Integrated Pest Management (IPM) in Museums, Archives and Historic Houses - Proceedings of the International Conference in Vienna, Austria 2013

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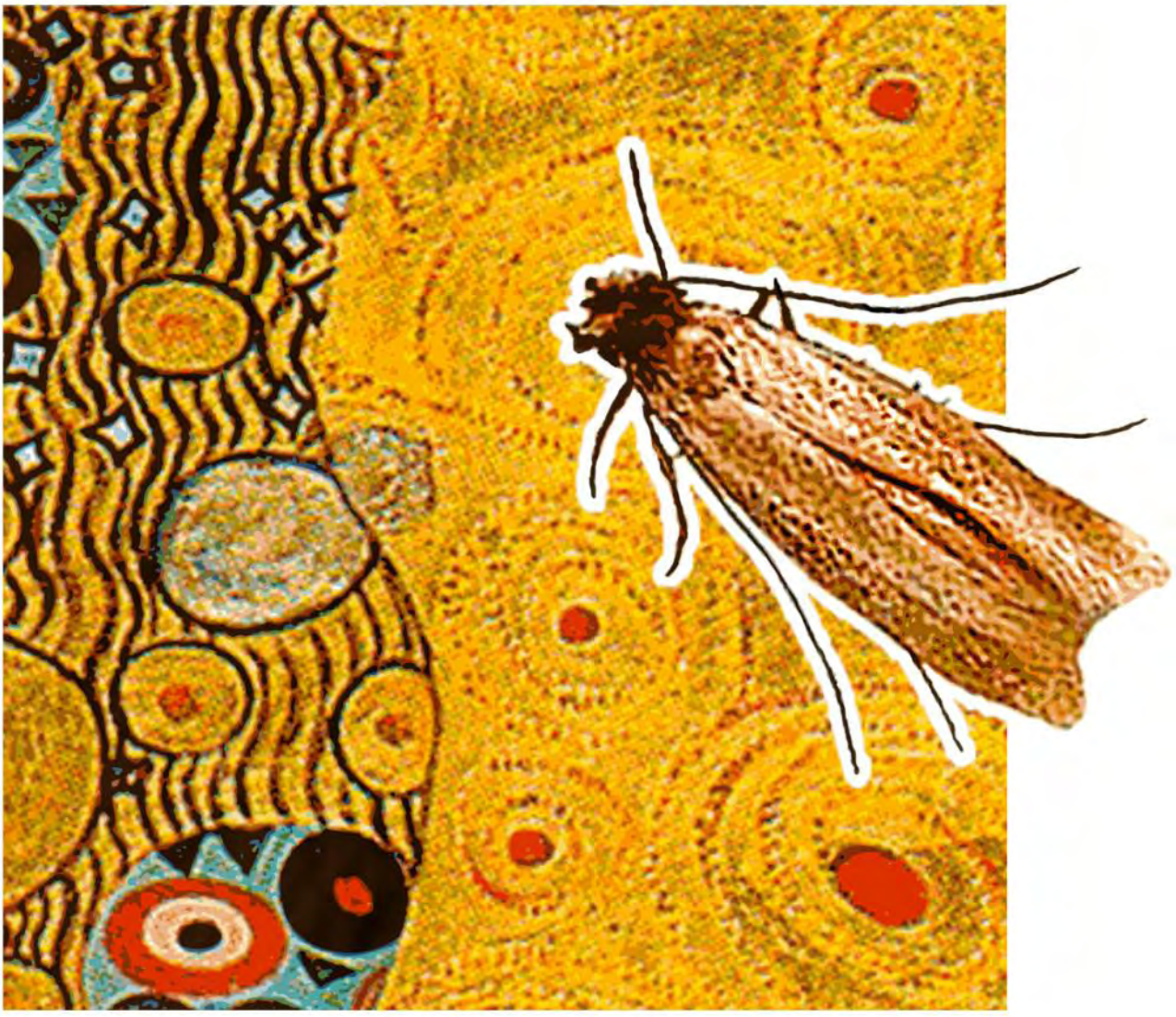
Section III: Treatment Methods



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Section III

Treatment methods

The New EU Biocides Regulations 528/2012 and the effect it will have on museum IPM

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Abstract
The EU Biocides Regulation 528/2012 came into force on 1 September 2013. It replaced the Biocidal Products Regulations which implemented the Biocidal Products Directive (98/8/EC) whose aim was to ensure that all biocidal products on sale were safe when used properly and freely traded within the EU. These regulations replaced individual countries' own laws on the use of biocides. The current Regulation, since its introduction, has been subject to a number of problems and is likely to be further adapted. The new regulations may radically affect those who work in IPM on historic and artistic collections. This article summarises the new EU Biocide Regulation and the impact it will have on museums.

Keywords: Biocides; EU Biocides Regulation (528/2012)

1. Introduction

In the post war period, use of biocides, including agricultural pesticides, increased enormously as new products were developed. At that time there was little, if any, legislation controlling their uses, as the benefits from increased food production and the control of disease vectors, such as malaria carrying mosquitoes, was of overriding importance. The publication of 'Silent Spring' by Rachel Carson, in 1962, highlighted some of the dangers of the large-scale use of toxic pesticides.

Many countries established regulations for the control of biocides, many, including a number of European Union countries used health and safety or hazardous substance laws. The United Kingdom introduced specific laws affecting the use of pesticides in the Control of Pesticides Regulations 1986. This Act required pesticides to be tested and approved before they could be used or sold and required users to be competent in their assessment, use, storage, disposal etc., of the approved products.

In the following the new EU Biocide Regulation is described (section 2-4). The impact it will have on museums is summarised in section 5 and 6.

2. The Biocides Regulation

2.1 Definition

Biocidal products are defined as 'chemicals or micro-organisms or mixtures of either or both, intended to control unwanted organisms such as animals, insects, bacteria, viruses and fungi'. They are composed of 'actives' which are the active ingredient which are then made up into commercial 'biocidal products' (Foundation for Water Research).

2.2 Active substances

Article 3(c) of the EU Biocides Regulation 528/2012 (see References) defines an active substance as a substance that has an action on or against harmful organisms. All active substances need to be tested for efficacy and safety and regulated by being placed on the annex 1 of the Regulations. Monitoring of the active substances is carried out by the European Chemicals Agency (ECHA, see References) and allows EU use of the substances in biocidal products.

2.3 Biocidal products

Biocidal products are intended to 'destroy, deter, render harmless, prevent the action of or otherwise exert a controlling affect on any harmful organism by any means other than mere physical or mechanical action. They are registered by individual EU countries for use within that country but can be further registered for use in other EU countries. They contain active substances as well as other materials such as solvents.
Food and food products used as attractants or repellents are not included in the regulations so long as they are of a suitable food quality.

2.4 Product types

Annex V to the EU Biocides Regulation classifies biocidal products into 22 types. Of interest to the museum community are PT8 for wood preservatives; PT18 for the control of arthropods (e.g. insects, arachnids and crustaceans) by means other than repulsion or attraction; PT19 repellents and attractants and for some contemporary artists PT22 embalming and taxidermist fluids.

3. Registration of active substances and biocidal products

The registration of active substances and biocidal products is monitored by ECHA. It is an on-going process during which current country legislation applies. Registration of new materials is expensive, time-consuming and not always guaranteed. Moreover current products can loose their registration.

4. Treated articles

Article 58 states that objects treated with biocides must use products listed in the Regulation, this includes objects manufactured within the EU and those imported from outside. The objects treated must be suitable labelled.

5. IPM

Section (38) states where possible the presence of harmful organisms should be avoided by means of suitable precautionary steps such as proper warehousing, relevant hygiene standards and proper disposal of waste.

Article 18 (c) encourages 'the development and application of integrated pest management principles with respect to the use of biocidal products'.

6. Areas of concern

Because the new regulations are in a transitional state, there are areas that need clarification. Guidelines on the application of the regulations are currently being prepared which may address some of these concerns. Clarification is needed in some of the following areas:

6.1 Pheromone traps

Currently sticky blunder traps are exempt from the Regulation. However, those with attractants such as sex pheromones are not. Some pheromones (such as for *Tineola bisselliella*) have already been placed on the annex 1 list, but many have not. It may not be commercial to register some of the niche pheromone lures currently available (such as for *Anthrenus sp.*) in which case their use may become illegal.

