting blocks, with the slats having a higher average EMC. This is likely due to the higher extractive content observed in the block wood (Ridout, 2004). The desorption isotherm indicates that the minimum RH for beetle control at 12 % wood EMC would be 59.8 %. If the lower figure of 10 % is used, the RH would need to be below 46.3 %.

Environmental Data

The literature relating to conditions that are favourable to A. punctatum suggest that an EMC of 10–12 % should see a significant decrease in activity. The experimental data shows that for the pallets this equates to an RH of 46.3–59.8 %. It is worth noting that this RH level is lower than that taken from published isotherms for other wood species that are commonly found in historic collections. For example those calculated by Bratasz et al., (2008) for oak show that an EMC of 10–12 % equates to 64.5–74.5 % RH (desorption) and for walnut that an EMC of 10–12 % equates to 70.5–81 % RH (desorption).

The temperature and relative humidity is monitored in both stores. At HA Store the environment is uncontrolled; the monitored data from 2017 is plotted over the data available from the literature in Figure 7. In a similar manner, the data from WPC Store Area 2 with RH control for 2017 is shown in Figure 8. Both indicate that A. punctatum activity in the pallets is supported in the store environments. The comparatively high RH levels needed for an EMC of 10–12 % in oak and walnut might be why we are currently only experiencing an infestation in the pallets and not the artefacts.

Review of Options to Control Infestation

The options for the control of furniture beetle at both stores were reviewed and are summarised in Table 2.

The response at HA Store was comprised of two stages. The first stage involved the heat treatment (in the Thermo Lignum mobile trailer) of historic timber collections before relocation to another RH controlled store in a separate building on the same site. The second stage, for both HA Store (uncontrolled) and WPC Store Area 1 (passive control), is to replace all wooden pallets with plastic pallets. Collections must be carefully transferred onto plastic pallets and some stonework requires specialist lifting equipment. Carrying out the work over several years allows it to be undertaken by current staff alongside their normal duties and a relatively small fund is needed each year to purchase replacement plastic pallets.

As the RH in WC Store Area 2 is controlled by two dehumidifiers, it was decided to replace the small number of affected pallets with plastic and trial reducing the EMC by reducing the RH. On 4th January 2018, the set point of both dehumidifiers was lowered from 75 % to 50 % RH to keep the RH below 55 % which should result in an EMC of 12 % or below. Data from January to October 2018 shows that the RH was under the target of 55 % for 98 % of the time, with a maximum RH of 66.8 %. The RH fluctuations recorded did not occur for more than 27 consecutive hours and the store spent less than 1 % of the time over 59.8 % RH (which equate to the measured 12 % pallet wood EMC). However, the store was over 46.3 % RH, equating to above 10 % pallet wood EMC, for a third of the recorded data.

In order to measure the EMC of wooden pallets in the store, a Protimeter Timbermaster was purchased. To determine the accuracy of the meter it was checked against the samples where EMC had been determined gravimetrically. The meter has
TABLE 2. Summary of options appraisal for dealing with the *Anobium punctatum* infestations

