Supplementary issue paper

Linking webbing clothes moths to infested objects or other food sources in museums

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The webbing clothes moth *Tineola bisselliella* (Hummel, 1823) is one of the most common museum pests and can be found all over the world. The larvae damages objects made of feather, wool, fur, and other keratinaceous materials. Pheromone traps are important tools in integrated pest management, which allow the detection of infestations and evaluation of their extent. Organic-rich dust (detritus) or other materials of animal origin, such as dead birds, can be an alternative food source for the moths. This paper analyzes monitoring data collected with pheromone traps from six different museums in Vienna and Berlin and tries to differentiate between moths resulting from infested objects or moths coming from other food sources, such as organic-rich dust. Annual totals of moths trapped and catch rate (moths per trap) are important guides for selecting appropriate remedial measures. Long-term data (over six years) enabled us to interpret monitoring results and differentiate between active infestation of objects and cleaning or housekeeping problems. However, detailed knowledge of the site and buildings, availability of high-quality food for the larvae, and lack of regular cleaning are also important factors to consider when interpreting the data.

**Keywords:** Cleaning, Housekeeping, Food quality, Dust, Infestation, Monitoring, Pheromone traps, IPM

**Introduction**

The webbing clothes moth *Tineola bisselliella* (Hummel, 1823) is one of the most common museum pests in many countries. Over the last few decades, the moth has caused severe damage to many museum objects and along with Dermestid and Anobiid beetles is a key pest (Querner, 2009, 2012; Blyth & Smith, 2011; Querner & Simon, 2011; Thomson, 2011; Querner et al., 2013). According to Plarre and Krüger-Carstensen (2011), this clothes moth probably originated in central and southern Africa, but today has a world-wide distribution and can be found wherever humans live. Infestations seem to be concentrated in cities where webbing clothes moths are primarily found in occupied buildings and not associated with natural structures such as bird nests (Plarre & Krüger-Carstensen, 2011). The larvae are responsible for damage to a wide range of materials, such as stored products, domestic items, and museum artifacts. The ecology, biology, development time, and their occurrence in cities are described in Cox and Pinniger (2007), Plarre (2009), Krüger-Carstensen and Plarre (2011), and Plarre and Krüger-Carstensen (2011).

A variety of food sources are utilized by the larvae of the webbing clothes moth. In museums they commonly feed on:
- bird feathers
- textiles made of animal wool, such as carpets, rugs, and clothing
- animal fur, hair, and other keratin
- pianos and other felt-containing objects
- silk, linen, cotton, synthetic fibers (occasionally and only attractive when stained with food, body oil, or urine)
- blankets made from recycled textiles.

Other potential food sources for the larvae are:
- organic-rich dusts
- animal excrement
- dead animals, such as birds and mice
- bird nests in buildings
- fishmeal, milk powder
- brush bristles

(see http://www.MuseumPest.net and Collection Trust (http://www.collectionstrust.org.uk) fact sheets for information on webbing clothes moths in museums).
‘Dust’ in museums
‘Organic-rich dust’ or ‘detritus’ is the material accumulating in museums, storage facilities, and other buildings with human activity. It consists of textile fibers, human hair and human skin, mixed with all other fine organic and inorganic materials (fragments of insects, minerals). In the context of insect food, the keratinaceous components, such as human and animal hair, skin, fibers from animal wool, and dead insect parts are all attractive for webbing clothes moths (Titschack, 1922; Crowell & McCoy, 1937; Leene, 1965) and other museum pests like Dermestid beetles (Pinniger, 2004, 2008). The insects need a certain mixture of materials to complete their development and all of these compounds have to be found in their food source.

Dust can be defined as particles in the atmosphere that come from various sources such as soil, dust lifted by weather (an eolian process), volcanic eruptions, and pollution. Dust in homes, offices, and other human environments contains small amounts of plant pollen, human and animal hairs, textile fibers, paper fibers, minerals from outdoor soil, human skin cells, burnt meteorite particles, and many other materials which may be found in the local environment.

Detritus can be defined as non-living particulate organic material (as opposed to dissolved organic material). It typically includes the bodies or fragments of dead organisms as well as fecal material.

Pheromone trapping of webbing clothes moths
Since the isolation of webbing clothes moth insect sex pheromones and their use in commercially available pheromone traps, locating an infestation has become much easier. These have been incorporated within the monitoring elements of integrated pest management (IPM) (Child & Pinniger, 1993; Cox et al., 1996; Child, 2011; Thompson Webb, 2011). However, experience is needed to place the traps correctly and interpret the results. These traps are very efficient in catching male moths and can be bought at relative low cost (1–2 € per trap). Most museums include such pheromone traps in their IPM programs and information collected with the traps helps to find infested objects, and problems resulting from the poor building maintenance or bad housekeeping.