6.2 Anoxia

Currently, Rentokil Ltd., are registered to use nitrogen for anoxic fumigation, but only using bottled gas. The status of using nitrogen generators is still uncertain as is the legality of museums' using anoxia within their own institutions and not for commercial purposes. Article 17(1) of the Regulation states 'biocidal products shall not be made available on the market or used unless authorised in accordance with the Regulation'.
Oxygen absorbers are considered exempt from the Regulation.

6.3 Desiccant dusts

These are used as effective insecticides in many circumstances. They gave rise to discussion under the UK Control of Pesticides Regulations as to whether the particle size was important as to whether they needed to be registered or not.

6.4 Treated articles

The Regulation states that articles placed on the market can only be treated with registered biocides. It is unclear what the status is of historic material that may have been treated in the past with biocides such as DDT, arsenic, mercuric chloride etc.

Conclusion

The roll-out of the Biocidal Regulation EU 528/2012 is still continuing and is likely to be adapted and modified over the following years. Clarification from the publication of the Guidelines will undoubtedly help but there are still likely to be a number of unforeseen problems in the implementation of these regulations.

Disclaimer

This paper is based on the current understanding of the Regulation by the author in October 2013 and through discussion with the UK Biocides Competent Authority Chemicals Regulation Directorate of

the Health and Safety Executive for whom I am grateful for their advice and assistance. Any errors of interpretation are accidental and hopefully, can be corrected in the future.

References

The EU Biocides Regulation (EU528/2012)
http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2012:167:0001:0123:EN:PDF

European Commission Biocide website
http://ec.europa.eu/environment/chemicals/biocides/regulation/regulation_en.htm

European Chemical Agency (ECHA) Biocide website
http://echa.europa.eu/regulations/biocidal-products-regulation

UK Health and Safety Executive biocides website
http://www.hse.gov.uk/biocides/news.htm

EU Business News website on biocides
http://www.eubusiness.com/topics/environ/biocides

PAN Germany part of the Pesticide Action Network International
www.pan-germany.org

Anoxia treatment using oxygen scavengers for disinfestations of large museum objects

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Abstract
This paper looks back at the practical use of oxygen scavengers for disinfesting large museum objects without extern nitrogen sources. In larger volumes a sufficient amount of absorbent material and a hermetic sealing of the enclosure are necessary to achieve the required minimum of oxygen. Testing these relationships in practice and to investigate the suitability of only using oxygen scavengers, a Venetian gondola on display in a showroom at the Museum of European Cultures in Berlin was treated. The object has been attacked by drywood termites. Moving and total wrapping of the gondola was not possible. The treated volume was approx. 25 m³. To reach 100% mortality by inserted test organisms a total of 58 oxygen scavengers were needed to maintain the required level below 0.2 % oxygen.

Keywords: Anoxia treatment; oxygen scavengers; $ZerO_2$; drywood termites; museum pest

1. Introduction

Using Anoxia to kill insect pests is a common treatment method in the last years for many museum objects. It is used worldwide with great success and mostly achieved with external nitrogen sources like cylinders (Borig 2011, Macgregor 2011) or generators (Conyers 2001). Both methodologies are called dynamic systems (Daniel *et al.* 1993, Maekawa and Selwitz 1998), because they flush nitrogen with high-pressure gas cylinder, generator or liquid-tank to reduce the oxygen level inside enclosures (Maekawa and Elert 1996). The volume of portable bubbles and user-made tents usually ranges from 1 to 30 m³ (Maekawa and Elert 2003).

Another methodology of Anoxia treatment is using chemical absorbers which are binding oxygen to reach low oxygen conditions in small-scale hermetic sealings (Maekawa and Elert 2003, Biebl and Reichmuth 2013). This methodology is called a static system (Daniel *et al.* 1993, Maekawa and Selwitz 1998), because it is only based on the chemical process of oxygen absorption. Daniel *et al.* (1993) described small scale treatments without purging of air in small to medium-sized bags or pouches < 100 litres, Maekawa and Elert (2003) treatments in pouches of < 300 litres. Valentine (1993) report on the efficacy of the static-dynamic method in three different containment systems: tiny plastic bags (80 cm³), rigid vacuum chamber and a 6.2 m³ fumigation bubble made of PVC.

Disinfestations of museum objects under anoxic conditions are considered reliable and compatible with museum materials. In sealed wrapping absorbers bind oxygen and respectively increase nitrogen concentrations to a lethal level for pests. In large volumes, a sufficient amount of absorbent material and hermetic sealing of the enclosure are necessary to achieve the required minimum concentration of oxygen; the lower the oxygen content, the slower the speed of oxygen reduction inside the sealed volume. This can extend the duration of treatment significantly.

This paper shows the feasibility to kill insects by Anoxia with just using oxygen scavenger at large museum objects without extern nitrogen sources.

2. Material and Methods

Testing in practice and to investigate the efficiency of commercial $ZerO_2$ oxygen scavengers, a Venetian gondola on display in the Museum of European Cultures in Berlin (Fig. 1) was treated to eradicate a drywood termite attack (Fig. 2). For the first time a volume of approx. 25 m³ was treated. A total package with floor-foil was impossible, because for conservative reasons moving should be avoided. Under requirements, no noise conditions and treatment by using non-dangerous materials (without nitrogen cylinders) in exhibition, anoxic conditions were achieved by using commercial oxygen absorbers and test organisms used, to ensure success and efficiency of the treatment.

Fig. 1: Venetian gondola on display at the Museum of European Cultures, National Museums Berlin.

Fig. 2: Colony of drywood termites (*Cryptotermes brevis*, Walker) - alates and larval pseudergates (lab reference).

50 oxygen scavengers ($ZerO_2$) were placed beside the gondola (Fig. 3). Because the internal temperature of scavenger gets warm during the initial stages, all scavengers were packed closely on wooden laths on the base frame of the gondola. That avoids contact with surfaces and supports the access of oxygen over both sides of the scavengers. Two pouches of aluminium foil filled up with 4 scavengers were placed as buffer inside the tent for activation in case of unforeseeable leaks.

For regulation the humidity, one humidifier and dehumidifier were placed inside the tent and connected with electronic control unit Biebl 09 (INVAN4) outside. The electronic control unit measures and records continuous oxygen rates and regulates the humidity inside the tent. The condensate from the dehumidifier was removed over a flexible tube and sampled into a plastic canister outside the tent. All electric cables and tubes passing the barrier foil were sealed with gastight aluminium-tape.

Fig. 3: Oxygen absorbers placed all around the object to enhance chemical reaction (oxidation) by a maximum of scavengers surface area.

Fig. 4: On top closure fixed to floor for anoxic treatment.

The very heavy, almost immovable object was sealed in situ with opaque aluminium foil (Vacupac) composed of layers of HDPE, Aluminium and PET. For reversible fixation, the aluminium foil was stuck together with gastight aluminium tape and fixed on a commercial powertape which stuck down around the object on the exhibition room floor.

Before starting the treatment, test organisms of three different species, drywood termite (*Cryptotermes brevis*, Walker), carpet beetle (*Anthrenus flavipes*, LeConte) and webbing clothes moth (*Tineola bisselliella*, Hummel) in oxygen permeable styrene containers (Fig. 5) were placed inside the tent to evaluate the efficacy measured by means of mortality rate. Together with a food source, two groups of six larvae of each species were treated. Untreated reference organisms of the same batch were stored beside the tent and checked for activity after the treatment. The biological reference material should be representative to the target organisms of the pest control action (Plarre 2013).

Fig. 5: Samples of pest insects as reference material in anoxic treatment.

4. Results

After 28 days and medial 24 °C the analysis showed 100 % mortality of inserted test organisms. All untreated reference insects showed normal activity after the treatment. Oxygen concentration during the treatment remained below a required level of 0.2 % (Valentin and Preusser 1990, Valentin 1993, Berzolla *et al.* 2011) for 16 days (Fig. 6). The two buffers inside the tent were activated over small cuts during the treatment to control little peaks of rising oxygen level. After 30 days the oxygen recording showed an increasing value up to 0.9 %, probably caused by some smaller leaks at the heat sealed junctions of the blanks of the aluminium foil. All data of temperature, humidity and oxygen level were logged every 20 minutes with the electronic control unit continuously during the treatment (Fig. 6).