<table>
<thead>
<tr>
<th>OPTION</th>
<th>Est. COST £’s</th>
<th>PROS</th>
<th>CONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. CONTROL THE ENVIRONMENT</td>
<td>£5000 equipment £7358 energy cost each year</td>
<td>• No need to replace pallets. • Deals with any potential infestation of historic wooden objects at the same time. • If maintained could use the stores to keep wooden artefacts in again in the future</td>
<td>• Great uncertainty that RH could be sufficiently lowered in HAS as it’s very leaky building and we have never attempted such close control in this type of building. • WPCS is more airtight but Area 1 is a huge volume. • If very low RH level is required this could cause damaging dimensional change to wooden objects that have acclimatised to high RH conditions • Poor eco. credentials</td>
</tr>
<tr>
<td>B. LIVE WITH THEM</td>
<td>£2000 each year</td>
<td>• Low cost • Existing pallets are close-boarded and none are loaded to capacity so they should remain structurally stable for some time despite the beetle activity</td>
<td>• Long term presence of furniture beetle in the store. Year on year the damage could increase. How would we monitor further beetle activity within the pallets? • Every pallet would need to be checked regularly—this is a huge and possibly unsustainable task. • H&amp;S risk of collapse of structurally unsound pallets during forklifting.</td>
</tr>
<tr>
<td>C. REPLACE ALL WOOD PALLETS WITH NEW HEAT TREATED WOOD PALLETS IN ONE PHASE</td>
<td>£69,000 [Contract staff £40,000 Heat treated wood pallets cost – £19,000 Enabling costs – £10,000]</td>
<td>• Removal of all wood infested or potentially infested with furniture beetle • Opportunity to undertake a deep clean of store and objects, update documentation.</td>
<td>Risk that wood pallets will become infested as RH will remain high, especially as emergence times not necessarily as previously thought • Need to employ additional staff to help with the project. • High team resource to support</td>
</tr>
<tr>
<td>D. GRADUAL REPLACEMENT OF WOOD PALLETS WITH PLASTIC PALLETS</td>
<td>£102,000 £65,000 Helmsley £37,000 Wrest [New pallets £71,000 Materials &amp; equipment £8000]</td>
<td>• Phased over a number years • Can be achieved over five years at Helmsley and three years at Wrest. • No risk of infestation in future</td>
<td>• Staff resource to plan and deliver meaning time away from other core tasks</td>
</tr>
<tr>
<td>E. INTERNAL HEAT TREATMENT OF THE PALLETS AND COLLECTIONS IN SITU</td>
<td>In the region of £70,000 for Helmsley only (£54,000 plus £17,000 for gas £600 caravan £1300 scissor lift Security guard)</td>
<td>• Eradication of furniture beetle larvae and adults from all wood pallets and objects.</td>
<td>• Risk that not all larvae are killed as pallet racking difficult to wrap. • Concerns about the efficacy of in situ ‘tent’ treatment because the RH and temperature control cannot be so precise as in a purpose built unit • Security of the store compromised as large vent holes required within the building envelope—security guard required for 3–4 weeks • Gas storage on site is challenging and requires adherence to a lot of regulations • Risk to electronics of roller racking at HAS • Doesn’t address the concern over pallet structural stability for the damage that has already been done</td>
</tr>
</tbody>
</table>
two calibrations suggested for pine, B and C. Calibration B was found to best correlate. A temperature correction was applied to all measurements through use of the temperature probe supplied with the Protimeter. Measurements of a selection of pallets in Area 2 were taken four times over the period of a year. The readings indicated that the EMC of the pallets ranged between 8.40–12.41 % (±1.07). The analysis of the variance showed a significant difference in pallet EMC over the year (p=<0.001), where 9 % of measurements were over 12 %. The results indicate that the decrease in RH level has resulted in a decrease in EMC; however, beetle numbers and EMC levels will continue to be monitored to confirm whether this will result in an effective method of control. Despite taking Protimeter measurements in a controlled way, the high variability in the low grade wood used for the pallets make the Protimeter readings of limited value to gain accurate information on EMC of each pallet. However the overall trend, in this case a reduction in wood EMC, is promising.

Whilst effective at reducing the EMC, energy use is estimated to have increased by 15,000 kWh for the whole of 2018, which is four times the amount used during 2017, increasing the annual cost by approximately £2500. It is not known how long the EMC needs to be kept below 12 % to ensure that all A. punctatum will die out, although this could be as short as one year (Williams, 1983). Once beetle activity has been eradicated, the RH level could be relaxed back to a set point of 75 % combined with a strict quarantine procedure for this storage area.

Conclusion

This experience has highlighted the risk from furniture beetle A. punctatum to wooden pallets used by EH for the bulk storage of archaeology and architectural collections. Environmental conditions in these stores whilst acceptable for the collection materials have resulted in EMC in the pallets that sustain A. punctatum. All pallets in these stores will therefore be changed to plastic over the next five years and a new policy of using only plastic pallets at all EH stores has now been introduced.

