

**Integrated Pest Management (IPM) in
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Astrid Hammer**

Section II: Case Studies



- Contents -

Section II Case studies.....	75
Distribution of wooden-damaging beetles captured by adhesive traps in historic buildings in Nikko Hayashi, Mikiko; Kigawa, Rika; Harada, Masahiko; Komine, Yukio; Kawanobe, Wataru & Ishizaki, Takeshi.....	76
Large-scale survey of wood-boring anobiids by adhesive ribbons in historic buildings at the Nikko World Heritage Site and investigation of effective eradication measures during an extensive restoration Kigawa, Rika; Harada, Masahiko; Hayashi, Mikoko; Komine, Yukio; Nomura, Makito; Fujii, Yoshihisa; Fujiwara, Yuko; Torigoe, Toshiyuki; Imazu, Setsuo; Honda, Mitsuko; Kawanobe, Wataru & Ishizaki, Takeshi.....	85
Craigievar: long term problems, long term solutions Houston, Mel & Davidson, Ian M.	105
IPM in the palace of Schönbrunn in Vienna, Austria Querner, Pascal; Iby, Elfriede & Wohlfart, Michael.....	114
Update on the IPM programme at English Heritage Lauder, Dee	121
Everyday struggles with insects at an ethnological museum Fürnkranz, Sophie.....	132
Infestation by the blue bottle fly (<i>Calliphora vicina</i>) and the clothes moth (<i>Tineola bisselliella</i>) inside an Italian art museum Di Domenico, Davide & Maistrello, Lara	139
Integrated Pest Management in Italian cultural heritage institutional structures Berzolla, Alessio; Chiappini, Elisabetta; Minoli, Denise; Nelli Roberto & Reguzzi, Christina.....	144
A tricky road to IPM at the <i>Centre des monuments nationaux</i> (CMN) in France Gunn, Agnoko-Michelle & Nicosia, Grazia.....	147
Monitoring of the webbing clothes moth (<i>Tineola bisselliella</i>) as a prerequisite for an Integrated Pest Management in the Imperial Furniture Collection, Vienna, Austria Rausch, Matthias & Halmschlager, Erhard	156
<i>Tineola bisselliella</i> at the Natural History Museum, London Ryder, Suzanne; Mendez, Armando & Kelly, Clayre	162
Control of the wood boring weevil (<i>Pentarthrum huttoni</i> ; Coleoptera: Curculionidae) by changing the environmental conditions in the crypt of St. Michael's church, Vienna Halmschlager, Erhard; Kritsch, Peter & Dobart, Nina.....	167
IPM at the Technisches Museum Wien Ljubić Tobisch, Valentina; Wetzenkircher, Martina; Weixelbaumer, Friedrich; Clouter, Chris & Sánchez, Bettina	177
Thirteen years of IPM at the Imperial Carriage Museum, Vienna - from the beginnings to now Morelli, Michaela	186

Relocation of the collections from the Kunsthistorisches Museum Wien to a newly built storage site
– consequences for the IPM

Querner, Pascal & Kimmel, Tanja 194

Section II

Case studies

Distribution of wooden-damaging beetles captured by adhesive traps in historic buildings in

Nikko

Hayashi, Mikiko; Kigawa, Rika; Harada, Masahiko; Komine, Yukio; Kawanobe, Wataru & Ishizaki, Takeshi

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Abstract

During restoration work in 2008, very severe damage was found in some structural wooden pieces of the Sambutsu-do in Rinnohji Temple (part of the Nikko World Heritage Site). A quantification of the insects that caused the damage is the first priority in restoration and conservation plans and in the design of methods to prevent further insect damage to historic buildings. To determine the approximate numbers of insects in the affected structure, surveys with adhesive traps (fly catching ribbons) were conducted in 2009 to observe the adult insect emergence on the temple grounds. A large-scale adhesive-traps survey of many more historic wooden buildings in Nikko was conducted in 2010 to further delineate the numbers and species of wood-damaging insects. Nikko World Heritage Sites consists of the two shrines and the one temple. About 27,000 adhesive traps were used in the lofts and basement spaces of 72 buildings and structures on the Rinnohji temple grounds, Futarasan shrine grounds and Tosho-gu shrine grounds. *Priobium cylindricum*, *Trichodesma japonicum* and *Sculptotheca hilleri* were trapped by adhesive tapes in 2009. *Hadrobregmus pertinax* and *Oligomerus japonicus*, which were not found in 2009, were found in 2010. It is not clear how much these anobiid beetles were involved in the damage to wooden structures. However, since they were detected, surveys were conducted to determine the levels of damage they have caused. This 2010 large-scale survey added a great deal of information about the overall damages. The distributions of pests in some major buildings were scrutinized, and some correspondence was observed between the visual distribution of beetles and the damage to the buildings. Interesting ecological characteristics of wood-boring beetles were revealed by the data, including light attraction. Together the finding will be useful for future treatments such as fumigation, and for restoration and conservation plans.

Keywords: wood-boring anobiids; insect trapping; adhesive traps; historic wooden buildings; Nikko World Heritage Site

1. Introduction

During restoration work in 2008, severe damage was found and reported in some structural wooden pieces of the Sambutsu-do in Rinnohji Temple, part of the UNESCO World Heritage Site in Nikko, Japan which is approximately 140 kilometres north of Tokyo (Komine *et al.* 2009). Insects found in one of the pieces were identified as *Priobium cylindricum*, a very rare anobiid beetle species in Japan

(Komine *et al.* 2009). Other species of wood-boring anobiids were later found in Rinnohji Temple (Komine *et al.* 2010). Further studies were conducted by X-ray computer tomography (CT) to observe insect larvae inside the wood (Kigawa *et al.* 2009; Torigoe *et al.* 2010) and by Resistograph to check the physical strength of major structural beams (Fujii *et al.* 2009, 2010).

From June to August (the warm season) in 2009, adhesive tapes (fly catcher ribbons) were used to investigate the adult insect emergence. At the Taiyu-in Nitenmon structures on the Rinnohji Temple grounds, *Priobium cylindricum* was not found but other anobiids - *Trichodesma japonicum* and *Sculptotheca hilleri* - were trapped by adhesive tapes in the loft and basement spaces (Komine *et al.*, 2010). However, the 2009 survey was limited to two historic wooden buildings and did not assess to the rest of the Nikko World Heritage Site, which is comprised of over 100 buildings and structures. It is extremely important to precisely determine the extent of insect damage situation to make plans for conservation and restoration and to propose preventive methods.

In 2010 a large-scale survey of the wood-boring anobiids in 72 buildings was conducted with adhesive tapes in order to clarify the active infestation throughout the Nikko World Heritage site (Hayashi *et al.* 2011). The distribution of beetles in the Sambutsu-do (a large hall) and the Taiyu-in Nitenmon (a large gate) were scrutinized using the large-scale survey data (Hayashi *et al.* 2012). This Short Communication describes mainly the methods and results of the large-scale survey and the analysis of the distribution of beetles in the Sambutsu-do and the Taiyu-in Nitenmon.

2. Material and methods

The large-scale survey was conducted as part of Detect step in an Integrated Pest Management (IPM) program (Avoid, Block, Detect, Respond and Recover) (Strang and Kigawa 2009). About 27,000 adhesive traps were used in the loft and basement spaces of wooden buildings around the entire Nikko site. All wood-boring anobiids, which are harmful to wooden buildings, were counted and identified. The counting and identification took almost 4 months. The distribution of beetles in the wooden structures was then analysed.

2.1 Adhesive traps

The adhesive traps were commercial products that are usually used to catch flies. About 27,000 adhesive traps (width: 4 cm; length: 78 cm, Daiso Industries, Hiroshima, Japan) were placed in the loft and basement spaces of 72 wooden buildings at the Nikko site from the end of April to the beginning of October 2010 over a 5-month period. This time of year is warm enough that adult insect emergence can be observed. The association for the Preservation of the Nikko World Heritage Site Shrines and Temples placed and removed the adhesive traps (Fig. 1a) (Harada *et al.* 2011). Adhesive traps were positioned at near regular intervals. Counting and identification were originally to have been done on the spot. However, there was not enough light in the lofts and basement spaces to count the insects, and it was difficult to identify the insects precisely in the dark and confined conditions. About twenty adhesive traps at a time were sandwiched between two sheets of polyethylene and were sent to the National Research Institute for Cultural Properties, Tokyo (NRICPT) for the identification and counting of species (Fig. 1b).

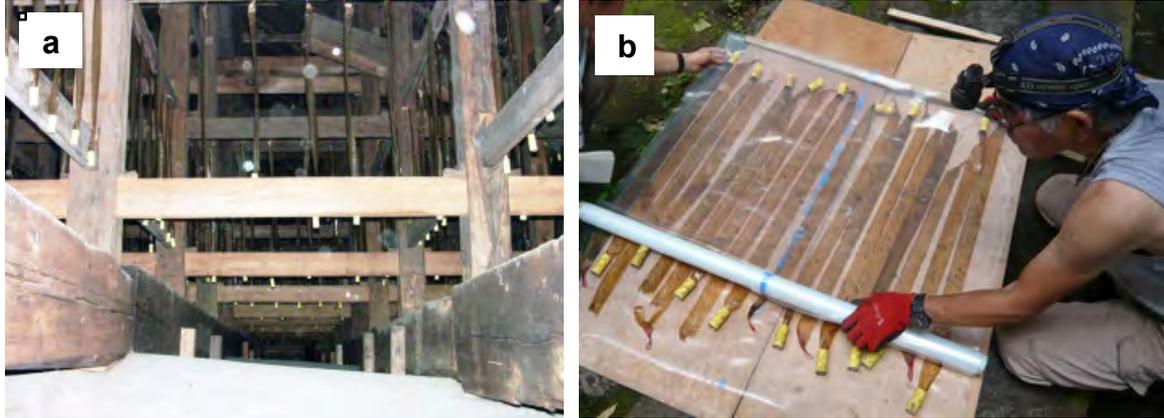


Fig. 1: Setting and removing adhesive traps for anobiid beetles at the Nikko World Heritage Site. **a**: Adhesive traps set in the loft space under the roof. **b**: Adhesive traps collected on one sheet.