Monitoring with pheromone traps is an important part of IPM and is used to find infestations and solve pest problems (see Pinniger, 2004, 2008; Blyth & Smith, 2011; Lauder, 2011; Querner & Simon, 2011; Ryder, 2011; Xavier-Rowe & Lauder, 2011; Querner et al., 2013). The author of this paper has gained practical experience in moth trapping using pheromones over the last six years. This experience revealed a large variation in the number of individuals to be found on the traps, from 0 to 15 over the whole year in an entire store or museum, to extreme cases where as many as 140 were caught on a single trap in only a few weeks. If large number of moths are caught that suggests an active infestation of an object close to the trap. It is more difficult to interpret more modest catches of perhaps 5–15 moths caught in a storage room over a year. Here, it may not be clear whether the insects are coming from objects with a low infestation or whether the insects derive from a background population utilizing other food sources, such as those present in organic dust (Querner & Morelli, 2009; Blyth & Smith, 2011; Chaviara, 2011). Feather material derived from birds’ nests can also be a food source for the moths and has resulted in high infestation in some museum and historic buildings in the UK. It is important to consider the probable threshold in the moth catch that allows a valid interpretation of monitoring data as signifying an infestation.

Besides infestation of objects, organic-rich dust can be an important food source for the webbing clothes moth in museums and stores and this food source has to be taken into account when starting a monitoring program. According to David Pinniger (personal communication, March 2014) and Blyth and Smith (2011) up to 100 moths can be found per trap resulting from dust as a major food source. About 5–10 years are needed in typical new museums and galleries, until sufficient dust has accumulated to provide a food source for the moths.

Observations over the past few years suggest that webbing clothes moth infestations might be differentiated by (a) the length of time the adult moths are active, (b) the first occurrence in the year, and (c) number of moths caught on each trap (catch rate). In this paper, trapping data are analyzed for webbing clothes moths caught in a large number of individual pheromone traps throughout storage facilities and museums in Vienna and Berlin. The aim of this comparison is to develop concepts to determine the presence of an active infestation and establish whether the moths are coming from the active infestation of objects or whether they represent the background population.

Assumptions
(I) Moths select niches that present the most attractive and abundant food source to support an infestation.

(II) The development time and annual catch of moths depend on: food quality (type of material), food quantity (size and number of objects), temperature, relative humidity, predation, and other disturbances (light, human activity).

(III) The number of moths caught on the pheromone traps depends on the size of the population (total number of moths in the area).
Dust is assumed to be a low-quality food source, whereas infested museum materials, such as feathers, fur, or keratinaceous textiles can be of high food quality. This will result in a shorter development time for the moth population and therefore higher catch rate.

**Material and methods**

Pheromone traps (FINICON© type, provided by http://www.pestimoservices.com) were used for webbing clothes moths at all locations (Table 1). Traps were usually installed or replaced in March/April each year, and then checked five times during the warm months, until September/October. During the year all traps were replaced once with a new pheromone strip in the middle of the season (after about three months). This ensured a constant and high degree of attraction for the male moths. The traps were left in place during the winter months, but not checked at monthly intervals (this was done as no moth activity was observed in winter in all museums and storage areas over the last few years, heated and non-heated).

When a large number of moths were found on an individual trap, more traps were set out to increase the potential to locate the infestation. Additionally, museum staff searched for infested objects close to the trap which showed the highest catch, and then treated the objects by nitrogen fumigation or freezing. Dead moths, live larvae, pupae, and damage on the material were seen as evidence of an active infestation. If no infestation was found, other sources of food for the moths were assumed. In these cases, dust samples were taken and examined under an optical microscope to search for evidence of moth development. Usually, the remains of the head capsules of moth larvae were easily found in the dust together with some dead moths.

**Analysis of the data**

The results of the monitoring were compared over the full trapping period (years) and the total catch in each set of monitoring data, and the mean catch rate was calculated. The notion of catch rate is adopted in our analysis because the number of traps was not constant. Results as a catch rate are expressed in terms of the number of insects caught per trap (Brimblecombe *et al.*, 2013). This term catch rate has been adopted from fisheries research, where it is used as a measure of the number of fish caught for a given effort, i.e. the number of hooks, nets, or traps. Additionally, the trapping results from a single trap (in one case a second trap is also presented), that collected the highest number of moths over the total trapping period of one year for each location is presented. The catch rates for these traps are presented over the whole sampling period. Further information on heated or non-heated conditions of the locations and available food sources (high quality or low quality) are given in Table 1 and were used to locate infested objects and interpret the monitoring results.