For the historic wooden objects stored on wooden pallets, controlling RH to 55 % to reduce EMC to below 12 % appears promising as a control option for A. punctatum. However, on-going monitoring of beetle numbers, frass, RH and EMC is needed to confirm eradication.

The recorded emergence from wooden pallets in two English Heritage stores in the autumn is without precedent in the UK. Research into the potential genetic diversity of furniture beetles found in the stores along with close measurement of emergence times coupled with environmental data, may help elucidate this in the future. In the meantime we may have to accept that furniture beetles do not always behave in the way that you would predict from established knowledge.

Materials

250 ml Mason jars – Bernardin
Glycerol – VWR Chemicals
Distilled water – VWR Chemicals
Melinex – Preservation Equipment Ltd
Explorer Balance – Ohaus
Rotronic probe – Meaco Measurement and Control Ltd
Protimeter - Timbermaster
Dehumidifer - Munters CMS 300

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Endnotes
1 Full experimental data and calculated absorption
isotherm available upon request.
2 Using an average cost of £0.1657 per kWh (Ofgem,
2018).
Abstract

This paper reports on different Integrated Pest Management (IPM) courses, at the University of Applied Arts, Vienna, Austria and also on international IPM courses organized over the last six years. Courses vary from one, three to five days and are a combination of practical exercises and theory lectures. These courses have been well received, as the training in monitoring, treatment, prevention, identification and documentation can be applied hands-on in the home institution. Besides IPM courses, further activities to spread awareness of IPM consist of regular presentations at national meetings and conferences, publications in the native language and building a network of persons interested in IPM to meet yearly in a national IPM working group. Most experienced experts in IPM in museums start teaching courses after some years and the topics and contents are very similar. The background of the participating museum staff varies greatly between countries and institutions, making it an interesting and a learning experience also for teachers. Experts often team up together to teach, making it more diverse and stimulating for the participants. Developing guidelines, launching pest posters and starting a reference collection are all new activities, which may enable an institution to continue developing their IPM programme. In this paper, communicating and teaching of IPM is described and compared in different countries. National problems and challenges facing cultural heritage protection in different countries are also described.

Keywords: IPM, workshops; students; reference collection; lectures; practical work

Introduction

The concept of Integrated Pest Management (IPM) was developed in the 1950s in the food industry and since the 1980s has been successfully applied in museums. Today, IPM is an important part of preventive conservation focusing on the prevention of pest infestations and the reduction of pesticide application. This is achieved by sealing buildings against pests, adapting the (micro-) climate, maintaining high hygienic standards, quarantining new and incoming objects and monitoring pest infestations with traps. When necessary non-harmful methods are used to treat infested objects. Treatment methods such as heating, freezing or anoxic treatments, mainly with nitrogen, argon, carbon dioxide or oxygen scavengers, are applied. Chemicals are only used in emergencies, or when no other method can be applied. Insect pest monitoring is an important part of IPM, in order to detect pests, to provide specimens for the correct identification of species involved, and to locate the infested objects or problems in a particular building.

All these aspects require one dedicated person in charge of the IPM for coordination of data collection, treatments and setting priorities for further actions. This person should be trained in basic IPM procedures, pest identification, data management, and have substantial knowledge of treatment methods, in order to be able to apply these correctly (i.e. to select the correct method according to the pest and the object). Further, preventive actions need to be selected. This basic knowledge of IPM is the foundation of the IPM courses.
Training in IPM is not standardized and as preventive conservation is already an interdisciplinary field, people with different backgrounds come to work with IPM. Those responsible for IPM in cultural heritage institutions are mainly trained conservators who might have had specific training in IPM at the university. Often many years pass before they achieve a position in a museum or similar institution. They need to refresh and update their knowledge through internal or external workshops. Such workshops very often lead to more intense work in the field of IPM, when knowledge is needed on a regular basis and can be applied directly to the needs of the home institution. Courses are taught by different IPM experts in museums, at universities and online institutions like Museum Studies (www.museumstudy.com, see also Annex I). The structures of the courses are very similar, but the background, motivation, specific collections or materials in focus (for example natural history versus archive material) and the students’ educational backgrounds vary.