2.2 Selection of beetles, counting and identification

The front and the back of each sheet of adhesive traps were scrutinized using a hand microscope (Fig. 2a). Trapped beetles were circled with an oil-based red pen, and photos were taken as a record. The beetles were then counted and cut off from the sheets. The beetles on a given adhesive trap were grouped and identified. These processes were conducted with data tabulation sheets to ensure that the location of the traps and numbers of beetles were recorded (Fig. 2b). Many types of insects such as spiders, ants and dragonflies were present on the adhesive traps, but this survey targeted only the insects that cause damage to wood. Wood-boring anobiids had been reported in Rinnohji Temple the year before the large-scale survey, and these were identified and quantified by the survey. The counting and identification were carried out from the end of July to the beginning of December in 2010.



b Date Name Name of building

日付 2010年9月6日 作業者名: 杯 澤田 建物名: 東-武徳殿

Number of beetles

シートNo (書込む)	トラップNo	甲虫の数 (赤丸&シートNoを書込む)		写真	赤丸の虫 を切り取り
		表	裏		
8	B 781 792 766 715 742 734 722 794 705 742 765 129 733 708 707 752 747 785 747	4	12	✓	✓
9	B ? 962 967 988 990 989 957 982 ? 949 969 988 990 989 957 982 952 977 953	5	3	✓	✓
10	B 959 901 824 820 824 90 865 904 999 822 902 822 960 823 978 863 903 1000 864 825	16	5	✓	✓
11	B 883 882 834 835 830 851 864 917 918 836 831 834 833 861 915 916 832 898 923 874 914 832	13	11	✓	✓
12	B 928 1023 1042 857 871 860 450 902 879 817 939 878 434 925 855 854 933 876	10	6	✓	✓
13	B 1058 1055 1057 ? 1039 1056 1039 1038 1019 1018 ? 1039 1057 1038 1021 1001 737	89	2	✓	✓
14	B 1016 1015 1014 1054 1032 1033 1032 ? 1012 ? 1048 1050 1031 1031 1009 1010 ? ?	82	2	✓	✓

The front The back Photo Cutting

Number of sheet Number of trap

Fig. 2: Counting and identification of beetles. **a**: Scrutinizing a sheet of adhesive traps with anobiids. **b**: A data tabulating sheet.

2.3 Distribution of beetles

When the adhesive traps were set in the wooden buildings of the Sambutsu-do and the Taiyu-in Nitenmon, the consecutive numbers of traps were put on general drawings of the buildings. The number of beetles on each trap was transferred to the general drawings to analyse and display the beetles' distribution.

3. Results and discussion

Five types of wood-boring anobiids were found throughout the Nikko site: *P. cylindricum* (Fig. 3a), *Trichodesma japonicum* (Fig. 3b), *Hadrobregmus pertinax* (Fig. 3c), *Oligomerus japonicas* (Fig. 3d), and *Sculptothecha hilleri* (Fig. 3e). *P. cylindricum*, *T. japonicum*, *H. pertinax* and *O. japonicas* are large anobiids compared to *S. hilleri*. Large anobiid species can cause significant damage to wood.

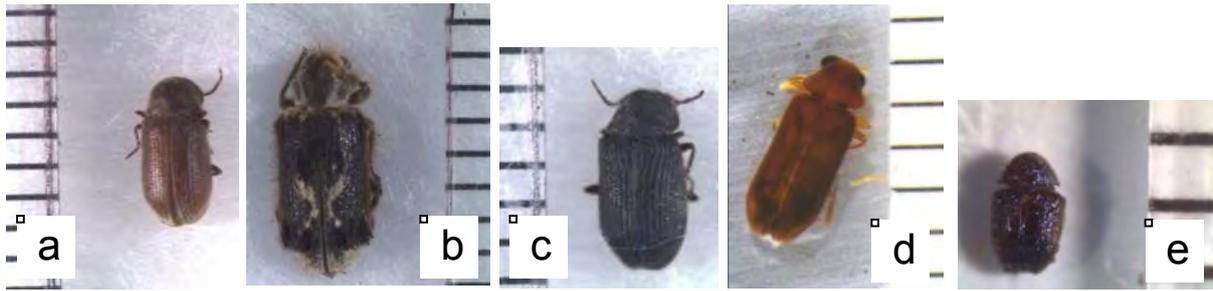


Fig. 3: Wood-boring anobiids found in the Nikko area (Komine *et al.* 2011). a: *Priobium cylindricum*. b: *Trichodesma japonicum*. c: *Hadrobregmus pertinax*. d: *Oligomerus japonicas*. e: *Sculптоtheca hilleri*.

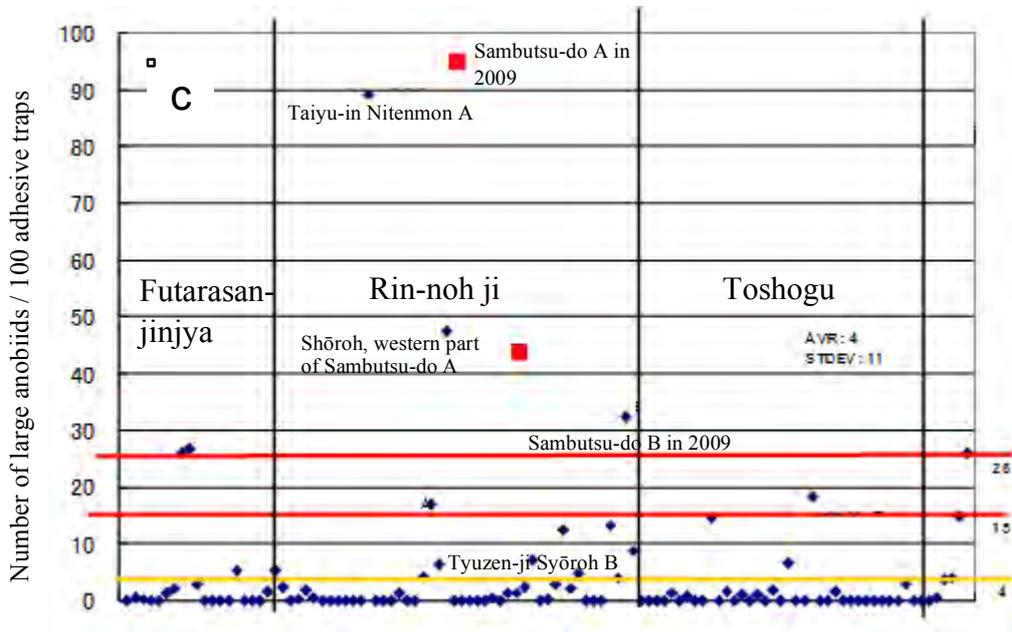
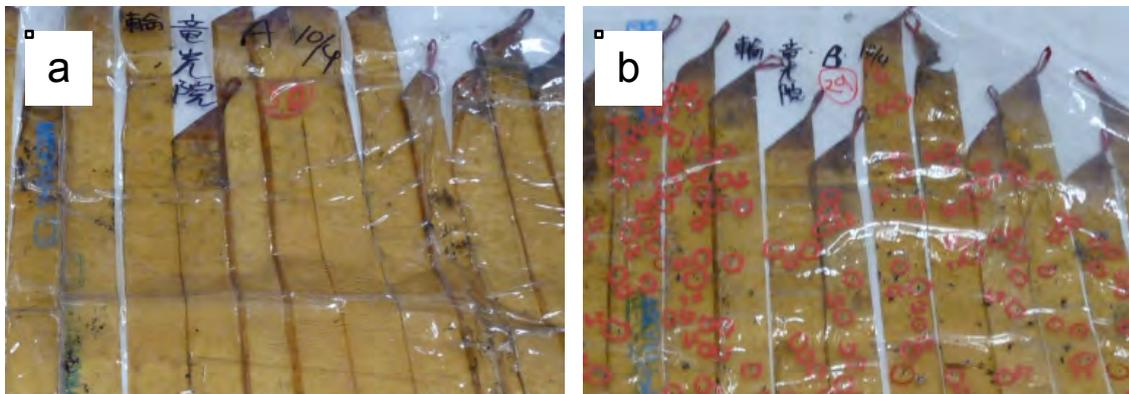


Fig. 4: Relative evaluation for total counts. a: Loft space under the roof, and b: basement space under the floor in Taiyu-in Bettoshō Ryukoh-in. c: The number of large anobiids number per 100 adhesive traps.

3.1 The total anobiid counts at Rinno-ji Temple

The results of the beetle counts are arranged mainly according to the species of anobiids in Table 1. It was not easy to identify all of the beetles on the adhesive traps because some of the sheets were crushed on the way to the NRICPT from Nikko, and so they were categorized as other types of beetles. Several beetles that can cause wood damage were found: bark beetles, weevils and longhorn beetles. Comb-clawed beetles and reticulated beetles can cause damage to infested wood, but they are not defined as museum insect pests. However, for cases in which the wood is heavily infested or has serious damage, these beetles can be museum insect pests.

The results at Rinno-ji show a tendency that is often seen in historic wooden buildings where one species is dominant; in the Sambutsu-do, most of the anobiids were *P. cylindricum* and in the Nitenmon, most of the anobiids were *T. japonicum*.

Table 1: Total counts in Rinno-ji Temple.