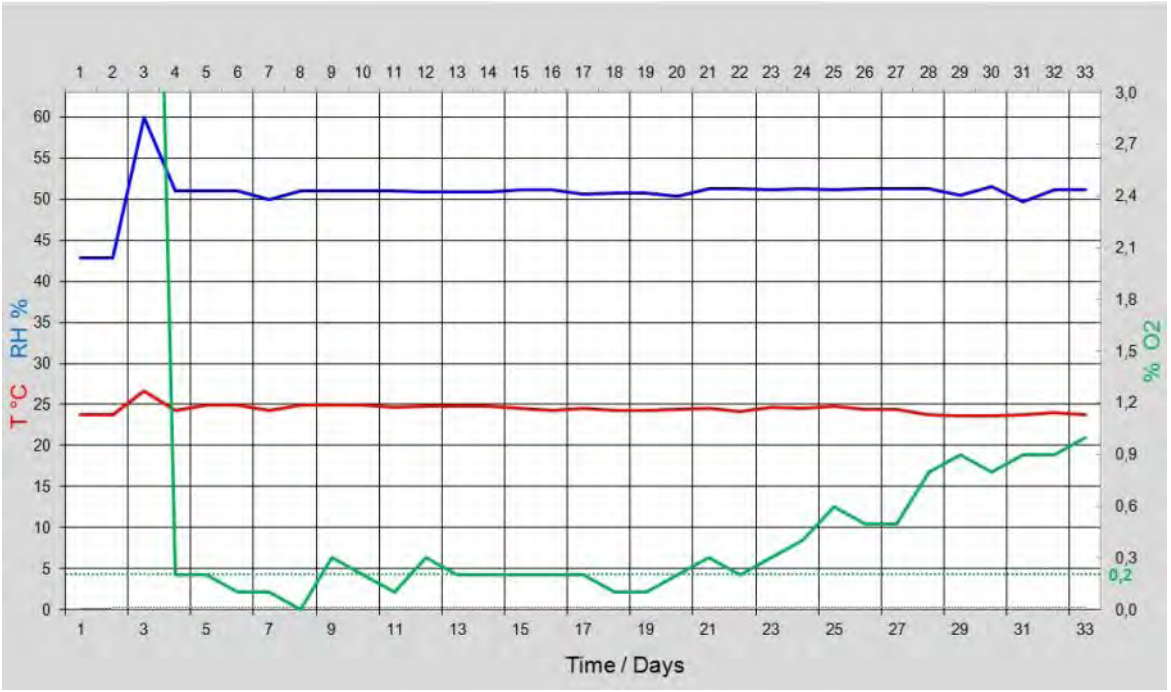

Fig. 6: Record of environmental parameters inside treatment package.

5. Discussion

The results of this study reveal the feasibility to treat large objects in a static mode without purging the air. A number of field studies (Hanlon *et al.* 1992, Vinod *et al.* 1993) describe static and static-dynamic treatments with oxygen scavengers in smaller bags and pouches less than 300 litre. Maekawa and Elert (2003) and other early investigators used just small sized oxygen scavengers like Ageless (Mitsubishi), FreshPax (Multisorb) and Atco (Standa) while commercial suppliers offer larger oxygen scavengers $ZerO_2$ in combination with aluminium 'Flexicubes' sizes from 1 till 5 m³. Comparative investigations of user-made aluminium-foil tents and $ZerO_2$ oxygen scavengers are described by Smith (2012, personal comm.) with a volume of 22 m³ and Biebl (2012) with 7 m³. In summary, $ZerO_2$ scavengers appear to be more efficient and adequate for larger objects.

Technical requirements are airtight floor conditions and a hermetically sealed wrapping to reach an oxygen level ≤ 0.2 %. To avoid a higher oxygen transmission rate (OTR) over the surface of the barrier foil, best results will be given by opaque aluminium foil with OTR <0.01 cm³/m²/day. To observe indicators for oxygen and relative humidity transparent films or windows are not necessary, if using an extern control unit.

The floor sheet and all transmissions (cables or tubes) have to be sealed with aluminium-tapes before treatment to avoid cracks and splits. Especially the outlet of the flexible tube through the barrier foil has to be sealed airtight. The lower end of the tube should always be placed below water level to avoid oxygen diffusion from outside into the hermetically system.

The use of $ZerO_2$ oxygen scavengers is an adequate and efficient solution, if (1) larger objects are too heavy / big to be moved from showrooms or (2) dynamic systems are inapplicable in exhibition areas due to their noise or for safety reasons, e.g. if dangerous appliances such as nitrogen cylinders are not allowed.

Manufactures and Suppliers of Material and Equipment

- IVAN4 electronic control unit, Moosreiner Elektronik GmbH, Munich, Germany
- VACUPAC aluminium foil, Antalis Verpackungen GmbH, Leinfelden-Echterdingen, Germany
- $ZerO_2$ oxygen scavengers:
- Long life for art, www.cwaller.de/oxygen.htm
- InSituConservation, www.insituconservation.com

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Biological control of cultural heritage pests – a review

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Abstract
Natural enemies are known from many cultural heritage pests, but their potential for biological control has been only marginally exploited. In this publication, examples of practical and commercial application of parasitoids of beetles and moths are compiled as well as laboratory research that contributes to the development of guidelines for parasitoid releases. One the one hand there are parasitoids found to occur simultaneously with the pests in buildings, on the other hand there are parasitoids that were never found to be associated with the respective pests but accept them if brought into the cultural heritage environments e.g. parasitoid wasps. An example for the latter is *Trichogramma evanescens euproctidis*, a parasitoid of moth eggs including those of the webbing clothes moth (*Tineola bisselliella*). In semi-field trials it was shown that inundative releases of the egg parasitoids are necessary and that effectiveness is reduced on thick cloth with long strand. *Trichogramma* release units have to be placed directly on the cloth to be protected. A naturally occurring parasitoid of Anobiid beetles is the pteromalid larval parasitoid *Lariophagus distinguendus*. This parasitoid was applied against the drugstore beetle (*Stegobium paniceum*) in historic libraries and against spider beetles (Ptininae) in historic buildings. A simulation model for the population-dynamics of *L. distinguendus* and the golden spider beetle (*Niptus hololeucus*) is presented. Finally, monitoring of the Braconid larval parasitoid *Spathius exarator* used for indirect monitoring of the common furniture beetle (*Anobium punctatum*) is described. The future potential of parasitoids to control cultural heritage pests is discussed.

Keywords: museum pests; natural enemies; monitoring; parasitoids; parasitiod wasps; predators

1. Introduction

Biological control in a strict sense is the application of living organisms for the control of pests. A further subdivision into micro-biological control applying smaller organisms e.g. fungi or bacteria, and macro-biological control applying larger organisms like nematodes or insects is useful and relevant in the context of registration of biological control agents (Franz and Krieg 1982). Other biologically based controls, like bio-technological methods (e.g. Bt-toxins), pheromones and other semiochemicals, insect growth regulators and phytochemicals (botanical insecticides) are not included here. This review focuses on commercially available parasitoids for the control of beetles and moths attacking cultural heritage, and monitoring. Adult parasitoids search for hosts (i.e. pests) for oviposition, and the progeny of parasitoids typically need only one host individual to complete development (Franz and Krieg 1982). Consequently one advantage of parasitoids is the active search for pest individuals in hidden places and their ability to locate hosts also at low host-densities. Parasitoids feed exclusively on host insects, frequently the adults do not need to feed at all and they do not damage artefacts. However, parasitoids that attack wood-boring insect larvae or larvae feeding within other solid materials may produce emergence holes similar to the emerging pests (Paul *et al.* 2008).