Training courses outside Europe

Pest problems in a tropical climate with the presence of termites are harder to treat and monitor, compared with insect pests found in Central Europe. Higher temperatures and humidity lead to faster insect development and also to fungi growth. Courses in Sri Lanka, Hong Kong, Oman and Iran are compared with workshops in Germany and Austria. To prepare for the courses traps were sent a few months before to be able to identify and discuss findings during the course.

IPM Course in Sri Lanka

In 2013 the Goethe Institute and the National Library in Colombo, Sri Lanka, organized a three-day IPM course (Figure 1). Mainly librarians, but also some paper and book conservation staff from different libraries all over the country participated in the course, some traveling a few days to reach the capital. Tropical countries like Sri Lanka face difficult challenges in every topic concerning IPM: (1) high temperature and humidity, (2) tropical pest species such as termites, silverfish and wood damaging beetles which are active all year round and can cause severe damage to all kinds of paper, books and wood materials, (3) funding is very limited; it may not even be possible to buy sticky traps in order to start monitoring. However, the staff is often very motivated to preserve the collection and participants very much enjoyed learning something new outside their day-to-day routine library work. There is no formal education for book or paper conservation in Sri Lanka at the moment, which makes it important for external experts to visit the country and share their knowledge. Fungi, indoor food and drink restrictions and food pests like cockroaches, are further challenges.

Pesticides such as Phosphine, have been used in the past and are still common at larger institutions to treat infested collections. During the course, a carbon dioxide fumigation of books and papers was demonstrated by a pest contractor, normally working in food protection (Figure 2). Other methods like anoxia were demonstrated and discussed but seemed very expensive to the
In 2015 and 2016, similar three-day courses to the one in Sri Lanka, were held at the Hong Kong University and the University Art Museum and Gallery, a museum closely connected with the university. The training courses were organized by two expats living in Hong Kong and participants were mainly Chinese working for university collections, museums and libraries. In Hong Kong it is not possible to study conservation and also very few conservators live in the country. Objects are transported to the UK for conservation work most of the time (Beenk, 2015). With a semi tropical climate, Hong Kong has similar challenges to Sri Lanka: Termites were found from time to time inside the museum building and an active infestation was discovered during the course. Cockroaches were also abundant pests, found on the traps placed prior to the course; this is typical for all tropical climates where these pests are very abundant throughout the cities. In all tropical countries contact insecticides with pyrethroids are sprayed on a very regular basis in homes, offices and museums, but their effect on museum pests is questionable (they are mainly used against cockroaches and mosquitoes).

In Hong Kong, as in many of the other places described, insect pest identification literature concerning the most important pests is not available. Therefore, before the courses began, some time was spent on searching for identification literature (publications and web-based databases) in order to present the most common pest species during the course (Figure 4). Funding for traps and treatment is not a restriction in Hong Kong but at the

**IPM course in Oman 2014**

Outside Muscat in the National Archive, a three-day IPM course was organised mainly for the staff of the archive responsible for treating and cleaning books and paper materials from all over the country. The laboratories were very well equipped and the level of knowledge of the staff was high, the majority being trained chemists. In Oman, university level education in conservation is not available. Unexpectedly fungi are also an important issue in Oman, as it is a very mountainous country with considerable seasonal rainfall. Traps were sent ahead of the course and animals like scorpions or cockroaches were trapped, but the number of pests was very low (few firebrats *Thermobia domestica* and some *Anthrenus* larvae). Anoxia treatment with oxygen absorbers is a simple method that can be easily demonstrated at a course (Figure 3) and shows an alternative method to traditional pesticides. In general a low level of pests were found in the archive, showing that the focus of the course was more on preventing future infestation and getting up to date information. Funding for traps and treatment is not a restriction in Oman.
IPM Courses in Germany and Austria

One to three-day courses are held every year in Austria or Germany by the author, other experts and sometimes together, either in a museum or, as in recent years, also in archives and libraries. It facilitates teaching if more than one expert is involved, where each one has his own lectures and his special fields.