Rinno-ji Temple	Setting day of adhesive traps	Setting days	Number of adhesive traps	Number of beetles	Anobiid beetles					Click beetles	Other types of beetles
					<i>Scaphitrocha hilleri</i>	<i>Trichosoma japonicum</i>	<i>Ptilium cylindricum</i>	<i>Ptilium cylindricum</i> or <i>halpinigrum perleky</i>	<i>Glyptinus japonicus</i>		
Taiyulin Honzen	B**	2010.04.23	163	330	310	268	18			1	23(Comb-clawed beetles:1, Carabid beetles:1)
Taiyulin Anzen	E	2010.04.23	163	64	102	69	2				11
Taiyulin Hoken	A*	2010.04.23	160	351	422	419					3
Taiyulin Okusho	E	2010.04.23	163	351	410	396		1		1	12(Carabid beetles:1, Reticulated beetles:1)
	A	2010.05.17	136	174	345	284		3		1	47
	E	2010.05.17	136	174	75	25		1		2	47(Carabid beetles:1, Reticulated beetles:17)
Taiyulin Okusho Watercub	E	2010.05.17	136	51	40	11					29(Longhorn beetles:1, Reticulated beetles:5)
Taiyulin Nishimon	A	2010.05.18	99	117	11	5					6
Taiyulin Sanyo	A	2010.04.21	123	48	24	22					2
	E	2010.04.21	123	193	53	27				5	21(Carabid beetles:2)
Taiyulin Koroh	A	2010.04.21	153	48	43	41					2
	E	2010.04.21	133	163	34	21					13(Comb-clawed beetles:3, Weevils:1)
Taiyulin Nitenmon	A	2010.04.24	124	150	238	86		134		2	16
Taiyulin Saisho	A	2010.05.17	101	98	76	59					17(Carabid beetles:1)
Taiyulin Hoken	A	2010.05.20	133	216	24	22					2
	E	2010.05.20	133	216	237	146				7	64(Reticulated beetles:14, Tumbling flower beetles:2)
Taiyulin Gohkoku	A	2010.05.20	133	12	9	1		4			4
Taiyulin Okusho Hoken	A	2010.05.20	133	159	93	86				1	4(Comb-clawed beetles:1)
	E	2010.05.20	133	159	80	35				4	41(Reticulated beetles:1)
Taiyulin Bettonsho Ryukim-in	A	2010.05.05	153	720	92	60					32(Carabid beetles:1, Bark beetles:13)
	E	2010.05.04	152	720	4727	4604		107	21	3	63(False blister beetles:1, Reticulated beetles:2)
Sambutsu-do	A	2010.05.24	138	3308	476	73		346	43		11(Tumbling flower beetles:2)
	E	2010.05.25	115	2308	713	508		135	9	2	28(Carabid beetles:1)
Shoin, western part of Sambutsu-do	A	2010.05.20	103	40	21	2					
Hombu Omotemon	A	2010.05.21	102	69	1	1			12		
Kasen-do	A	2010.05.15	141	174	8	2					6
Juboku-do	A	2010.05.15	97	1068	673	658		1		4	10(Carabid beetles:4, Firefly beetles:1)
	E	2010.05.17	96	1068	380	318				12	50(Carabid beetles:5, Longhorn beetles:1, Euclyptid beetles:1)
Hakke-do	A	2010.05.15	99	357	175	165				2	6
	E	2010.05.17	97	357	570	522		2		7	39(Scarabid beetle:1)
Juso-do Hoken-do Watercub	E	2010.05.15	99	42	35	25					10
Utsunoi Hoken	A	2010.05.20	107	216	229	218		3			6
	E	2010.05.20	107	216	1022	1651		3		10	158(Comb-clawed beetles:2, Weevils:2, Reticulated beetles:3, Tumbling flower beetles:2)
Utsunoi Kiyashi	A	2010.05.20	107	84	73	63		1			6(Carabid beetles:1, Spider beetles:1)
	E	2010.05.20	107	84	180	93		2		14	67(Euclyptid beetle:2)
Utsunoi Sinyo	A	2010.05.20	107	5	28	24		1		1	2(False blister beetles:1)
Utsunoi Amidadon	A	2010.05.20	107	5	44	16		3		4	20(Carabid beetles:1, Longhorn beetles:1, Phasing tongue beetles:1)
Katsura-do	E	2010.05.21	125	15	23	22					4
Gohiten-do	A	2009.7.6	419	543	223	121		1		6	95(False blister beetles:1, Comb-clawed beetles:9, Scarabid beetle:2, Reticulated beetle:2, Tumbling flower beetle:1)
	E	2010.07.14	81	179	54	27		5		2	20(Scarabid beetle:5, Soldier beetles:2)
Kannon-do	A	2010.05.07	147	40	15	5		4		1	4(Comb-clawed beetles:1)
	E	2010.05.07	147	183	146	63		1		24	Weevils:1, Tumbling flower beetles:1)
Tsuzumi Tachikannon-do	A	2010.05.18	134	118	13	3					10(Carabid beetles:3, Carpet beetle:1, Euclyptid beetles:1)
Tsuzumi Tachikannon-do (left behind)		2010.06.24	97	21	9	2			1		6(Carabid beetles:1)
Tsuzumi Tachikannon-do (shibubai-entomo)		2010.06.24	97	20	7	5					2
Tsuzumi behind Senjukannon	A	2010.05.18	134	9	36	33					3(Spider beetle:2)
Tsuzumi Rinsen	A	2010.05.18	134	24	2						2
Tsuzumi Hachidokuten-do	A	2010.05.18	134	30	7	4					3
	E	2010.05.18	134	50	64	29				4	21
Tsuzumi Hachidokuten-do hidden	A	2010.05.18	134	30	3						3(Carabid beetles:1)
	E	2010.05.18	134	90	55	4		12		2	37
Tsuzumi Suroh (up, middle)		2010.05.18	134	74	11			3		1	7(Scarabid beetle:1, Carabid beetle:1)
(down)	E	2010.05.18	134	34	22			8	3	3	6(Carabid beetle:1, Soldier beetles:1, Weevils:1)
Tsuzumi Aizen-do	A	2010.06.24	97	34	7	1		2		1	3(Soldier beetles:1)

A*: Loft space under the roof. B**: Basement space under the floor.

3.2 Density of insects

Total counts of insects do not necessarily provide an accurate index for determining the level of damage observed. In addition, in the present survey, the numbers of adhesive traps were not the same or equivalent across all of the wooden buildings and structures. However, when the numbers of traps are the same, the density of the insects can be determined from the numbers of total insect counts or from the record photos themselves (Fig. 4a,b). At the Taiyu-in Bettosho Ryukoh-in building at Rinnohji Temple, the same number of adhesive traps was set in the loft space under the roof and in the basement space under the floor. We found that the density of insects differed in the record photos. The total counts were 91 in the loft space and 4.727 in the basement space. There were thousands of *S. hilleri* (a small anobiid) in the basement space.

However, even when the numbers of adhesive traps are not the same or equivalent, a relative evaluation is necessary to compare the damage to the various wooden structures. We focused here on the number of large anobiids because the damage from large anobiids was expected to be more severe than the damage from small ones. To compare the numbers of large anobiids, we calculated and plotted the large anobiids number per 100 adhesive traps (Fig. 4c). The numbers of large anobiids in the Sambutsudo and Nitenmon were significant, and based on this finding we confirmed that precise surveys of each historic wooden building were necessary.

3.3 Distribution of beetles

The distribution of beetles in the Sambutsudo was almost equal in the different parts of the basement space (Fig. 5a). The total count in the basement space of the Sambutsudo was 713; *P. cylindricum* numbered 135 (19%), and 539 (76%) were *S. hilleri*. The distribution of beetles in Fig. 5a is for *S. hilleri*. The distribution of beetles in the Nitenmon was not equal in the different parts of the loft space (Fig. 5b). The total count in the loft space of the Nitenmon was 238; 134 (56%) were *T. japonicum* and 86 (36%) were *S. hilleri*. The distribution of beetles in Fig. 5b is for *T. japonicum*. Most of the beetles were trapped in the central part of the Nitenmon. There are two entrances at the northern and southern central parts of the Nitenmon, and some sun-light enters these openings. Sun-light may have an effect on the distribution of beetles. The phenomenon of light attraction in wood-boring anobiids was reported (Kigawa *et al.* 2012).

Conclusions

Five species of anobiids were detected in the wooden buildings at the Nikko World Heritage Site. Damage to historic buildings by those species of Anobiidae had not been reported before in Japan, and thus the degree of damage by anobiids had not been clarified. The large-scale survey described herein provides important information about the characteristics of the insects and suggests ideas for appropriate countermeasures to protect the buildings from the insects. *P. cylindricum*, *T. japonicum* and *O. japonicus* were detected in some specific buildings. The characteristics of each anobiid were observed, and the distributions identified suggest the habits of beetles and add to the ecology of anobiids. These data can be utilized for the protection of wooden buildings.

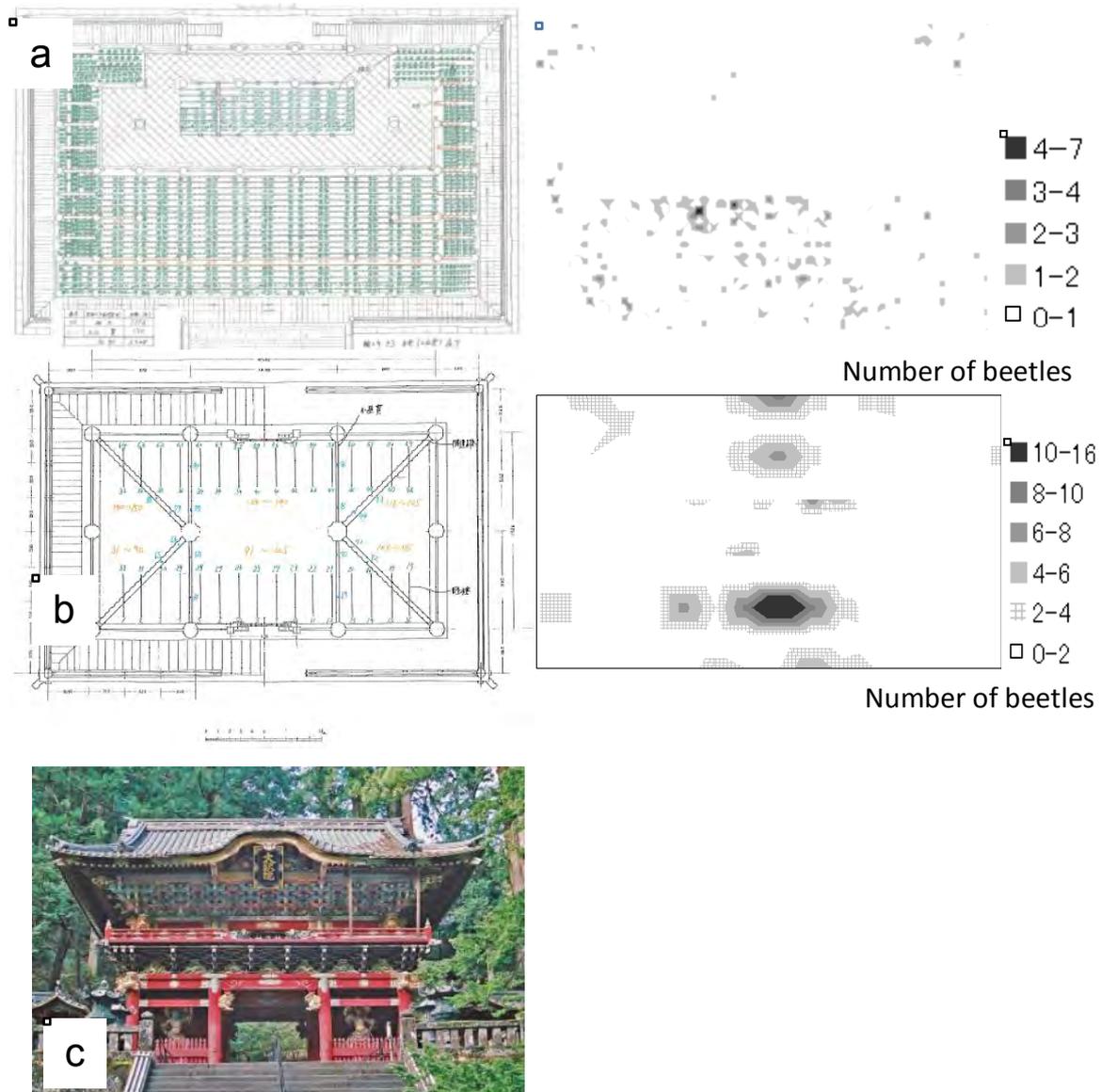


Fig. 5: Distribution of beetles in the Sambutsudo and the Nitenmon. **a**: The distribution in the Sambutsudo. **b**: The distribution in the Nitenmon. **c**: The outside of the Nitenmon.

Acknowledgements

We thank Nikko-zan Rinnoji Temple, Nikko Toshogu and Nikko Futarasan-jinja for kindly allowing us to conduct this study. We also thank the graduate students of the Tokyo University of Arts and students of the Tokyo University of Agriculture for their assistance in the counting of captured insects and data records.