**Results and discussion**

The number of moths caught per trap varies greatly. It ranges between none for the entire year and up to 130 moths caught during a period of four weeks. The date of first occurrence of the moths on the trap between heated and un-heated locations is different, but only by a few weeks, and the inspection intervals of the traps were not short enough to clearly date the first occurrence. The greatest numbers of moths were caught in all locations during the month of May each year. At Breitensee, Technical Museum Berlin (TMBerlin), Floridsdorf, Ägyptische collection, and

| Location                          | Types of materials                        | Heated | Number of rooms/stores at location | Total number of traps | Monitoring period | Active infestation discovered on objects | Available food source |
|-----------------------------------|-------------------------------------------|--------|-----------------------------------|-----------------------|-------------------|------------------------------------------|-----------------------|
| Floridsdorf, Vienna               | Technical objects (wood, metal, others), some historic cars and carriages | No     | 1                                 | 16–65                | 2007–2013         | Yes                                      | Only few objects     |
| Breitensee, Vienna                | Technical objects (wood, metal), some historic cars and carriages | Yes    | 19                                | 49–64                | 2007–2013         | Yes                                      | Only few objects     |
| TMBerlin, Berlin                  | Technical objects (wood, metal), some historic cars and carriages | No     | 6                                 | 24–59                | 2010–2013         | Yes                                      | In one room many objects |
| Schatzkammer, Vienna              | Textiles, fur, feathers                    | Yes    | 21                                | 56                   | 2008–2013         | No                                       | Many objects          |
| Ägyptische collection, Vienna     | Stone, very few textiles                   | Yes    | 10                                | 18                   | 2011–2013         | No                                       | Very few objects     |
| Kutschenhalle, Vienna             | Horse carriages                            | No     | 1                                 | 20                   | 2007–2013         | No                                       | Many                 |

**Table 1 Museums and stores in Vienna and Berlin investigated during monitoring of the webbing clothes moth**
the Schatzkammer, the total number of moths caught was clearly reduced over the years, showing that the IPM was working and that the control practices of searching and treating of infested objects were clearly successful (Figs. 1 and 2).

Three locations were found with active infestations (Fig. 1). The largest infestation was discovered in the storage facility at Floridsdorf in 2009, with a total of 2932 moths caught in the year. After the infested objects were found, they were treated on site with...
nitrogen during 2011 and 2012. Since then, very few moths were found in the traps, and this approach to IPM (monitoring, locating infested objects, and treating them) can be seen as successful. As this storeroom is a very big single hall, locating infestation was not as easy as in the smaller rooms that divide a collection as found in Breitensee.

In Breitensee, in 2008 a total of 860 moths were caught in the year. Also, the single trap analysis showed that there was an active infested object close to this trap. After the infested object (a horse carriage on the ground floor) was found, it was treated with nitrogen during 2009. Since this action, very few moths have been collected on this, or other traps in the surrounding area, through to 2013. In this storeroom, another infestation was discovered on the first floor in 2009. Again, the search for the objects was successful and the infestation was eradicated. In 2013, only very few moths were trapped over the whole year at this location, and the IPM approach was judged as successful. Although a large number of traps have continued to be set out, the lack of infestation suggests that the trap usage could be reduced in the future.

The third infestation was discovered in the TMBerlin storage facility, where some vintage automobiles and horse carriages were found to be heavily infested by moths. Monitoring started late in the year 2010. Nevertheless, a large number of moths were collected in the first year with a maximum of 260 moths found on a single trap and a total of 928 moths were found in this facility in 2010. Locating the infested objects was not easy as so many objects (vehicles) were infested. Only after placing traps in the cars (data are not presented here), individual infested historic vehicles were identified. These were treated after a −30°C freezing chamber was installed in the museum storage space in 2012, capable of reducing temperature in the automobiles. A further infestation was discovered in another room in this storage space in 2011. Again, the search for the infested objects was successful and the infestation eradicated. In 2013, significantly fewer moths were trapped over the year even though there may still be some infested objects within the collection.

In the three other locations, after analyzing the trapping data, no active infestation of objects seemed to be present. A good example of this is the Ägyptische exhibition space (Fig. 2) where moths were found in all rooms, sometimes in high numbers, up to 20 moths per trap. However, only two exhibit cases included objects such as textiles and mummies with a potential infestation. A pheromone trap inside an exhibit case did not capture any moths. Subsequently, dust samples were analyzed and there was evidence of activity and development of moths, suggesting that the dust was the food source. Also, in the Schatzkammer (Fig. 2) and Kutschenhalle (Fig. 2), moths were caught on the traps, but at much lower number than at the infested sites. Objects were checked for an active infestation, but none could be found. The dust samples in both locations showed proof of moth activity under the exhibit cases and between the wooden floor panels, where dust was able to accumulate over the years.