Certain questions are asked at every course (for example: Do we attract pests and a new infestation, when we use pheromones?). Other topics and interests change or increase, such as the infestation and spread of the grey silverfish *Ctenolepisma longicaudata*. Therefore, archives in particular have organised more IPM courses in the last three years, which are well attended and provoke interesting discussions.

We started handing out the German IPM textbook (Pinniger et al., 2017) as part of the course fee, and also a German IPM pest poster (Figure 7). Further in recent years preparing an insect reference collection has become part of the courses, using specimens that are reared in the lab and animals from sticky blunder traps (Figure 8). Thus, students have very good tools for future pest identification and comparison. Also other literature for identification is discussed (identification keys and online keys) but comparing pictures is still the method of choice for most conservators and those not trained as entomologists. Participant numbers are normally limited to 17 persons to keep the quality as high as possible.

Moment no company can provide anoxia or nitrogen treatment there.

**IPM course in Iran**

In Teheran a five-day IPM course was carried out in 2017 with conservators and museum staff from different cities across the country (Figure 5 and 6). Most of them had good university training in conservation, but little experience with IPM. They were very interested in the topic, even though the majority had no previous experience with pests. Excursions, for example to the Carpet Museum of Iran and the National Museum, were an important part of the course to show onsite and hands-on how to place traps, search for dead insect remains and discuss treatment methods. During the course anoxia treatment was demonstrated and also the equipment for basic nitrogen treatment was presented. As English was not easily understood by all participants, the presentations were translated by a conservation PhD student who was very interested in IPM. She could combine local knowledge and information on IPM with the course lectures, and was of considerable assistance. Also in Iran, pesticides are widely used in homes and buildings and the concept of IPM was still quite new. Solving termite problems in some areas of the country like the city of Yazd, a historic city entirely built of mud, straw and wood houses, is a very difficult challenge. Large subterranean termite colonies live below the buildings and infest different areas from time to time. They are hard to monitor and even harder to treat. However, in Yazd two biologists coordinate monitoring and treatments for termite and wood boring beetle control.
both have a fee and come from USA based institutions). They are a good option if no courses are available in the country but there is a disadvantage in the lack of practical work.

Challenges in the courses can be for example the different backgrounds of students: They may be trained chemists, biologists, archivists, librarians or conservators, but there are also technical staff for storage or building maintenance who participate in the courses.

In some countries it is also difficult to overcome basic problems in the application of IPM after the course: for example, funding for sticky blunder traps (as in Sri Lanka) or the use of alternative treatment methods to chemicals can be a big challenge (in Iran for example). Often in low-income countries with a tropical climate, insect pests can cause severe infestations and problems. Termites are present and much harder to treat and monitor, compared with insect pests in Central Europe. Higher temperatures and humidity lead to faster insect development and to fungi growth.

Discussion
Teaching in workshops is an essential way to spread knowledge about IPM and to help museum staff working in different institutions like museums, archives, libraries and historic buildings. The workshops are all similar in content, focusing on prevention of attacks, monitoring, identification of insect pest species, collection of data and interpretation of results. Treatment methods are also discussed and demonstrated to some extent. As IPM is a hands-on activity, most courses spend at least 50 percent of the time on practical exercises such as insect pest identification, anoxia treatment, placing new traps or evaluating a building. This is essential in order to give the participants tools to start an IPM program in their home institutions.