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Large-scale survey of wood-boring anobiids by adhesive ribbons in historic buildings at the Nikko World Heritage Site and investigation of effective eradication measures during an extensive restoration

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Abstract

A very rare anobiid species in Japan, *Priobium cylindricum*, was found by chance in 2008 during a small-scale restoration project at the Sambutsu-do building of Rin-nohji Temple, a huge wooden structure in Japan. Very severe damage in hard heartwood was observed with infested parts extensively damaged to a powdery state. This damage was not easily visible from the outside of the structure, because of the thick layer of urushi lacquer. X-ray computed tomography scanning of some infested pieces showed that many live insect larvae were inside the wood, and Resistograph measurements indicated that the physical strength of major structural beams was quite low because of the insect damage. An extensive reconstruction of the building was thus planned. A survey using adhesive tapes (fly catcher ribbons) was performed to determine the extent of active and ongoing infestations inside the building, from June to August 2009, the season of adult-insect emergence. As a result, large numbers of the anobiid were caught at almost all of the areas of the building. The survey turned out to be very effective for detecting active damage by wood-boring anobiids, and thus a large-scale survey with an extensive number of adhesive insect tapes (about 27,000) was conducted at about 70 historic buildings at the Nikko World Heritage site in 2010, from the end of April to August. The adhesive ribbons were set inside the buildings, in the lofts and under floors, where the traps did not disturb tourists. This survey provided information about which buildings had active damage and the priority of buildings to be treated and restored promptly. To identify effective treatment options to eradicate the anobiids for the extensive restoration of the Sambutsu-do, we examined the efficacy of carbon dioxide fumigation and Vikane® fumigation using heavily infested wooden pieces and wooden blocks which were thickly painted with red urushi. We found that Vikane treatment was a viable and effective method for eradicating the anobiid infestations, if it was applied to wooden blocks with some non-painted surfaces.

Keywords: wood-boring anobiids; insect trapping; adhesive traps; historic buildings; Nikko World Heritage site; Vikane

1. Introduction

Wood-boring anobiids are frequently found in historic wooden buildings in Japan. The most frequently observed species is *Nicobium hirtum* (Yamano 2004), but there is a report of a rare case by infestation by *Gastrallus* sp. (Kigawa *et al.* 2007). Before 2005, when a large-scale infestation of wooden historic structures became a problem, fumigation with toxic gases such as methyl bromide was conducted, and more recently the fumigant Vikane® (sulfuryl fluoride) has been used. Unfortunately, few data about the wood-boring anobiid species that infested the historic wooden buildings have been collected.

A very rare anobiid species in Japan, *Priobium cylindricum*, was found by chance during a small restoration project at the Sambutsu-do of Rin-nohji Temple in 2008 (Komine *et al.* 2009). The Sambutsu-do building is a very large wooden structure (approx. 25.5 m high, 33.8 m wide, and 21.2 m long, and the surface of the building is coated with a thick red layer of urushi, a type of lacquer. The damage was not easily visible by observations from the outside of the building, as it is coated with the red urushi. The damage had different characteristics compared to the damage that is most often observed; for example, the damage by *Nicobium hirtum*. The hard (heart) wood was severely damaged to a powdery state, and such wooden parts lost physical strength completely (Fujii *et al.* 2009, Komine *et al.* 2009, Harada *et al.* 2010).

In general, when an infestation is found, it is not easy to determine whether the infestation is an active one or an inactive infestation that occurred in the past. Acoustic emission is often used to detect termite activity or in some cases, anobiid activity in wooden structures (e.g. Fujii 2001). Other detection measures such as ultrasonic techniques are sometimes applied to check for the existence of active insects (e.g. Fujii 2011). However, such detection measures are not always applied, and robust wooden parts with sound physical strength are often reused in restorations without insect-eradication efforts. We have used X-ray computed tomography (CT) scanning to examine damaged wooden pieces, and it clearly showed that many larvae were active inside the pieces (Kigawa *et al.* 2009, Torigoe *et al.* 2010).

It was also demonstrated that the physical strength of important structural beams at the Sambutsu-do was lost due to the insect damage (Fujii *et al.* 2009) and some large columns were also affected by insects (Fujii *et al.* 2010). The progression of such damage can be disastrous for a wooden building, and thus a large-scale reconstruction of the building was initiated. To evaluate the presence of the same type of devastating infestation in buildings across the Nikko World Heritage site, a survey using adhesive tapes (fly catcher ribbons) was performed in 2010. This method turned out to be very useful in detecting possible active damage by wood-boring anobiids, providing important data that, together with the results of the visual inspections and the collections of insect frasses in each structure, identified the buildings with the most urgent need for treatment and restoration.

This report describes the entire process, which began with the finding of extraordinary damage by an anobiid species in a large historic wooden building and continued with successive surveys of the infested building, which led to the insect survey of the entire Nikko World Heritage site. The decision-making process used to choose the most effective treatment option for eradicating the insects as part of the large-scale restoration of the Sambutsu-do is also explained.

2. Damage by *Priobium cylindricum*

2.1 Identification of the insect and examination by X-ray CT scanning

A very rare type of insect damage was found by chance during a small restoration project at the Sambutsu-do of Rin-nohji Temple (Fig. 1a) in June 2008. Heavy damage was observed in 22 of 30 wooden parts which were supporting the weight of the building's lower roof. The hard heartwood, which is not usually damaged even by termites, was severely damaged to a powdery state, and the wood parts had completely lost their physical strength (Fig. 1c–f). The carpenters were surprised to find unexpected severe damage inside the beams and other pieces, especially at the wood joints. The damage had different characteristics compared to the damage that is usually observed, such as that caused by *N. hirtum*. The carpenters said that they had never seen such severe and peculiar damage. The damage was not easily detected by observations from the outside of the building, as it is coated with a thick red layer of urushi, a natural laquer originated from urushi tree sap (Fig. 1a,b).

The carpenters initially considered the infestation inactive because they did not observe any insects when they found the damaged pieces at wood joints (Harada *et al.* 2010). However, X-ray CT scanning of damaged wooden pieces performed at the Kyushu National Museum clearly showed that many larvae were inside the pieces (Kigawa *et al.* 2009). The larvae were confirmed to be active by repeated X-ray CT scanning observations over a 5-day interval, as the positions of the larvae changed (Fig. 2a,b) (Torigoe *et al.* 2010).

Yukio Komine (one of the authors) and Katsuji Yamano examined a damaged piece (Fig. 1f) and they found one adult insect (Fig. 2c) from the piece. They identified the insect as *Priobium cylindricum* (Komine *et al.* 2009). We collected and observed the insect larvae from damaged wood; the larvae became pupae (Fig. 2d, right) and adults of *P. cylindricum*.

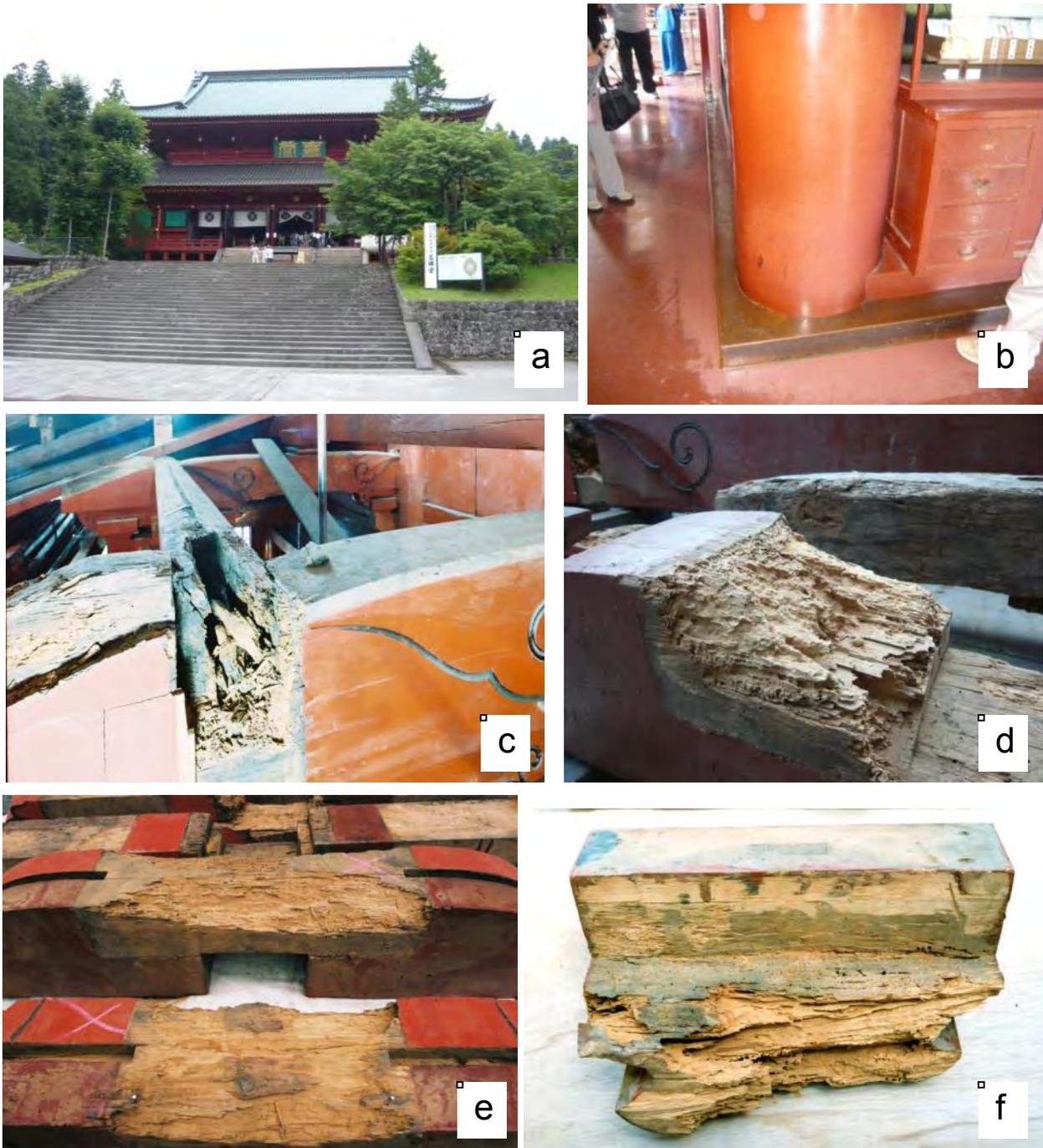


Fig. 1: The Sambutsu-do building of Nikko-zan Rin-nohji Temple and the damage by the anobiid *P. cylindricum*. **a**: Outside view of the Sambutsu-do. **b**: An example of one of the huge columns in the Sambutsu-do, approx. 16 m long, painted with a thick layer of red urushi. **c-f**: Examples of the damage by *P. cylindricum*.