Comparison of the pooled catch rates from all locations (Fig. 3) shows that there is no clear threshold between locations with an active infestation and locations with housekeeping problems and dust accumulations. A catch rate of 1.8 moths per trap was found in the Ägyptische collection. This value is only a little lower than the rates at Breitensee, which experienced an infestation of objects, yet showed two moths per trap, on average. This indicates, as might be expected, that average catch rate is not an indicator of infestations. Further analyses are planned to separate individual rooms in the analysis of the trapping data.

**Heated versus non-heated locations**

A clear difference in the occurrence of moth development over the year related to temperature (heated/non-heated) could not be detected. In all locations, heated and non-heated months were found over a period of 5–6 months, from about March/April when traps were renewed each year until the end of the summer (August/September). Effects of heat (Titschack, 1925) and humidity (Griswold & Crowell, 1936) are important factors for the development of moths, but the checking intervals within the active time of the moths were probably not short enough (may be two-week intervals would have...
given better results than 4–6 weeks). In all our sites, we are not sure whether more than one breeding generation was developing each year, as the data presented in Figs. 1 and 2 do not show clearly two peaks during the year of monitoring, as would be expected with more than one generation. This is in contradiction to Blyth and Smith (2011) who found three breeding generations of moths per year in some heated buildings in the UK.

Control of infestation
IPM in museums uses different chemical-free options to treat infestation, such as freezing (Florian, 1990; Strang, 1997), controlled heat treatment (Strang, 1992; Pinniger, 2003), anoxia (Gilberg, 1989, 1991; Maekawa & Elert, 2003), parasitoid release (Querner & Biebl, 2011), or insect growth regulators (Gilberg & Roach, 1997) (see also Querner and Kjerulff (2013) for an overview of treatment methods used in museums). But we clearly show that the often discussed ‘housekeeping’ or ‘deep clean’ is an important part of preventive conservation, to reduce moth activity in museums and stores. Regular training and expertise is also an important part of IPM, to evaluate the site and building and determine whether there are nests of birds, uncleaned chimneys, etc. The availability of high-quality food for larvae in high-risk collections such as furs and feathers means that they are more likely become infested than technical equipment made mainly out of wood and steel. Therefore, in such high-risk collections, more emphasis is placed on IPM, monitoring, and also cleaning. But the data presented here show that also in low-risk collections, with a lack of regular cleaning, dust can accumulate and harbor an unwanted pest or moth population. Keeping this in mind is also important in interpreting monitoring results correctly.

Analyzing dust samples is an important tool to demonstrate that this organic material accumulating behind exhibit cases, under objects, or on floor boards is a food source for the moths. To prevent long-term moth activity, these food sources and potential starting points of an object infestation must be identified and removed.

When an infestation is found, the number of pheromone traps is usually increased to better locate the infestation or source of the moths. This was also successful in our cases, but placing more traps has a strong influence on the catch rate and has to be taken into account when comparing catch rates between sites. To avoid this bias, a minimum distance of 10 m between traps was given for the traps and lures we used. There might still be an overlap of the pheromones in the air, and it was assumed that more traps would not have caught significantly more moths.

Guidelines for pheromone trap use based on the results of this work
- Place new traps preferably in spring to start new monitoring (March).
- Traps should be placed at least 5 m from doors and windows.
- Place at least one pheromone trap per 100–200 m², also in locations without objects that can be infested by moths.
- Replace all pheromone traps at least once during summer (May/June).
- Use the same type of pheromone traps in all rooms and years to be able to compare results.
- Search for dust accumulation and/or infested objects in the area if moths are found on the traps (radius of about 10 m).
- If you cannot find the infestation or source, place more traps, also outside of the doors, hallways, staircases, in shafts, or chimneys.

Concluding remarks
Our results show that monitoring with pheromone traps is an essential part of IPM and allows infested objects and rooms to be found as described in Child and Pinniger (1993), Cox et al. (1996), Pinniger (2004), Child (2011), Thompson Webb (2011), and Querner et al. (2013). Interpreting the results of traps requires a continuity and consistency of data, if they are to be helpful in finding infestations. Analyzing long-term data, such as that presented here, can show trends in the catch rate over time (see also Brimblecombe and Brimblecombe (2014) for long-term data analysis of monitoring data from different historic houses of English Heritage in the UK).

Brimblecombe and Lankester (2013) used simple modeling to suggest that a changing outdoor and indoor climate can shorten the development times for pests and other insects in historic houses. Data presented here show that the detection of individual infested objects, and the treatment of these, strongly influences the number of insects caught. Remedial treatments are likely to reduce the insect catch and would be likely to obscure the effects of climate change.

Acknowledgments
The author thanks the museums for supporting the IPM programs and for allowing use of the data for this analysis. The author would also like to thank Peter Brimblecombe for his help with the figures, comments on the first drafts of the paper, and discussion on this topic.

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