Courses are usually organised by one museum or institution. Sometimes they are free for the participants; sometimes a fee is needed to finance the course. Online courses provide another possibility for basic IPM training, helping to find resources (online and literature) and a forum for questions (see Annex I for two examples of online courses;
It may also be a challenge for the participants to start for the first time with insect identification to species level. During the courses pest posters and illustrations from books are used to identify the most common pests. This works well for many of the common pest species and saves considerable time, but in the real world of monitoring and trapping, many more species and types of arthropods and insects are found on the traps. In the latest courses a collection of dry insect pest species was also provided (see species list in Table 1). This is very good additional information for the future together with the pest poster and IPM book. Course participants build up their own reference collections during the course (Figure 8); some insects are pinned, others glued and all need to be identified by the participant (during the course the experts check the ID of each species).

TABLE 1. Species list of insect pests provided for identification exercises in IPM workshops in Austria and Germany, also used as a reference collection for each participant.

<table>
<thead>
<tr>
<th>Species Name</th>
<th>Species Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stegobium paniceum</td>
<td>Anthrenus verbasci</td>
</tr>
<tr>
<td>Lasioderma serricome</td>
<td>Anthrenus scophularidae</td>
</tr>
<tr>
<td>Anobium punctatum</td>
<td>Anthrenus larvae</td>
</tr>
<tr>
<td>Anobium punctatum frass sample</td>
<td>Trogoderma angustum</td>
</tr>
<tr>
<td>Hylotrupes bajulus</td>
<td>Gibbium psylloides</td>
</tr>
<tr>
<td>Hylotrupes bajulus frass sample</td>
<td>Niptus hololeucus</td>
</tr>
<tr>
<td>Lyctus sp.</td>
<td>Ptitus fur</td>
</tr>
<tr>
<td>Lyctus sp. frass sample</td>
<td>Lepisma saccharina</td>
</tr>
<tr>
<td>Lardarius</td>
<td>Ctenolepis longicaudata</td>
</tr>
<tr>
<td>Attagenus smirnovi</td>
<td>Ctenolepis calva</td>
</tr>
<tr>
<td>Attagenus unicolor</td>
<td>Ctenolepis lienata</td>
</tr>
<tr>
<td>Attagenus larvae</td>
<td>Tineola bisselliella</td>
</tr>
<tr>
<td></td>
<td>Tinea pellionella</td>
</tr>
<tr>
<td></td>
<td>Plodia interpunctella</td>
</tr>
</tbody>
</table>
An IPM course given by an external expert can lead to a better awareness of pests and to the option of non-chemical treatment methods with an encouraging rate of success. Positive results tend to promote collecting and monitoring data in competent institutions. I am in continuing contact with many of the participants and observe their interest in following up IPM and also in visiting international IPM conferences. Traditional treatment methods with pesticides like Phosphine and Pyretroids are widely used in most of the countries described, mainly because of the lack of alternatives provided by pest control companies. For the institutions it is often a big challenge to obtain equipment and to encourage further training: for example, in the use of nitrogen fumigation. In the future such courses could be combined with online courses, which are already available but need to be adapted to national needs. Follow up courses were not held but are planned in Sri Lanka in the near future. It would be very interesting to bring former participants together after some years to see their experiences with IPM. IPM is developing new methods (parasitoids for example), establishing new regulations (EU biocide regulation) and standards.

Besides the IPM courses, further activities to spread the awareness of IPM in a country are (1) regular presentations at national meetings and conferences, (2) publication activities in the native language and (3) building a network of persons interested and working in IPM. Since 2013 a yearly meeting of a national IPM working group was started in Austria following the example of the UK IPM group (http://www.pestodysssey.org/) and the meeting of the US museumpests group (https://museumpests.net/). These meetings are very promising, not least for exchanging information and mutual assistance. The development of such a national group to exchange experiences is suggested at every course, as it can be very helpful to stay up-to-date and share knowledge and experiences.