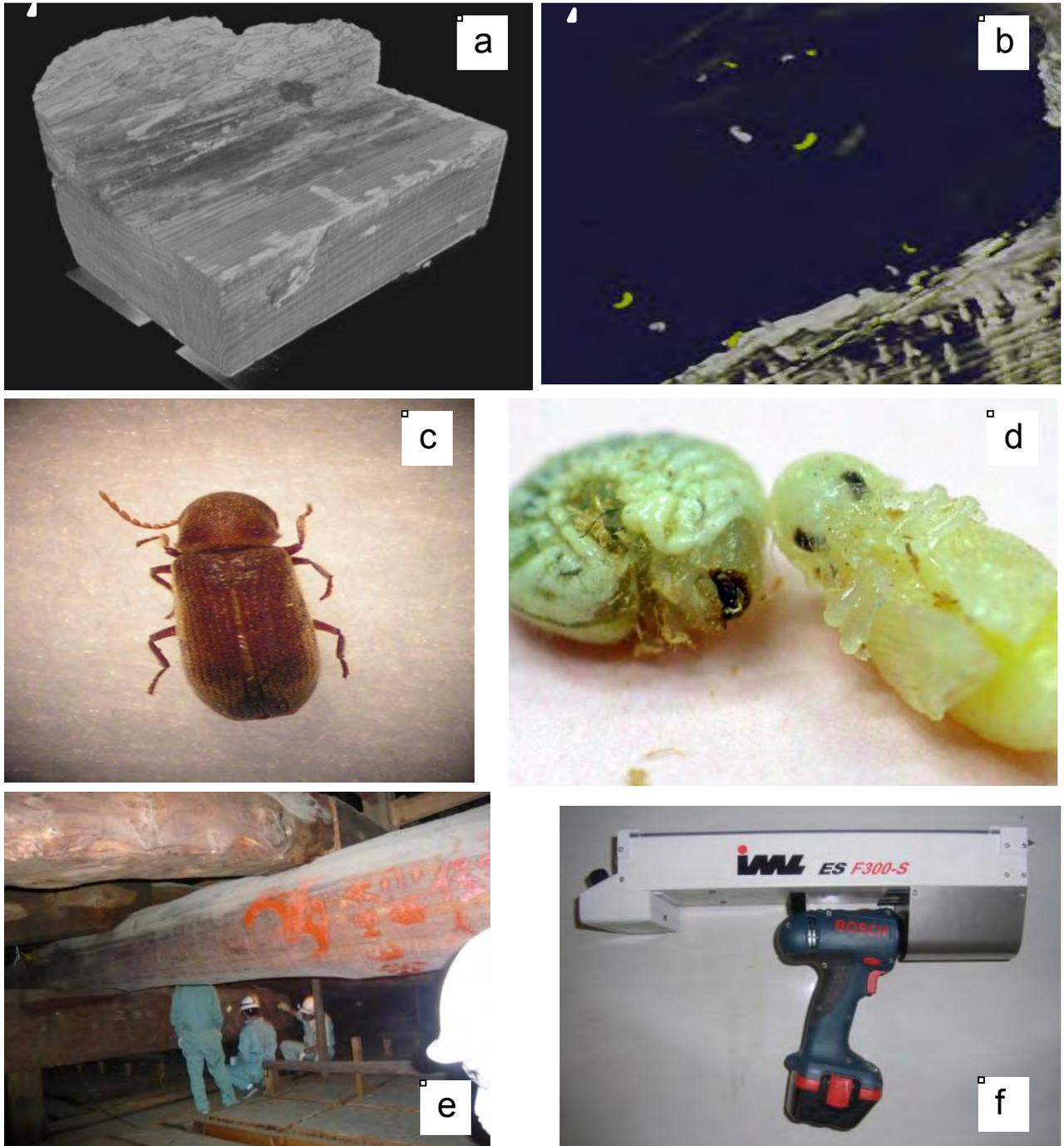


Fig. 2: Survey of insect damage by X-ray CT scanning and the Resistograph drilling resistance instrument. **a, b**: X-ray CT scanning of a damaged wooden piece from the Sambutsu-do. The larvae's positions changed over a 5-day interval (indicated in white and yellow), demonstrating that the larvae were active (Torigoe *et al.* 2010). **c**: *P. cylindricum* adult emerged from a damaged wooden block. **d**: A larva and a pupa of *P. cylindricum*. **e, f**: Resistograph and a survey of physical strength with it (Fujii *et al.* 2009).

2.2 Survey of physical strength of structurally important wooden parts and decision making regarding the large-scale restoration

As the damage to larger areas in the Sambutsu-do became obvious, it was necessary to appraise the level of physical strength - especially of structurally important wooden parts of the building. Authors Y. Fujii and Y. Fujiwara of Kyoto University and responsible staff conducted surveys using a Resistograph drilling resistance instrument (IML-RESI F300, IML, Orange Park, FL, USA) (Fig. 2e,f). This instrument is used to determine the resistance value of wood when its thin drill bit is drilled into the wood. The resistance is a measure of the wood's physical strength.

It was found that the physical strength of some important structural beams was significantly lost due to the insect damage. As shown in Fig. 3, at the sites of insect damage the resistance value was quite low (Fujii *et al.* 2009). The carpenters tied one of the damaged large beams to the ceiling with cables as it was in danger of falling down at any time. Beneath the beam are three enormous wooden Buddha sculptures (Sam-but-su). Based on the results of this survey, it was decided that a large-scale restoration of the Sambutsu-do building was necessary.

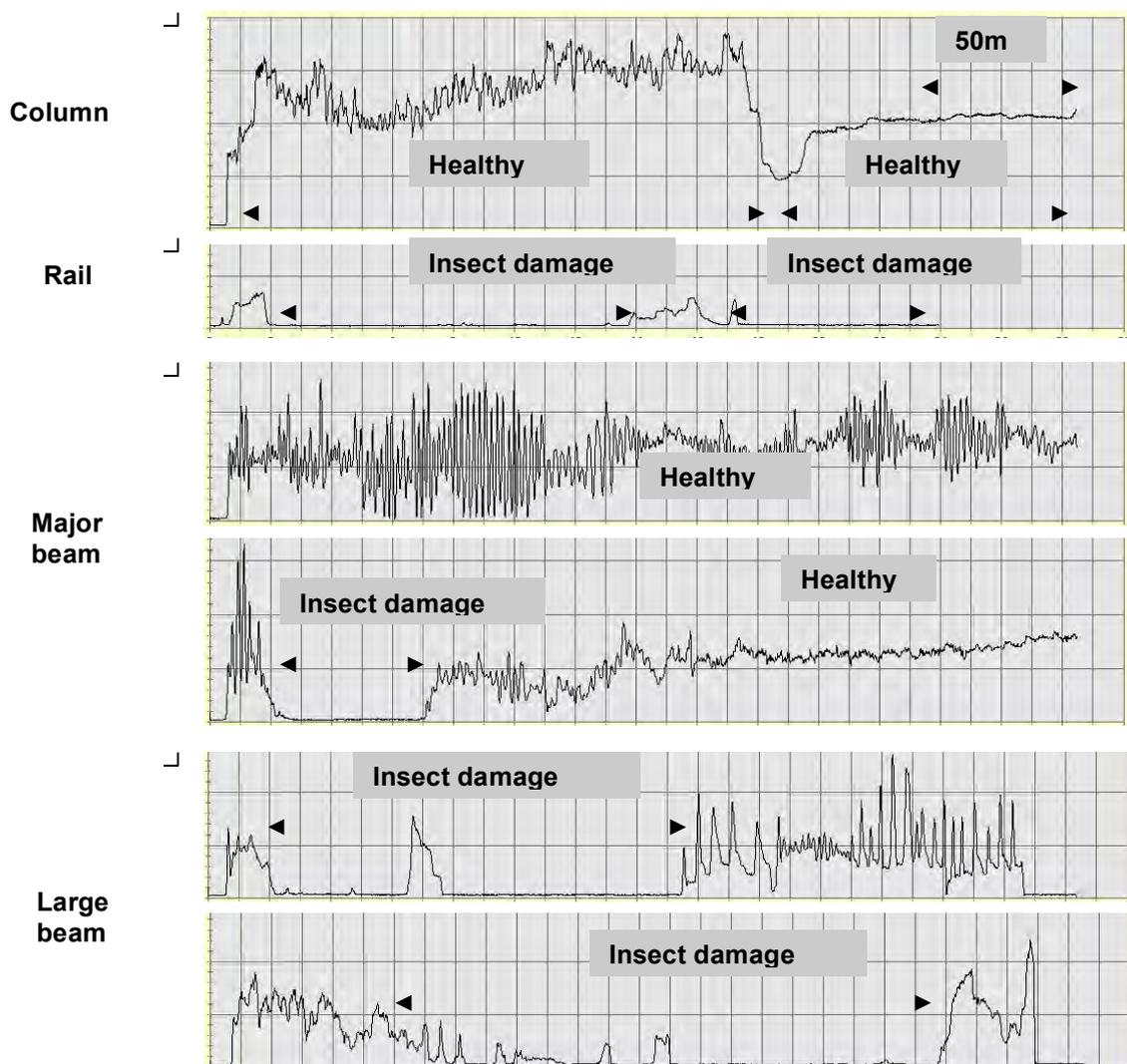


Fig. 3: Examples of the results of the Resistograph survey (Fujii *et al.* 2009).

Vertical axis: resistance value indicating the physical strength of the wood. Horizontal axis: depth from the surface of the wood (0 to 300 mm).

3. Large-scale survey by sticky insect ribbons throughout the World Heritage site

3.1 Necessity of large-scale survey

There are more than 100 important historic buildings that comprise the Nikko World Heritage site: nine are designated as National Treasures and 94 buildings are designated as Important Cultural Properties. When the severe insect damage was revealed at the Sambutsu-do, there was concern about whether any of the other buildings had also been invaded by *P. cylindricum*. To determine the status of active insect damage of other buildings in the area of the World Heritage site and to identify the buildings with active, ongoing infestations, a large-scale survey was conducted in 2010. Trapping was conducted in 72 buildings (Fig. 4) in a vast area from Nikko san-nai to the Lake Chuzenji area.