The target pests are synanthropic insects attacking wood or other materials used for museum items, or the buildings themselves. While a number of species can be found almost exclusively associated with

these materials, there is another group of species that attack additionally stored products for human consumption. These stored-product pests may destroy materials as well, either by feeding on the materials or on their way to pupation sites. While little information is available on natural enemies of the more specific cultural heritage pests, and almost none on biological control, a lot of information is available on natural enemies and biological control of stored-product pests (Schöller *et al.* 2006). In Table 1 information is given on selected natural enemies of cultural heritage pests, namely those whose biology was studied in detail and / or those that had been evaluated in semi-field trials or field trials. For information on other naturally occurring parasitoids and predators see Becker (1954), Haustein (2010), Plarre (2005), and Steidle *et al.* (2007).

Table 1: Natural enemies evaluated for biological control of moths and beetles attacking cultural heritage

Pest species	**Parasitoid species**	**Host stage**	**Reference**	**Field trial / commercial application**
Moths				
Tineola bisselliella	*Trichogramma evanescens*	Egg	Zimmermann (2005)	yes / yes
	Trichogramma piceum	Egg	Zimmermann (2005)	no /no
	Apanteles carpatus	Larva	Plarre (2006)	yes / no
	Baryscapus tineivorus	Larva	Matzke & Plarre (2013)	yes / yes
Tinea pellionella	*Trichogramma piceum*	Egg	Zimmermann (2005)	no /no
	Baryscapus tineivorus	Larva	Matzke & Plarre (2013)	no /no
Beetles				
Anobiidae				
Stegobium paniceum	*Lariophagus distinguendus*	Larva	Kaschef (1955)	yes / yes
	Anisopteromalus calandrae	Larva	Schöller (unpubl. data)	no / yes
Lasioderma serricorne	*Lariophagus distinguendus*	Larva	Steidle *et al.* (2006)	no / yes
	Anisopteromalus calandrae	Larva	Schöller (unpubl. data)	yes / yes
Niptus hololeucus	*Lariophagus distinguendus*	Larva	Kassel (2008)	yes / yes
	Anisopteromalus calandrae	Larva	Kassel (2008)	yes / yes
Gibbium psylloides	*Lariophagus distinguendus*	Larva	Kaschef (1961), Kassel (2008)	yes / yes
	Anisopteromalus calandrae	Larva	Kassel (2008)	yes / yes
Anobium punctatum	*Spathius exarator*	Larva	Becker (1954)	yes / yes
	Cephalonomia gallicola	Larva	Paul *et al.* (2007)	no / no
Dermestidae				
Trogoderma angustum	*Laelius pedatus*	Larva	Al-Kirshi (1998)	no / no
	Xylocoris flavipes	Larva	Landsberger *et al.* (this volume)	yes / no
Anthrenus verbasci	*Laelius pedatus*	Larva	Al-Kirshi (1998)	no / no
	Xylocoris flavipes	Egg, Larva	Landsberger *et al.* (this volume)	no / no
Attagenus unicolor	*Xylocoris flavipes*	Larva	Landsberger *et al.* (this volume)	no / no

Attagenus smirnovi	*Xylocoris flavipes*	Egg, Larva	Landsberger *et al.* (this volume)	no / no
Anthrenocerus australis	*Xylocoris flavipes*	Egg, Larva	Landsberger *et al.* (this volume)	no / no

2. Do we want to get natural enemies established in museums and historic houses?

Looking at the natural enemies studied in this context, there are species that are associated with human-based habitats and their stored-product insect or museum pest hosts. There are also beneficials that accept stored-product or museum pest insects as hosts, but were transferred from agricultural ecosystems to indoor habitats. The spontaneous occurrence of natural enemies is only prevented by massive application of synthetic insecticides, or by insect-tight packages, showcases or cabinets. Otherwise the natural enemies will arrive sooner or later. The advantage of an established population of natural enemies is the potential control of pests newly arrived e.g. with cultural heritage items. However, in most cases they will arrive too late to control an established infestation, and it is quite uncertain if the natural enemies' population will build up to numbers that prevent damage to museum items. This is the reason why different biological control strategies were developed.

3. Biological control strategies

In agricultural systems, spontaneously occurring natural enemies might be supported by habitat structures for alternative hosts, or provision of food, but there are no such examples for the cultural heritage environment. Other biological control strategies are based on laboratory-reared natural enemies that are released at scheduled times and specific release points. The main strategies are the inoculative and inundative release strategy.

The inoculative release strategy aims to introduce natural enemies at a time where pests are present for multiplication of the natural enemy; the control effect is executed by the progeny of the laboratory-reared natural enemies. In contrast, the control effect is executed by the laboratory-reared natural enemies in the case of the inundative release strategy; the effect of the progeny is negligible here. The inundative release strategy was developed already in the 1960's to resolve the problem of naturally oscillating populations of pests and their natural enemies by the release of large numbers of laboratory-reared natural enemies in order to artificially augmenting the number of parasitoids compared to the hosts, i.e. the pests (DeBach and Hagen 1964). Each parasitoid female is adapted to increase its own fitness, i.e. to produce as much offspring as possible, and this may lead even to a local extinction of the host in such an artificial system. It was the inundative release strategy that was applied both in stored-product protection and in the commercial applications of biological control in museums so far. In the cases of *T. evanescens, B. tineivorus* and *L. distinguendus* cost seems not to limit the application, however, this might be an issue for more specialised natural enemies or those that are difficult to mass-rear.

3.1 Biological control of moths

Several parasitoid Hymenoptera were evaluated for biological control of the webbing clothes moth (*Tineola bisselliella*, Hummel 1823) (Fig. 1, top) and the case-bearing clothes moth (*Tinea pellionella*, Linné 1758) (Fig. 1, bottom and Table 1), including both egg- and larval parasitoids.

Fig. 1: Adult of the webbing clothes moth (*Tineola bisselliella*) (top) and the case-bearing clothes moth (*Tinea pellionella*) and its pupal exuvia (bottom).

3.2 Biological control of the clothes moth Tineola bisselliella

Egg parasitoids in the genus *Trichogramma* (Fig. 2) are applied for biological control of various pest Lepidoptera in field crops like corn or apple. They are polyphagous and accept eggs of many Lepidoptera (Wajnberg and Hassan 1994). Immature *Trichogramma* sp. are glued on cardboard release units, the adults emerge continuously for several weeks. Nowadays, release units are available that provide activity of *T. evanescens euproctidis* (Girault 1911) for three or even 4 weeks. Several species of *Trichogramma* have been shown to accept eggs of *T. bisselliella* including *T. evanescens euproctidis*, the species currently applied against stored-product moths in Central Europe (Zimmermann *et al.* 2003).


Fig. 2: The dwarf wasp *Trichogramma evanescens*, adult and parasitised moth eggs.

Trichogramma spp. were shown to walk distances of at least 15 m on smooth surfaces within 1 hour, equalling 30,000 times a wasp's body length in 1 hour, comparable to a vehicle 2 m in length driving at 60 km/h (Quednau 1958). However, for *Trichogramma* spp., the surface structure of textiles and carpets is comparable with hairy leaf surfaces. Hairy leaf surfaces were shown to reduce the foraging activity of *Trichogramma* sp., e.g. on tomato leaves (Wührer 1994). In order to test if a large surface will reduce the effectiveness of released parasitoids on cloth, Zimmermann (2005) placed cloth (25 cm x 45 cm) in cages (100 cm x 50 cm x 65 cm) previously used for semi-field trials with *Trichogramma* spp. on green plants. He compared 3 types of cloth: (1) Finely woven cloth 1.5 mm in thickness without long distant strand (fibres) (2) medium-finely woven cloth ca. 3.0 mm in thickness with long distant strand and (3) tanned sheepskin rug ca. 25 mm in thickness. Five batches of eggs with 120 *T. bisselliella* eggs each were placed 10 cm, 20 cm, 30 cm and 40 cm from the release point as baits. Fresh *T. bisselliella*-host eggs were provided on day 2, 3 and 5 after release of *Trichogramma* individuals. The number of *Trichogramma* individuals on the egg baits was recorded as well as parasitism by counting black host eggs. The number of female *T. evanescens* active on the cloth was increasing with an increasing number of parasitoids released. The number of *Trichogramma*-females active on the cloth was decreasing with increasing thickness of the cloth (Fig. 3). The conclusions drawn for the release recommendations were: *Trichogramma* spp. have to be applied inundatively, in most cases all year round, and the release units have to be placed directly on the cloth or shelf to be protected. Currently 1000 *T. evanescens* per m^2 and week are recommended.