Advice for preparing IPM courses in countries with no established IPM training:

- Send sticky traps in advance to collect pests and animals for identification during the course.
- Bring a reference collection or make one during the course, which can stay in the country.
- Get in contact with local entomologists to find out the scientific names of the most common pests.
- Develop an insect and IPM pest poster in the local language.
- Contact local pest contractors to see what services they provide or can provide in the future for the museums.
- Offer PDFs of the most relevant IPM literature freely available for further training.
- Start an IPM working group in the country where participants can exchange experiences once per year.
- Encourage the students to start teaching IPM themselves to spread the information.

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References
Beenk, J. 2015. Conservator at the University of Hong Kong Library. Interview December 2015.

Annex 1
*Online courses:*
“Integrated Pest Management in Museums, Historical Sites and Archives” by the Northern States Conservation Center (USA) taught by Christina Cain https://www.collectioncare.org/integrated-pest-management-museums-libraries-and-archives-line-course
List of posters

During the conference, 16 posters were presented. All but one can now be found as downloadable pdf files on the conference website www.raa.se/ipm2019.

Analysis of ten years data and countermeasures to reduce significant bird strikes on the large glass walls of a museum building by lighting design
Rika Kigawa, Junko Akiyama, Hiroki Watanabe, Shiho Tomimatsu, Mika Matsuo, Hirofumi Oki-do, Hironori Kakimoto & Hiroto Okabe

Biodegradation of traditional Japanese style shake roofs and preservative effect of copper plates on wooden shake (NB. Not available as pdf.)
Yuko Fujiwara, Yosei Kozuma, Hitomi Nakano & Yoshihisa Fujii

Biological control of the webbing clothes moth Tineola bisselliella with Baryscapus tineivorus: experiences from five years of practical application (Lepidoptera: Tineidae, Hymenoptera: Eulophidae)
Sabine Prozell, Undine Köhler & Matthias Schöller

How to repel bees without chemicals
Joel Voron

Inside the wood: Biological control of Anobium punctatum with Spathius exarator
Alexander Kassel, Christine Opitz & Judith Auer

Integrated Pest Management: Informing the decision making process
Amy Crossman & David Pinniger

Lizards in the Library: A case study of an established resident population of Mediterranean house geckos in collection storage areas
Alan Van Dyke

Nitrogen as a biocide?
Sergio Piras

Nondestructive evaluation of development, feeding, and oviposition of the bamboo powderpost beetle, Dinoderus minutus
Hiroki Watanabe, Yoshiyuki Yanase & Yoshihisa Fujii

Old books infestation by Gastrallus pubens Fairmaire (Coleoptera Anobiidae)
Sara Savoldelli, Costanza Jucker, Serena Malabusini, Matteo Zugno & Daniela Lupi

Oligomerus ptinoides, the discovery of a new Anobid woodborer in the UK
Samantha Higgs & Rebecca Rees

Practical IPM—work at the conservation studio 2019
Lotti Benjaminsson

PRE-MAL: Pests, Research, Education – Museums, Libraries and Archives
Ingela Chef Holmberg & Carola Håggström

Selling IPM – Pest awareness in times of change
Amy Sampson

The early bird catches the worm – participatory methods to implement IPM-strategies within small and middle-sized museums
Maruchi Yoshida

What IS eating your collection? Is it eating mine?
Jane Thompson Webb, David Pinniger & Lisa Nilsen

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Threats by pests to cultural heritage are now more than ever on the agenda for museums, archives, libraries and historic houses. It is therefore important that professionals within the sector, such as collection managers, conservators, curators, archivists, librarians, scientists and others, meet and discuss methods of dealing with the challenges posed by pests. The conference *Integrated Pest Management (IPM) for Cultural Heritage* took place in Stockholm 21–23 May 2019. It was the 4th international conference on IPM and emphasized the following themes: *Communicating IPM, IPM in the era of globalisation* and *IPM in a changing climate*. The papers in this volume illustrate the challenges within these areas and the importance of cooperation and networking within the field of IPM.