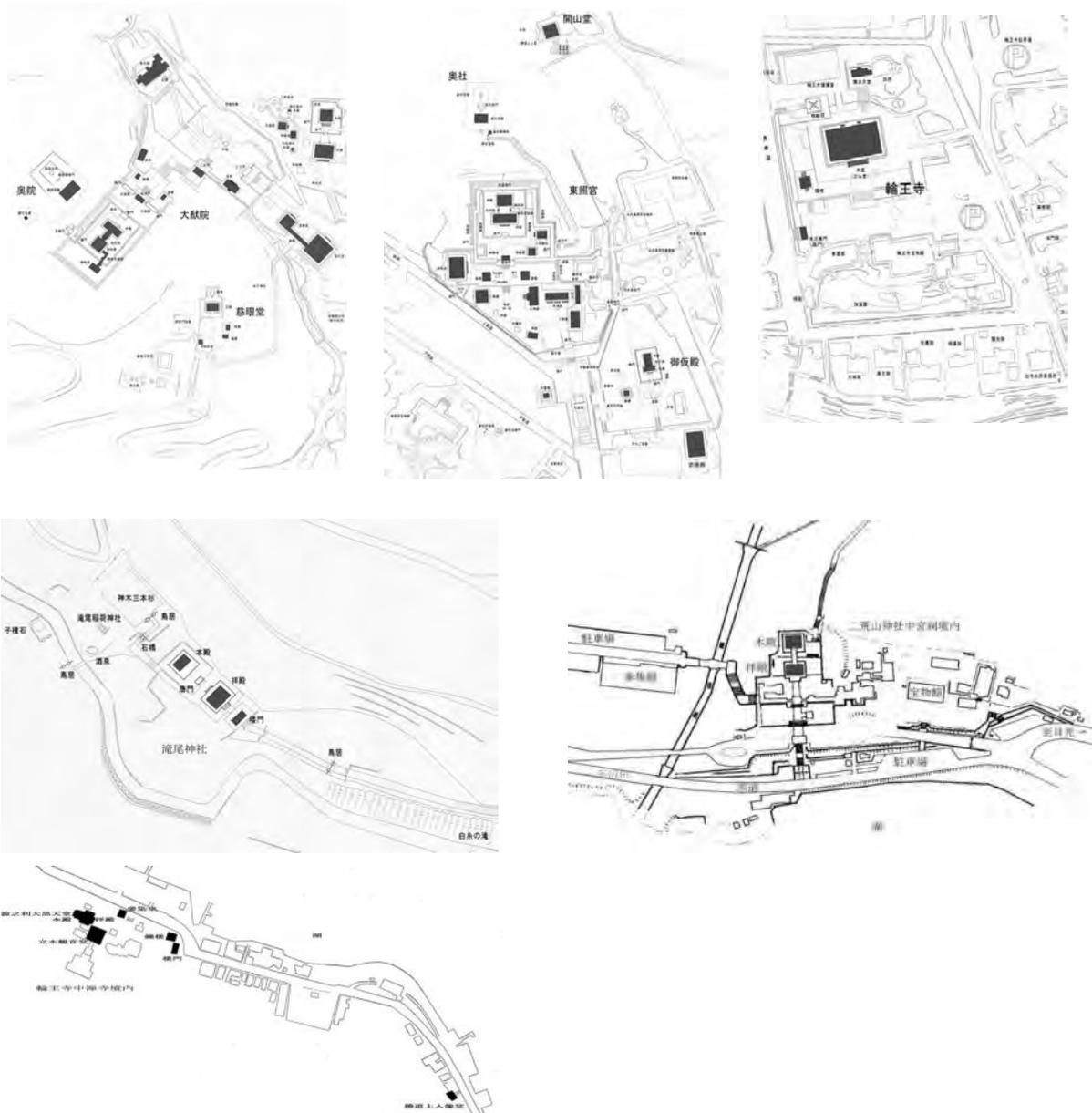


Fig. 4: Wooden historic buildings at the Nikko World Heritage site. Sticky insect ribbons were set in the structures painted black (Harada *et al.* 2010).

3.2 Effectiveness of the trapping method to detect ongoing damage by wood-boring anobiids

One year before the large-scale survey, a trial survey was conducted by Harada *et al.* (Harada *et al.* 2011). When adhesive fly traps were set in place in the loft and under the floor of the Sambutsu-do, about 700 adult *P. cylindricum* were caught by approx. 1,000 of the adhesive tapes. These simple sticky ribbons were quite useful for identifying active infestations when they were used during the period of adult emergence, which in this case was from June to August.

3.3 Methods and results of the 2010 large-scale survey

The details of the large-scale survey methods and the results will be described by Hayashi *et al.* (submitted), but here we provide a brief overview.

The adhesive ribbons were set in the lofts and under the floors (examples are shown in Fig. 5a,b) where they would not disturb or be disturbed by the many tourists who visit the buildings. The total number of sticky ribbons set by carpenters was 27,021, with the total length of 21 km (Harada *et al.* 2011, Hayashi *et al.* 2011). From September to October 2010, the traps were collected and set between transparent polyethylene sheets, then sent to the National Research Institute for Cultural Properties, Tokyo for analysis (Fig. 5c,d). The data recording and identification took about 4 months (Hayashi *et al.* 2011).

All of the beetles that were stuck on the adhesive ribbons were cut off from the sheets, then grouped and identified by Yukio Komine. Five wood-boring anobiids were found in this manner in ribbons placed throughout the Nikko area: *P. cylindricum* (Fig. 5e) and a larger species, *Trichodesma japonicum* (Fig. 5f), *Hadrobregmus pertinax* (Fig. 5g), *Oligomerus japonicus* (Fig. 5f), and *Sculptotheca hilleri* (Fig. 5i) (Komine *et al.* 2011). The large anobiids such as *P. cylindricum*, *T. japonicum* and *H. pertinax* caused severe damage. We analysed the data revealing the numbers of such large and destructive anobiids species per 100 adhesive tapes (Hayashi *et al.* 2011, Hayashi *et al.* submitted), and a few buildings were found to have a significant density of these anobiids. For example, the Sambutsu-do showed significant densities of both *P. cylindricum* and *S. hilleri* that indicated active infestations by these anobiid species, and the Daiyu-in Nitenmon gate showed significant densities of *T. japonicum* and *S. hilleri*. It was concluded that both structures had significant and on-going infestations.

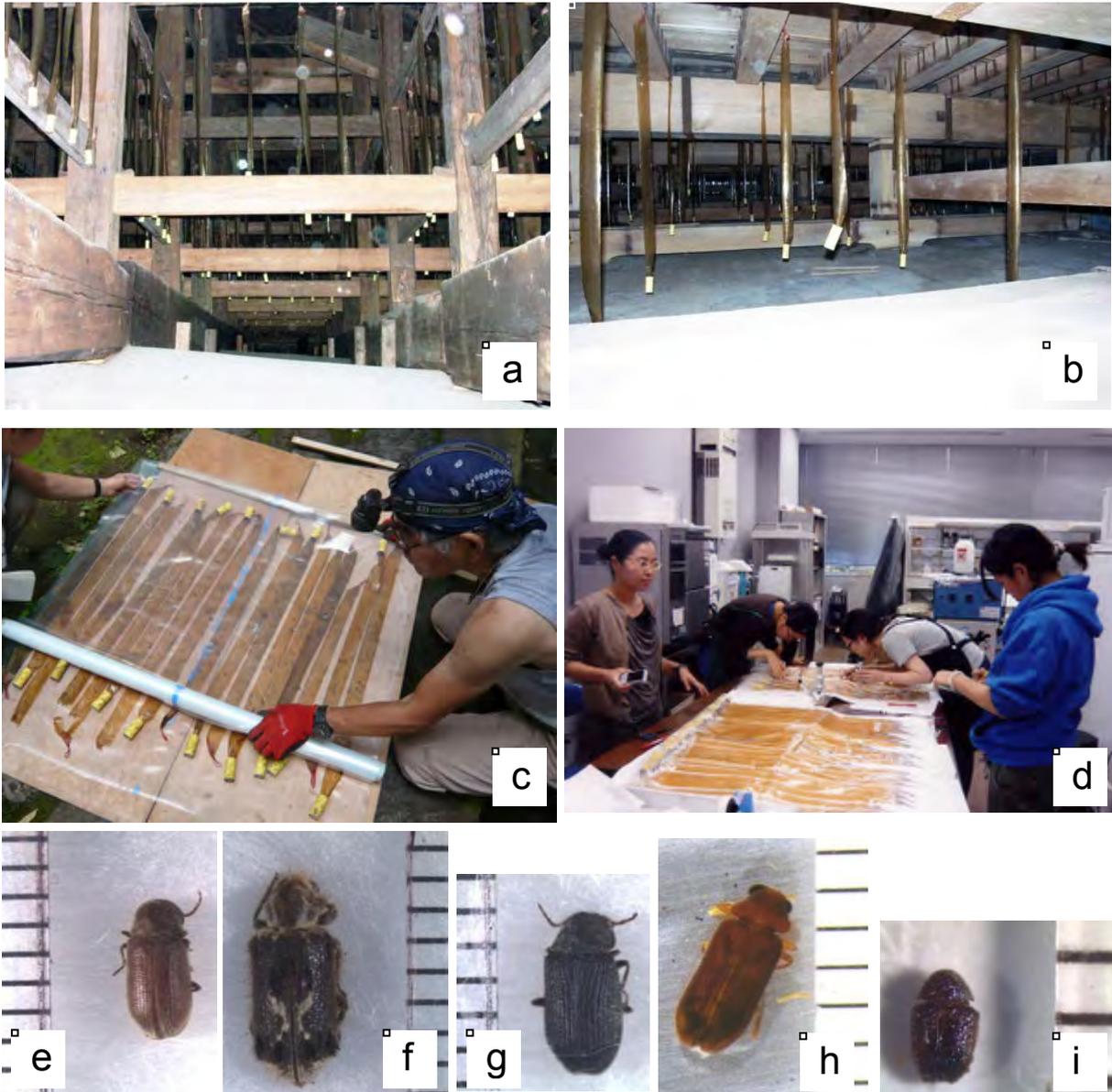


Fig. 5: Insect survey by sticky insect ribbons, and the wood-boring anobiids found by the survey. **a**: Insect ribbons set in the loft of the Sambutsu-do, Rin-nohji Temple. **b**: Insect ribbons set under the floor of the same building. **c**: Collected insect traps. **d**: Data records at the National Research Institute for Cultural Properties, Tokyo. **e-i**: Wood-boring anobiids found in the Nikko area (Komine *et al.* 2011).

3.4 Characteristics of the wood-boring anobiids captured in the Nikko area

The five species of anobiids listed above were all first finds in historic buildings in Japan, and they are thought to inhabit the forests in the Nikko area, based on the dispersed pattern of small numbers of anobiids captured in many buildings over the entire area (Komine *et al.* 2011). The buildings are in the mountains, surrounded by natural forests. *N. hirtum* is a well-known anobiid which infests wooden objects and buildings in Japan, but unexpectedly this species was not observed in this survey of the Nikko area.

Along with the trapping survey, we performed visual inspections inside the trapping sites at the same time, collecting insects and insect frasses. Such samples were quite useful to relate the insect species to the observed patterns of damage, and to match each insect frass to its species. The collection of the

insect frasses enabled us to identify which insect(s) damaged the wood by simple observation of the frasses together with the pattern of damage in the Nikko area (some examples are described in Komine *et al.* 2012). In addition, the detailed analysis of the density of captured anobiids inside each building revealed some characteristics such as light attraction of some species and preferred conditions of humidity (Hayashi *et al.* 2012, Kigawa *et al.* 2012, Hayashi *et al.* submitted).