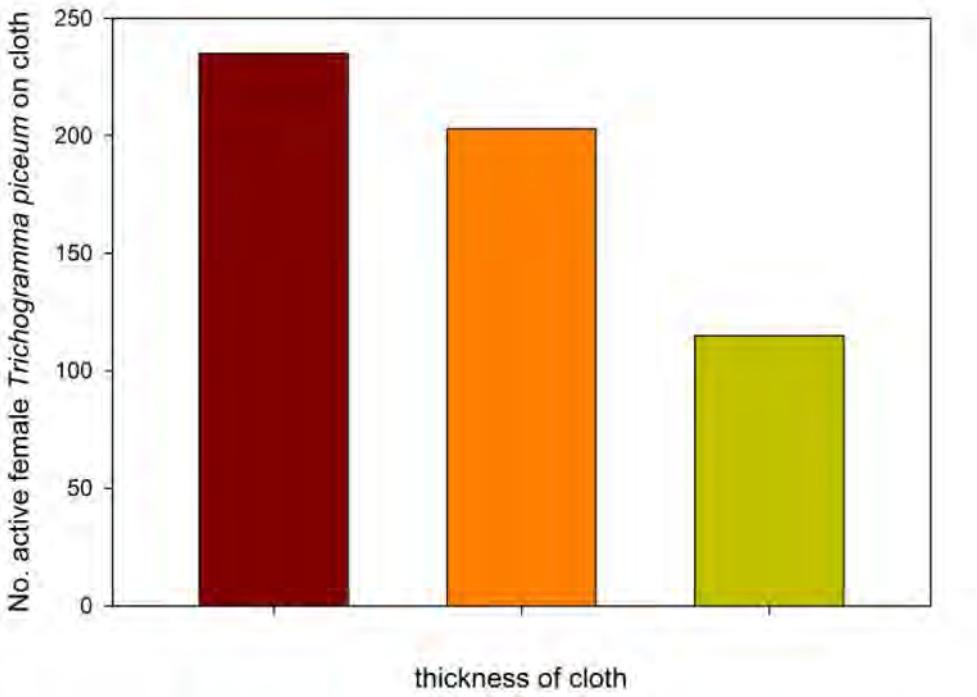

Fig. 3: Number of active female *Trichogramma piceum* on cloth depending on the thickness of the cloth (brown bar = 1.5 mm thickness of cloth, orange bar = 3.0 mm, green bar = 25 mm). Based on data in Zimmermann (2005).

Recent promising results have been obtained for the mass-release of *T. evanescens* in museums (Querner & Biebl 2011b). First practical applications of *T. evanescens euproctidis* were performed in a depot of an ethnographical museum in South-West Germany, and in the Jewish Museum in Berlin. In depots, the identification of infested items might be very time consuming, but the parasitoids actively search for moth eggs. In the Jewish Museum, the parasitoids helped to suppress a residual clothing moth population feeding on fluff balls formed by wear debris of the visitor's wool clothes in cracks and crevices and was integrated with an improved cleaning procedure. Historic cars in museum exhibition rooms were treated in Vienna (Austria), Munich (Biebl 2009) and Bochum (Germany). Felt mats within the cars were infested by *T. bisselliella*. The surface area of felt is relatively small compared to other woollen materials, and monitoring of the moths with the help of pheromone-baited sticky traps showed a breakdown of the moth population after parasitoid release. The number of *T. evanescens* released per week on a total of 60 cars was 45,000 (Biebl 2009). Art by Joseph Beuys containing felt was protected from infestation by *T. bisselliella* in an exhibition room of the Neue Galerie Kassel (Germany) (Dummer and Prozell 2013). For more information on recent releases in museum collections see also Querner and Biebl (2011a, b). In 2012, we released *T. evanescens euproctidis* in carpet stores by sprinkling the parasitised host eggs loosely instead of placing the release cards, a technique that allows an even distribution of the beneficials.

One of the problems associated with the release of *Trichogramma* spp. for control of the clothing moths is the exclusive acceptance of the egg stage of the moth. The disruption of the developmental cycle is expected to be slow due to the slow developmental speed of the clothing moth. Consequently the integration with larvicidal strategies is a future challenge. However, as a preventive control strategy at low densities of the clothes moth (*T. evanescens*) is already a valuable tool.

Trichogramma spp. can also serve as a valuable tool to detect pesticide residues on surfaces. The egg parasitoids are very susceptible towards insecticides, and have been chosen as test organisms for side effect testing on terrestrial non-target arthropods for registration of plant protection products in the European Union (EU) (Hassan *et al.* 2000). Typically, dead *Trichogramma* sp. individuals lay a few

centimetres around the release card in case of contaminated surfaces (Anheuser and Garcia Gomez 2013). As the price for a *Trichogramma*-release card is quite low, this biotest is much cheaper compared to a chemical analysis of residues and can serve as a quick test.

Considerable work has also been done to study the braconid wasp *Apanteles carpatus* (Say 1836), however, this parasitoid is not commercially available yet. *Apanteles carpatus* is a solitary koinobiont endoparasitoid of *T. bisselliella* and *T. pellionella* L., 1758 larvae, i.e. one wasp develops per moth host larva and the moth larva is carrying the parasitoid larva for some time before being killed by the latter. *A. carpatus* is capable of complete development in all larval stages of *T. bisselliella* (Plarre *et al.* 2000). For a field study in a heavily infested rug store, Plarre *et al.* (1999) released laboratory reared *A. carpatus* monthly. The release of *A. carpatus* alone had no suppression effect on the clothes moth population, only the combination of *A. carpatus*-release with a sanitation program significantly reduced the pest. Another larval parasitoid, the eulophid *Baryscapus tineivorus* (Fig. 4) was recently studied with *T. bisselliella* and *T. pellionella* as host. Per late instar *T. bisselliella* host larva, 2 to 36 parasitoid progeny develop. Developmental time from egg to adult is about three weeks at 28°C and 75% RH. This parasitoid has a sex ratio very favourable for biological control, i.e. 85% females (Matzke and Plarre, 2013).

A number of other predators, parasitoids and pathogens of *T. bisselliella* are known (see Zacher 1933, Wudtke 2002, Zimmermann 2005), but none of these was evaluated for biological control so far.

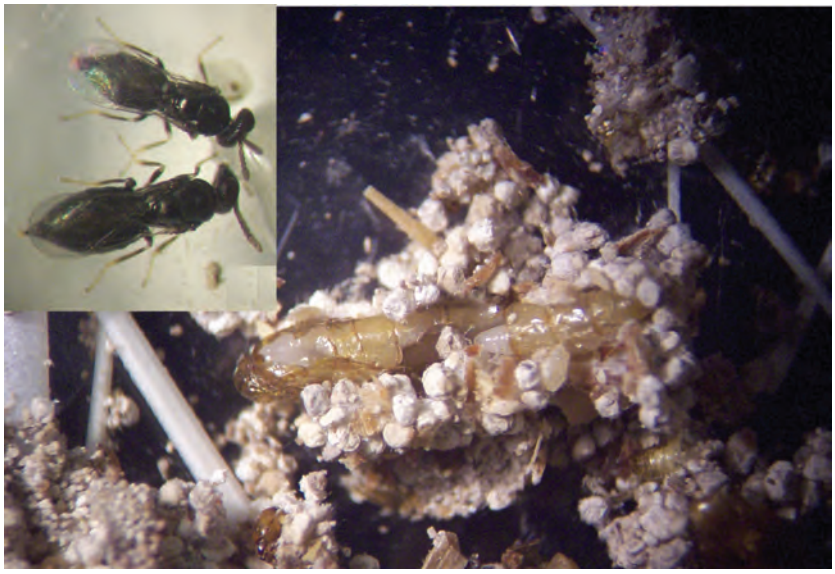

Fig. 4: The clothes moth parasitoid *Baryscapus tineivorus*, adults and parasitised pupa of *T. bisselliella* containing larvae of *B. tineivorus*.

3.3 Biological control of the drugstore beetle Stegobium paniceum

Stored-product pests may destroy materials as well, either on their way to pupation sites or because the materials contain ingredients suitable for development. In Halle / Saale, Saxony-Anhalt, Germany, a historic library became infested by the drugstore beetle (*Stegobium paniceum* L. 1758). The beetles were thriving both below the floorboard on wheat straw used as insulation, and in book covers. The books originated from the 16th to 18th century, when the book covers were filled with pulp made from linen scraps. *Stegobium paniceum* developed in the pulp, produced the characteristic exit holes and therewith destroyed irreplaceable cultural heritage. The books were moved to a fumigation-chamber and treated with nitrogen. However, some re-infestation was detected after the books were moved back to the library, presumably originating from the floorboard. The store chalcid *Lariophagus*

distinguendus (Förster 1841) was released on the shelves, 2000 individuals in October and 2000 individuals in June. The release was evaluated to have successfully suppressed the re-infestation of the library (Schöller 2010). Another trial on host-finding in boxes containing books was carried out in an Israeli library, where *L. distinguendus* was shown to find host larvae both between and inside infested books (Wilamowski *et al.* 2008). More recently, store chalcids were regularly released against *S. paniceum* in the Kunsthistorisches Museum Vienna (Querner *et al.* 2013). A bibliography of the natural enemies of *Stegobium paniceum* and the tobacco beetle (*Lasioderma serricorne* F. 1792), a species with similar biology, is given in Schöller (1998).

3.4 Biological control of spider beetles (Anobiidae, Ptininae)

Spider beetles are mainly scavengers feeding equally on plant or animal materials. Beside their natural habitats, a number of species infest historic houses feeding on organic insulation materials and become a nuisance in residences (Howe 1959). Moreover, spider beetles were found to infest historic books and herbaria (Gamalie 2006). A number of spider beetle species were found to be suitable hosts for *L. distinguendus*, such as *Ptinus fur* L., 1758 (Herold 1933, Hüsing 1935), *Ptinus tectus* Boieldieu, 1856 (Kaschef 1955), *Gibbium psylloides* (Czenpinski 1778) (Kaschef 1961) and *Niptus hololeucus* (Faldermann 1835) (Schöller, unpubl.). Spider beetles are difficult to control in houses because the larvae develop hidden within walls and in dead floors, and no monitoring devices are available. In recent years, *L. distinguendus* was released against the hump beetle (*G. psylloides*) and the golden spider beetle (*N. hololeucus*) in Germany by pest control companies and became a regularly applied control technique (Kassel 2008). However, due to the lack of appropriate monitoring techniques, the optimal timing of the parasitoid releases has still to be determined. In this case, modelling the pest and parasitoid's population dynamics might be useful. As a first step, a modelling software 'SITOPHEX' (Roßberg *et al.* 2004) was used originally programmed for the system *Sitophilus granarius – L. distinguendus*. The biological data of the granary weevil *S. granarius* (L. 1758) was replaced by those of the golden spider beetle (*N. hololeucus*) (Schöller and Prozell 2011). One of the major differences in biology of the granary weevil compared to the golden spider beetle is the low reproduction of the latter at temperatures higher than 25°C.

The current release strategy by pest control companies is the monthly release when temperature conditions are favourable. The susceptible old larval stages and the pupae are controlled within one month and the population is suppressed in a way that few or no adults enter the living rooms. If the number of releases is reduced to four, one in beginning of July, September, March and May, respectively, an increase in young larvae is predicted in June. However, if the timing of the four releases is changed to beginning of July, March, May and June, this increase in young larvae can be suppressed (Schöller and Prozell 2011). This effect can be explained by the poor development of *N. hololeucus* during high temperatures in September, indicating the importance of population suppression early in spring in temperate climates. Even though these models cannot be validated at present due to the lack of monitoring devices, simulation models are thought to give some decision-support for parasitoid releases.

3.5 Biological control of larder beetles

Larder beetles (Dermestidae) are among the cultural heritage pests most difficult to control by chemical means. Two approaches for biological control were tested so far, the control by a parasitoid naturally occurring in houses, and the control by a generalist predator transferred from the stored-product environment.

The parasitoid *Laelius pedatus* (Say 1836) (Hymenoptera: Bethylidae) is a gregarious ectoparasitoid of several larder beetle species including *A. verbasci* and *T. angustum*. The shiny black wasps measure 2

to 3 mm in length (Reichmuth *et al.* 2007). During its life span a female wasp paralysed 74 ± 20 larvae of *A. verbasci* (Al-Kirshi 1998). The average number of eggs per female wasp and day was 1.42 ± 0.2 if larvae of *T. angustum* were used as host. Most egg-laying activity was observed at temperatures between 25° and 28°C, while no oviposition occurs at 15°C. A mated female lives 6 to 8 weeks at room temperature (Al-Kirshi 1998). This parasitoid is occurring spontaneously in Central Europe in buildings, but there are not studies on the biological control potential of laboratory-reared wasps in field trials. Larder beetles in the genera *Attagenus* are not parasitized (Al-Kirshi 1998), as well as *Anthrenocerus australis* (Hope 1843) (Schöller, unpubl.).

The predatory pirate bug (*Xylocoris flavipes*, Reuter 1875) is a natural enemy of various pest Coleoptera and Lepidoptera (Arbogast 1978). The potential for biological control of larder beetles attacking cultural heritage was only recently evaluated (Landsberger *et al.*, this volume). Eggs and larvae of five larder beetle species in the genera *Anthrenus*, *Attagenus*, *Trogoderma* and *Anthrenocerus* were found to be accepted as prey (Schöller and Prozell unpubl.).

Fig. 5: The dermestid bethylid *Laelius pedatus*; adult, parasitised larva of *Anthrenus verbasci* bearing egg of *L. pedatus*, and pupal cocoon of *L. pedatus*.


Fig. 6: The golden spider beetle (*Niptus hololeucus*), larva in opened cocoon (top) and adult (bottom).

4. Indirect monitoring of wood destroying beetles by monitoring parasitoids and predators

The study of natural enemies of cultural heritage pests might be useful not only for biological control, but also for monitoring. Early detection of material destroying pests is essential to prevent damage, especially in case irreplaceable objects of cultural heritage are concerned. However, monitoring of these pest species is often difficult. For example, pheromone traps for detection of *Anobium punctatum* (DeGeer 1774) resulted in very poor trap catches in field trials in Germany. For other wood-destroying beetles, no pheromone-traps are available. During the course of study of natural enemies, it turned out that some natural enemies are more easily detectable and give indirect evidence of the presence of the pest.

Haustein (2010) demonstrated the simultaneous monitoring of the death watch beetle (*Xestobium rufovillosum* DeGeer 1774) and its predator *Opilio mollis* (Linnaeus 1758). The monitoring was performed by gluing paper on wood, and the beetle species were differentiated by the respective emergence hole diameters produced. In Northern Germany (Mecklenburg) the emergence of adults of both species started mid of April when room temperatures reached a mean of 9.5°C, and most beetle emergence was recorded when temperatures reached 12°C or more. In a similar study, Haustein (2010) showed the blue clerid beetle (*Korynetes caeruleus* DeGeer 1775), a predator as well, can be recorded prior to its prey, the common furniture beetle (*A. punctatum*). In Northern Germany, the emergence of adult *K. caeruleus* started already in May at a mean temperature of 13.3°C, while *A. punctatum* started to emerge later in June at a mean temperature of 17°C. Another predatory checkered beetle (Cleridae), i.e. *Tillus elongatus* (Linnaeus 1758) was recorded to emerge from *Fagus sylvatica* wood prior to its

prey, the hardwood anobiid *Ptilinus pectinicornis* (Linnaeus 1758), but only five days earlier (Haustein 2010).