4. Countermeasures for active infestation and damage

4.1 Insect damage and large-scale restorations (reconstruction) in the past

According to records kept for the Sambutsu-do, the building was extensively restored also about 50 years ago because of peculiar damage very similar to the damage seen from 2008 to 2009 (Harada *et al.* 2010). At that time, original wooden parts which had been considered structurally healthy were reused without treatment. Fig. 1f is an example of jointed original wood (lower half) with a new part (upper half) added at that time. The original wooden part that had been considered healthy 50 years ago is now severely infested. We suspected that some insects remained in the old wooden parts in that reconstruction and spread after that.

4.2 Policy of eradication and necessity of experiments

If insects remain inside wooden blocks that are reused, the infestation will occur again. It was very important to eradicate the insects in all of the wooden parts which would be reused in the present large-scale reconstruction. However, the selection of an efficient eradication measure was a difficult issue: The Sambutsu-do is a very large building painted with thick layers of urushi lacquer which might prevent the permeation of gaseous fumigants. Also, this was the first description of *P. cylindricum* in a historic wooden building, so we did not have data on the susceptibility of this insect to various treatments. We therefore performed several experiments to help us choose an appropriate and feasible treatment measure.

*4.3 Determining the efficacy of treatments to eradicate *P. cylindricum**

We examined the effects of two treatment options on the *P. cylindricum* using actual damaged wooden blocks from the Sambutsu-do. First, T. Torigoe imaged many damaged blocks by X-ray CT scanning, and we chose those blocks which had many insects (mainly larvae) inside. We used the selected blocks to evaluate the efficacy of fumigation with carbon dioxide or Vikane® (sulfuryl fluoride) fumigation (Kigawa *et al.* 2011). Photos illustrating the carbon dioxide treatment and Vikane fumigation are shown in Fig. 6.



Fig. 6: Experiments to choose appropriate treatment measures and Sambutsu-do, Rin-nohji temple under recent reconstruction. **a,b**: Carbon dioxide treatment test (November 2009). **c,d**: Vikane fumigation tests (January and September 2010, respectively). **e**: Shelter building for reconstruction of Sambutsu-do (photographed in December 2012). **f**: Inside the shelter, after 1disassembly of the whole roof. Large beams are visible after the removal of the roof, viewed from upper side of the building (photographed in December 2012).

We evaluated the effects of these two treatments by observing the movements of the insect larvae by repeated X-ray CT scanning after the treatments. We performed one carbon dioxide and two series of Vikane treatment tests. Table 1 shows some core results of these experiments (Kigawa *et al.* 2011). We found that the carbon dioxide treatment (60%–80% vol. of CO₂ at 25°C) and the Vikane treatment applied for more than 48 hours were both efficient to eradicate the *P. cylindricum* larvae in the

damaged wooden blocks. Vikane treatment for 24 h allowed the survival of small populations of larvae, whereas Vikane treatment for 72 h resulted in shrunken, dead larvae inside the wooden pieces. We did not have data on other developmental phases (for example, eggs) of *P. cylindricum*, but in light of the larvae susceptibility results, we suspect that the susceptibility of *P. cylindricum* at other developmental phases would be similar to that of other beetles such as *Sitophilus zeamais* and *Lasioderma serricorne*, for which we have sufficient data on treatment-caused mortality. Moreover, the treatment conditions we used here for *P. cylindricum* were found earlier to effectively eradicate these other resistant species of beetles at all developmental stages.

Table 1: Results of observation of *Priobium cylindricum* larvae inside treated wooden blocks by X-ray CT scanning. Details of the conditions of treatments and X-ray CT measurement are described by Kigawa *et al.* (2011) and Torigoe *et al.* (2010).

Wooden block	Treatment*	Observation of larvae by X-ray CT**
Q-1	Non-treated control	Active movement
Q-2	CO ₂ 60%–80% Vol., 25°C, 2 weeks	No movement
5-1	Non-treated control	Active movement
Y-2	Non-treated control	Active movement
X-1	Vikane, 24 h	Movement (partially)
C-2	Vikane, 24 h	No movement
X-2	Vikane, 48 h	No movement
Y-1	Vikane, 48 h	No movement
5-2	Vikane, 72 h	No movement (shrunken larvae)
C-1	Vikane, 72 h	No movement (shrunken larvae)

* Vikane® (sulfuryl fluoride) fumigation was performed at the gas concentration of 50–70 g/m³ at 20°C in January 2010. Carbon dioxide treatment was performed at 60%–80% vol. of CO₂ at 25°C for 2 wks in November 2009.

** Q-1 and Q-2 were observed twice at an interval of 5 days. Other blocks were observed twice at an interval of 75 days.

4.4 Experiments evaluating the influence of the thick urushi layer against treatments

In the first treatment plan, the carpenters were planning Vikane fumigation of the entire Sambutsu-do building. However, the building is coated with thick layers of urushi lacquer, as shown in Fig. 1a,b. The huge columns (approx. 16 m high; Fig. 1b is an example) are thickly painted with such urushi, and we suspected that gaseous fumigants may not permeate these layers easily. We therefore newly prepared 300-mm cubes of zelkova wood blocks (approx. 20 kg each) for the experiments with the same type of urushi paint finish used for the building (Fig. 6a,c) to examine the effects of treatments on the insects inside the blocks. Four types of blocks were prepared: (1) Non-painted block, (2) Painted with urushi but with a 50 x 50 mm area of urushi removed, (3) Painted with urushi but with two 50 x 50 mm areas of urushi removed, and (4) Fully painted with urushi (Fig. 6a,c).

As a test insect for this experiment, we used all the developmental stages of *Sitophilus zeamais*. This was because *P. cylindricum* larvae became weaker when we picked them out from damaged wood and were not suitable for this experiment. Our major interest was to see the difference of permeability of fumigant gases into wooden blocks with or without urushi paint. We had previously used *Sitophilus zeamais* for many experiments and had reliable data on all the developmental stages of this insect.

Adults and rice containing eggs, larvae and pupae of *Sitophilus zeamais* were put inside the wooden blocks then sealed with a silicon plug, silicon caulking agent, and aluminium tape. Carbon dioxide treatment for two weeks and Vikane fumigation for 24, 48 and 72 hours were all performed twice, and the results of the first tests are given in Tables 2-1 and 2-2.

Table 2-1 shows the results of the first carbon dioxide treatment. After carbon dioxide treatment with 60%–80% CO₂, some of the eggs, larvae and pupae of *S. zeamais* in all of the urushi painted blocks (Fig. 6b–d) survived after a 2-wk treatment at 25°C, whereas control insects in gas-permeable bottles showed 100% mortality. Even in the case of the non-painted block of dense zelkova wood (Fig. 6a, approx. 20 kg), a small portion of the test insects survived (Table 2-1). The results of the second CO₂ treatment were essentially the same (data not shown).

The results of the first Vikane fumigation are shown in Table 2-2. Small numbers of eggs, larvae and pupae of *S. zeamais* survived in some of the urushi-painted blocks even after 72-h Vikane fumigation. The results obtained with a urushi-painted block with one 50 x 50 mm urushi-free window (Table 2-2, Fig. 6c) were perplexing, as all the test insects showed 100% mortality following the fumigation, unlike the results of the completely painted blocks. We suspect that this result was due to an experimental failure in sealing because in the second Vikane fumigation test, insects survived the 72-h Vikane fumigation of this block (data not shown). Test insects inside the unpainted zelkova block showed 100% mortality after the 24-, 48- and 72-h Vikane fumigations.

Based on these results, we concluded that to ensure the effective treatment of anobiid-infested wood painted with urushi lacquer, carbon dioxide treatment or Vikane fumigation should be applied only to separate wooden parts which have non-painted areas. This means that the structural fumigation of the whole Sambutsu-do building as had first been planned- might not have been completely effective.

Table 2-1: Effects of treatments on the insects (*Sitophilus zeamais*) inside urushi-painted wooden blocks (CO₂ treatment, 1st test). CO₂ treatment was performed in November 2009 under the condition of 60%–80% vol. of CO₂ at 25°C for 2 wks. Test insects (adults and rice containing eggs, larvae and pupae of *Sitophilus zeamais*) were put inside the wooden blocks (n=1 each) and sealed with a silicon plug, silicon caulking agent, and aluminium tape. Details of the conditions of the treatments are described by Kigawa *et al.* (2011).

Treatment	Conditions of test insects	Live adults	Emergence in 14 days	Emergence from 15 to 28 days	Emergence from 29 to 42 days	Emergence from 43 to 56 days	Total emergence
CO ₂ treatment	Control (gas permeable bottle)	0 / 41	0	0	0	0	0
	a. Not-painted	0 / 36	0	1	2	0	3
	b. Urushi-painted, 2 windows	0 / 37	2	34	7	12	55
	c. Urushi-painted, 1 window	0 / 36	3	24	13	5	45
	d. Fully urushi-painted	0 / 36	3	49	20	10	82
Non-treated control	Control (gas permeable bottle)	55 / 57	60	55	28	23	166

Table 2-2: Effects of treatments on the insects (*Stitophilus zeamais*) inside urushi-painted wooden blocks (Vikane treatment, 1st test). Vikane (sulfuryl fluoride) fumigation was performed at the gas concentration of 50–70 g/m³ at 20°C in January 2010. Details of the conditions of treatments are described by Kigawa *et al.* (2011).

Vikane treatment	Condition of wooden blocks or containers for test insects	Live adults	Emergence in 10 days	11-20 days	21-30 days	31-40 days	41-50 days	51-60 days	61-70 days	Total emergence
24 h	Control (gas permeable bottle)	0 / 40	0	0	0	0	0	0	0	0
	a. Not-painted	0 / 37	0	0	0	0	0	0	0	0
	b. Urushi-painted, 2 windows	28 / 38	1	35	23	8	12	32	15	126
	c. Urushi-painted, 1 windows	0 / 40	0	0	0	0	0	0	0	0
Non-treated	d. Fully urushi-painted	8 / 40	0	6	3	2	0	0	0	11
	Airtight bottle	47 / 48	117	90	13	13	47	10	4	284
	Control (gas-permeable bottle)	42 / 43	99	92	11	9	49	14	1	275
48 h	Control (gas-permeable bottle)	0 / 40	0	0	0	0	0	0	0	0
	a. No-painted	0 / 40	0	0	0	0	0	0	0	0
	b. Urushi-painted, 2 windows	0 / 37	0	0	10	6	0	13	52	81
	c. Urushi-painted, 1 windows	0 / 41	0	0	0	0	0	0	0	0
	d. Fully urushi-painted	0 / 39	0	0	8	8	1	2	50	69

	Airtight bottle	31 / 39	4	86	62	3	52	69	5	281
Non-treated	Control (gas-perm.b.)	38 / 41	11	102	70	1	63	39	0	286
	Control (gas-permeable bottle)	0 / 39	0	0	0	0	0	0	0	0
	a. No-painted	0 / 40	0	0	0	0	0	0	0	0
	b. Urushi-painted, 2 windows	0 / 41	0	0	3	2	0	0	0	5
	c. Urushi-painted, 1 windows	0 / 41	0	0	0	0	0	0	0	0
	d. Fully urushi-painted	0 / 40	0	0	6	3	0	0	0	9
	Airtight bottle	3 / 40	15	102	32	1	83	32	6	271
Non-treated	Control (gas-permeable bottle)	40 / 40	25	106	29	9	42	19	8	238

72 h

4.5 Actual treatment applied during restoration of Sambutsu-do

The CO₂ and Vikane results were used in the decision-making process concerning the optimal treatment for the Sambutsu-do. Since CO₂ treatment was technically difficult to apply for such a large structure because of difficulty of proper sealing of the tarps at the ground, and to maintain required CO₂ concentration for more than two weeks, Vikane fumigation was the primary choice. However, such a large-scale fumigation presents many problems to consider from the aspects of both safety and efficacy. We were unable to find an example of such a large-scale fumigation with Vikane in recent years. In addition, it was impossible to completely take apart the entire building due to some constraints.