The method is decisive for the effectiveness of the monitoring, e.g. *X. rufovillosum* was successfully trapped on white sticky traps, but only small numbers of its predator *K. caeruleus* and no parasitoids were obtained in a study by Belmain *et al.* (1999). Different temperature thresholds for flight-initiation of the predator and the prey might be responsible for the low numbers of *K. caeruleus* caught in this case-study, as Haustein (2010) found a lower the temperature threshold of 26°C ambient temperature (no direct exposure to sun light) for flight for *K. caeruleus*. The spatial orientation and the colour of the sticky traps do also influence the trapping results depending on the target species. Haustein (2010) trapped significantly more Hymenoptera with multi-coloured, horizontally placed sticky traps compared to white sticky traps and both trap types placed vertically. On the other hand, for protection of the beneficials horizontally placed white sticky traps were suggested because they caught sufficient Anobiid beetles but few chequered beetles (Haustein 2010).

Paul *et al.* (2007) studied *A. punctatum* and its natural enemies in a church closed for restoration in Erfurt, Germany. Yellow dish traps, a monitoring technique used in outdoor ecological field studies was used here in the context of protection of museum artefacts and wood. Yellow dishes were filled with water and a bit of detergents in order to attract flower-visiting insects. These traps are especially attractive for parasitoids that do no host-feeding and rely on nectar for adult nutrition. Other arthropods are randomly trapped; the number caught in the trap is affected by the number of insects present and temperature. As an example, Table 2 shows the number of *A. punctatum* and the number of the braconid parasitoid *Spathius exarator* (L. 1758) as well as other natural enemies trapped in yellow dish traps in the study of Paul *et al.* (2007). Few *A. punctatum* were trapped, mostly between mid of June and mid of July. *S. exarator* was trapped throughout the trapping season from mid of May to mid of July in relatively large numbers, the peak coinciding with that of *A. punctatum*. The presence of *A. punctatum* could therefore be proven by the presence of the parasitoids before adult beetles became active.

Table 2: Insects trapped in yellow dish-traps in the church 'Allerheiligenkirche' in Erfurt, Thuringia, Germany, in 2006 (from Paul *et al.* 2007).

Species / Date	May 19	June 2	June16	June 23	June 30	July 7	July 14
Anobium punctatum	0	1	0	5	10	4	1
Spathius exarator	5	10	9	51	87	31	25
Korynetes caeruleus	4	0	4	0	1	0	0
Cephalonomia gallicola	2	4	3	2	1	1	1

High numbers of naturally occurring beneficials are a prerequisite for the indirect monitoring of wood-destroying pests. However, such cases might be common, e.g. Haustein (2010) recorded in a three years-study a total of 151 *P. pectinicornis*, and 79 and 66 predatory Clerid beetles and Braconid wasps *Hecabolus sulcatus* Curtis, 1834 summing up to 145 natural enemies, i.e. a ratio of almost 1 : 1 for pest and natural enemies.

5. Conclusions and outlook

Biological control of cultural heritage pests is in its very beginnings. Several species of natural enemies were recorded to occur spontaneously in houses, but even the host-parasitoid or predator-prey relationships are not clarified yet for all cases (Becker 1954). Their potential for biological control is far from been exploited. The examples of practical application described here show that both the

control strategies and the potential control success heavily depend on the artefacts to be protected and the biology of the pest species, i.e. every application has to be worked out in detail. For example, the population dynamics of *L. distinguendus* with *N. hololeucus* as host will not apply for *G. psylloides* as host. In many field studies parasitoids have been shown to be effective at low pest numbers, and typically heavy infestations cannot be control by natural enemies.

Biological control of stored product pests is nowadays widely known by farmers and industry and is applied by pest control companies in Central Europe against moths and beetles. Those parasitoids that attack both stored-product and cultural heritage pests will be commercially available for future field trials. Our company provides commercially *A. calandrae*, *L. distinguendus*, *T. evanescens euproctidis*, *B. tineivorus*, and *X. flavipes.* The development of a commercial application of other species of natural enemies might require 5 to 10 years, consequently a lot of work remains to be done for the commercialisation of natural enemies of cultural heritage pests.

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Parasitoids against insect pests - a future for IPM?

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Abstract
This paper looks back at the use of the parasitoid wasps *Trichogramma evanescens* against an infestation of webbing clothes moths (*Tineola bisselliella*) in the reserves of Geneva ethnographic museum. After two seasons of release of the parasitoids, accompanied by monitoring of the moths with pheromone traps, it was concluded that the wasps were inefficient because of their insufficient mobility, and possibly because of their low tolerance of biocides. The release of large numbers of parasitoid insects necessitated a comprehensive cleaning campaign of the entire collection in order to remove the dead wasps from the objects and shelving. The clothes moth infestation was finally overcome by traditional means of hygiene, thorough inspection and anoxic treatment.

Keywords: *Tineola bisselliella*; *Trichogramma evanescens*; parasitoid wasps; webbing clothes moth

1. Introduction

The use of parasitoids, natural enemies to control insect pests, represents a novel strategy in Integrated Pest Management (IPM) in museums. In recent years several publications have suggested potential beneficial effects of the release of parasitoids for the containment of active insect infestations of museum collections (Biebl 2009, Querner and Biebl 2011a,b, Schöller and Prozell 2011, Biebl 2013, Dummer and Prozell 2013, Querner *et al.* 2013). The new approach appears indeed to offer interesting perspectives. Letting nature have its own way promises not only to avoid or to reduce the use of toxic and costly pesticides but also raises hopes of a fashionable 'all natural' solution requiring less time-consuming human intervention.

This paper is an updated and abridged version of a full scientific publication in French (Anheuser and Garcia Gomez 2013). It relates the author's negative experiences with the use of the parasitoid wasps *Trichogramma evanescens* against a recurrent infestation of webbing clothes moths (*Tineola bisselliella*) in the reserves of Geneva ethnographic museum (MEG). This paper will explain why the release of parasitoids in a museum collection is counterproductive and to be strongly discouraged.

2. The situation

The reserve collections of Geneva ethnographic museum comprise some 70.000 objects and occupy a commercial underground storage space of 3.105 m^2 within Geneva freeport. The collections which are typical for an ethnographic museum include many objects highly vulnerable to insect attack, made of materials such as fur, feathers, textiles and wood.

Since 2004 when the museum moved to the premises, webbing clothes moth infestations were observed every year. These were centred on the African collection, 17.000 objects stored in a single room of 320 m^2. From there, moths threatened to spread to other collections in adjacent rooms.

Until 2009 no permanent conservation staff was available to deal with the infestations. Interventions by temporary staff were limited to anoxic treatment of a few isolated objects. No systematic cleaning or monitoring could be undertaken. In this rather desperate situation, temporary conservation staff decided to try a novel approach suggested by a commercial pest control contractor, the release of large numbers of the parasitoid wasps *Trichogramma evanescens* known to be natural predators of the clothes moths' eggs (Zimmermann 2005, Querner and Biebl 2011a,b).

3. The natural enemies

Trichogramma evanescens wasps, despite their systematic classification, bear little outward resemblance to ordinary yellow/black wasps (*Vespula* spp.). Only 0.3-0.5 mm long, they look like grey powder to the unaided eye, and are poor fliers who essentially move by walking despite having a pair of wings (Romeis *et al.* 2005, Zimmermann 2005, Schöller and Prozell 2011). Immature *Trichogramma* wasps were released, most of which were at the stage of pupae ready to hatch. These were provided and deployed by a commercial pest control contractor (Fig. 1).

Fig. 1: *Trichogramma* wasp and pupae.

Trichogramma pupae were initially poured directly on any object deemed at risk (Fig. 2). This was very soon considered unacceptable for conservation reasons and stopped after only six weeks by the temporary museum conservator supervising the treatment who was alarmed by the level of contamination of the collections. Distribution was then changed to placing cardboard envelopes, each containing 2.400 pupae, next to the objects in the hope that the wasps would be sufficiently mobile to find and destroy the moths' eggs on their own (Fig. 3). In total, 4.272.000 wasps were released over a period of two years, April to October 2009 and April to August 2010, at a cost of CHF 33.000 (€ 27.500) including monthly on-site visits by the contractor but excluding museum staff time.

Fig. 2: *Trichogramma* pupae on a feather object.

Fig. 3: Envelope with *Trichogramma* pupae next to a headdress made of fur, feathers and fibres.

4. Results and discussion

Fig. 4 shows the presence of moths in pheromone traps in the African collection 2009 and 2010. In 2009 because of lack of staff the release of wasps was not accompanied by any support measures such as searching and removing infested objects. Monitoring of moth presence was purely qualitative using the three categories featuring in the diagram, 3 (strong presence), 2 (medium) and 1 (weak). Large

numbers of adult moths remained present over the entire summer period until their natural disappearance with decreasing temperatures in autumn.

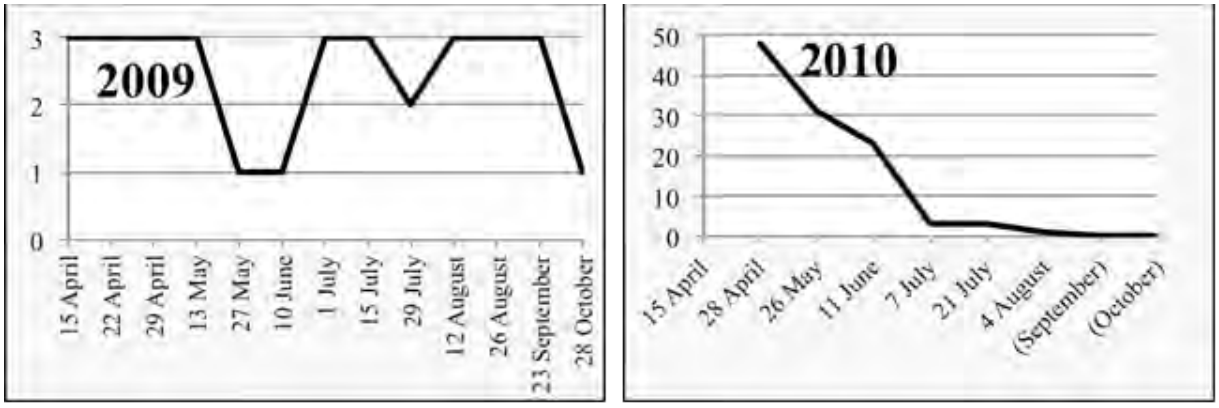

Fig. 4: Presence of clothes moths in pheromone traps 2009 and 2010 in the African collection. Results for 2009 are qualitative (3 = strong, 2 = medium, 1 = weak presence); 2010 results are quantitative (numbers of trapped moths in a calendar month). Dates on the time axis are wasp release dates.

In 2010 with the arrival of new conservation staff, monitoring became quantitative, recording actual moth counts, and a systematic search of the entire African collection for moth presence was carried out over a period of several months. At least a dozen infested areas were discovered, and some fifty objects subjected to anoxic treatment in a nitrogen chamber. In parallel, the release of *Trichogramma* wasps continued.

The reader should be reminded that the release of the wasps was not a scientific experiment conducted under strictly controlled and documented conditions but an attempt to counter a serious threat to the museum's collections with limited staff and resources, using all possible means at our disposal. Even though quantitative results for 2009 and 2010 are not directly comparable, the differences in the qualitative characteristics of the curves (undiminished moth presence in 2009, rapidly declining moth counts in 2010) are obvious.

The reproductive cycle of webbing clothes moths lasts about one year or, in favourable environmental conditions, less than this (Pinniger 2001). Temperatures in the Geneva ethnographic museum reserves approach or exceed 30°C for several weeks during summer, as the non-climatized premises are situated directly beneath a large black tarred surface exposed to direct sunlight. One would therefore expect more than one generation of moths per year. As the wasp trial lasted over a period of two full seasons one would have expected a visible impact of the release of the parasitoids on pest numbers with a reduced presence of moths in spring 2010 at the latest. As it were, clothes moths were just as present in April 2010 as they were in April 2009.

Zimmermann (2005 pp. 92-95 and 148-151) carried out mobility tests with *Trichogramma piceum* wasps (not *T. evanescens*) on two different textile surfaces and a sheepskin rug. His results demonstrated a strongly decreasing mobility of the wasps with increasing surface roughness. On the sheepskin which can be taken as a suitable model for many fur and feather objects, over a period of three days 80 % of the contacts between wasps and host egg targets took place within a distance of up to 20 cm from the release point (Zimmermann 2005 Fig. 108).

We observed an even more limited mobility of the wasps from the cardboard envelopes. In fact few of them managed to move more than 5-10 cm from their point of origin in the cardboard envelopes (Fig.

5). Unless they were directly placed on the objects, an undesirable choice for conservation reasons, very few of them would have arrived anywhere near their targets.

Fig. 5: Distribution of *Trichogramma* wasps around the point of release.

It appears that *Trichogramma* wasps are highly sensitive to the presence of insecticides, much more so than clothes moths. This limits their suitability for release in real museum environments. Many ethnographic and natural history collections were treated in the past with non-biodegradable, highly persistent insecticides (chlorinated aliphatic and aromatic hydrocarbons such as DDT, Lindane or PCP, or heavy metal salts such as arsenic oxide and mercuric chloride). Large-scale contamination of museum collections with these products is a challenge for conservators today. In many museums the presence of important concentrations of insecticides is a fact, even though they often remain unrecognized (Odegaard and Sadongei 2005).

At MEG Geneva DDT has been used in the past, in particular for the preventive treatment of wooden objects against wood-boring insects. Little is known about the quantity and the period when the insecticide was applied but an empty bottle was discovered in 2010 in the basement of the old museum building and analyses in 2011 of crystals on the surface of wooden objects in the African collection identified DDT. In that, the Geneva museum is typical for most other museums of its kind. In any case, even in an uncontaminated environment, typical surface textures such as fur and feather objects or porous foam layers on shelves would severely restrict the range of the microscopic wasps and in many cases prevent them from reaching their targets.

In terms of staff time and resources, the use of parasitoids is not a shortcut to the eradication of clothes moth infestations. Because of the very limited mobility of the natural enemies used against the moth infestation, all infested objects must be identified before the release of the parasitoids. In practice, screening of the collections to identify all affected objects is usually the most time consuming part of the intervention. Once this has been achieved, traditional freezing or anoxic treatment can be carried out in relatively little time in large batches. This is not only faster and cheaper than the release of parasitoids, but it also avoids the necessary cleaning of the objects from dead wasps. Unlike traditional treatments, natural enemies are also unlikely to eliminate an infestation completely, leaving the problem essentially unresolved.

If the real cost in staff time for cleaning the collection is considered, the release of parasitoids becomes prohibitively expensive, not to mention the fact that on many feather, fur and textile objects even the most delicate cleaning is likely to cause unavoidable irreversible damage. In practice the cost of

cleaning remains largely theoretical. As the museum does not have the necessary resources, the objects will remain contaminated for an indefinite length of time. Cleaning is only envisageable for selected objects, for example in case of a loan to another museum or if an object is to be put on display.

Conclusion

The release of parasitoids against an infestation of clothes moths may have looked like a good idea at the time, but with hindsight has proved inefficient, costly and counterproductive. Previous positive publications, written by biologists apparently unfamiliar with objects conservation practices, or by pest control specialists with a commercial interest in the promotion of the novel technique, simply do not address cleaning issues after the release of large quantities of natural enemies (Biebl 2009, Querner and Biebl 2011a,b; Biebl 2013, Querner *et al.* 2013). The IPM objective must remain to have fewer insects in the collection, not more.

The difference between the anti-insect treatments of 2009 and 2010 consisted essentially in a systematic search for infestations and the removal of infested objects from the reserve in 2010 which had been impossible in 2009. The release of *Trichogramma* wasps continued in 2010 as in 2009. It appears therefore reasonable to credit the successful outcome of the 2010 campaign to the additional hygiene measures. This is further supported by the observation of a very limited mobility of *Trichogramma* wasps in our real museum setting.

Past chemical contamination of a collection with biocides is likely to have a significant toxic effect on *Trichogramma* wasps. It is quite possible that insecticide residues have made an important contribution to the lack of success of the treatment at MEG Geneva. As most historic collections in ethnographic and natural history museums were treated with substantial quantities of insecticides at some point in the past, this alone would already rule out the use of these parasitoids.

From our experience we conclude that the use of parasitoids does not represent a useful alternative to thorough searching of the entire collection for infested objects, followed by a traditional treatment such as freezing or anoxia.

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