In light of these issues, we reconsidered another option, the application of a liquid-type insecticide (oil and emulsion) to each of the building's large columns. However, the permeability of the insecticide was quite limited, and this option cannot ensure sufficient effects against the insects inside the wood (e.g., Kimone *et al.* 2013). Therefore, the staff made efforts to maximize the efficacy of the Vikane fumigation by conducting the fumigation during the summer to make use of the warm temperatures, and disassembling the entire roof before the fumigation (Fig. 6f) which exposes areas of unpainted end grain on the top of each large column and separated wooden parts. In addition, following advice from Prof. Shigeru Tanaka of Jumonji University and Kanya Kato of Mitsui Chemicals Agro, Inc., the staff made a trench on the concrete basement to bury the fumigation tarp's edges with compacted soil to ensure good sealing at the ground.

In July 2013, the Vikane fumigation of the Sambutsu-do and its separated wooden parts was performed successfully inside the huge restoration shelter (Fig. 6e, approx. 37 m high, 66 m wide, and 40 m long), ensuring greater than 80 hours of fumigation at a sufficient gas concentration of greater than 70g /m³ at the temperature greater than 20°C.

5. Discussion

5.1 Preventive measures

We used Vikane fumigation to destroy the severe infestation inside the Sambutsu-do, but the results of the large-scale insect survey strongly suggested that wood-boring anobiids such as *P. cylindricum* inhabit the forests in the surrounding Nikko area. It is thus difficult to completely prevent insect infestation and damage to the wooden buildings in this area. Nevertheless, a large insect population inside wooden parts of the Sambutsu-do was reduced to nearly zero, and the building will survive much longer after its large-scale reconstruction. It will be necessary to apply liquid residual insecticides or repellents to the wooden parts used for reconstruction. However, as the durability of such chemicals is limited, monitoring and future treatments will be required to cope with insect damage at an early stage, as ongoing preventive measures.

5.2 Knowledge obtained from the large-scale insect survey

The large-scale survey of the Nikko site showed that the targeted monitoring of wood-boring anobiids during the period of adult insects' emergence was quite effective to find active infestations. Because the survey was performed simultaneously in many buildings over a broad area, solid information about what types of wood-boring anobiids reside in the surrounding natural environment was obtained. The trapping data, together with the results of the visual inspection of the damage and the collection of insect frasses in each building clarified the relationships among the visual characteristics of the damage, the frasses and the insect species that caused the damage. Such knowledge will allow the

easier identification of insects in this area from simply the observation of damage and insect frasses, and provide good information for decisions about appropriate countermeasures.

5.3 More treatment options

It was shown from our experiments that the eradication of insects inside wooden buildings that have thick urushi layers may not be easy, as the urushi layer prevents the permeation of fumigant gases. Much hard work was necessary for the Vikane fumigation of the Sambutsu-do. We think it necessary to widen the range of available treatment options for urushi-painted buildings. For example, now we are considering the possibility of applying thermal treatments. If infestations can be found at an early stage, the partial application of a thermal treatment may also help the building survive longer.

Conclusion

The large-scale survey of wood-boring anobiids in 72 buildings at the Nikko World Heritage site demonstrated that targeted monitoring during the period of adult-insect emergence was very effective to identify which buildings had active and ongoing infestations. The data provided information about major wood-borers in the Nikko area and some information about their ecological characteristics. Together with the visual inspections, visually observed damage was related to the insect species which cause the damage. The methods used to survey the insect damage, i.e., X-ray CT scanning and Resistograph measurements were quite useful for appraising timber condition and they provided important information used later in decisions about the restoration. The Sambutsu-do's thick urushi layer was shown to prevent permeation of the gaseous fumigants CO₂ and Vikane (sulfuryl fluoride), and in such cases extra care and effort are needed to achieve the effective eradication of wood-damaging insects.

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Craigievar: long term problems, long term solutions

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Abstract

Craigievar Castle is a highly regarded example of an early 17th century tower house, cared for by the National Trust for Scotland (NTS) since 1963. The castle has a long history of *Anobium punctatum* (common furniture beetle) infestation, predating the Trust's involvement. Localised, intermittent and questionably effective pest control treatments of structural timbers and collections have been employed by the family and subsequently by Trust staff over many years, though little control has been achieved. Integrated pest management (IPM) was introduced into the Trust in 2008 and included Craigievar in the programme in 2009. This paper describes the pest management undertaken since 2009 when IPM monitoring data indicated there were areas where beetle were active and at higher levels than previously observed. This paper will discuss the reason for the rise in the beetle population; a significant increase in the relative humidity (RH) in the Castle during a reharling project (2007-2009) and the strategies employed to manage the infestation. The key to the pest management at Craigievar and at all Trust properties is understanding how the insect 'functions', how the building 'functions', how the Trust 'functions' - and how that knowledge can be used by Conservators and Surveyors working together to control risks from pests to buildings and collections.

Keywords: Furniture beetle; National Trust for Scotland; historic building; training; study day

1. Introduction

1.1 Introduction Craigievar Castle

The NTS is Scotland's leading conservation charity with over 50 properties with collections in its care. The properties range from castles to cottages, from the north to the borders in the south. This paper focuses on one property, Craigievar Castle, in rural Aberdeenshire as an example of how the Trust is improving the way an effective IPM programme is used to manage insect pest infestations. It demonstrates that pests need to be managed on a case by case basis. Craigievar highlights an approach the Trust's Preventive Conservators have taken to a challenging set of issues which involves communication and participation with other specialist colleagues without whom it would not be possible to tackle the problems they face.

Finding effective solutions in a challenging environment will be described and also how this gave the Trust Conservators and Surveyors the opportunity to review how best to manage an *Anobium punctatum* infestation in structural timbers and collections holistically and effectively. For example, humidistatically controlled heating, the Trust's preferred option to manage RH in an environment (and hence a beetle infestation) was superseded through necessity by the reintroduction of natural ventilation in the Castle. Where conservation heating could be introduced locally RH set points are higher than Trust guidelines permit and graduated through the building to maximize air circulation and

mitigate the possibility of mould growth. The benefits of holding a *Furniture beetle Study Day*, at the Castle in July 2012, led by David Pinniger, and attended by all Trust Conservators, Surveyors and Craigievar property staff will be discussed in terms of how discussion facilitated increased sharing of relevant information between each department and how this continuing dialogue will assist with improving the overall management of the Castle.

Craigievar is being managed in a characteristically pragmatic, low-tech manner by the Trust. There is an appreciation that such a long term infestation can only be managed with a long term view and there are no short cuts to permanently lowering the woodworm (*Anobium punctatum*) population.

1.2 Craigievar: a history

Craigievar Castle (Fig. 1) has been described as the premier example of native Scots architecture. It is certainly the most important vernacular domestic building in the country and is arguably the Trust's greatest asset (NTS 2004). The castle was built between 1610 and 1626 and is a much loved example of the Scottish tower house. The castle is of international significance as an exceptionally well preserved early seventeenth century iconic Scottish Fortified house. The house itself was built in two phases, the first, probably a complete tower house, was occupied by the Mortimer family. It was then acquired by William Forbes in the early 17th century and a major reconstruction of the roof and upper works at the fifth floor corbel level with a major internal remodelling was completed this included the introduction of heavily enriched plasterwork in all of the principle rooms.



Fig. 1: South elevation of Craigievar Castle. © National Trust for Scotland.

This interior decoration is no less significant than the lauded exterior. Many of the floors date from the 17th century and the Forbes development. As was Scots tradition joists, flooring and decorative panelling was made from pine and not oak. Anecdotally, some of this was imported from the Baltic ports. The boards suggest that they may even have been taken from a single tree in some places, with the board tapering from one end to the other. These incorporate significant areas of sapwood that is susceptible to insect attack and old repairs to the edges are visible in a number of locations.

The interiors are innovative and Craigievar can boast the best moulded plaster ceilings in Scotland (Fig. 2). The collections are nationally important. Some of the furniture is thought to be original which in itself is 'exceptional in Scotland on account of its unsettled history' (NTS 2004). The majority of the rest of the collections reflect the material culture of the Forbes-Sempill family. The castle, domestic yet impressive, was very much a holiday home for the family and a crucial decision to preserve the castle's atmosphere was taken in the 1820's where 'roughing it' was part of the fun i.e. little in way of modern conveniences, like electricity supply, was therefore introduced.

So there is a significant building, significant interiors and significant contents. All of which are considered by the Trust to be of International significance.



Fig. 2: Decorative plaster ceiling in The Hall. © National Trust for Scotland.

1.3 Introduction of Integrated Pest Management

In 2009 the Trust Conservators set up IPM monitoring in the castle as part of the Trust's IPM programme (Houston 2011). The programme is a roll out of pragmatic monitoring, recording, reporting of pest species at properties in a consistent systematic manner. It relies on trained property staff monitoring and recording sticky trap finds, as the small team of Conservators do not have the capacity to carry out the required quarterly trap checks at every property. Staff is trained to be confident and competent in pest identification skills through; one to one support from their Conservators, access to pest identification resources supplied by the Trust and through compulsory attendance at an annual Trust IPM pest identification training day. Properties are added to the programme gradually, at a sustainable rate, due to capacity issues of the Conservator team to

adequately train staff to the high standard required. Craigievar was added in the first round of the IPM programme as there was a well-known issue with furniture beetle, which dated back to a timber infestation survey in 1990 during a repair programme to several of the enriched ceilings (George 1990). This highlighted concerns that insect and water ingress was causing significant damage to the structural timbers of the castle.

Early indications from the 2009 and 2010 IPM data for Craigievar and verbal reports from Craigievar property staff pointed to a substantial rise in the number of adult furniture beetle found in the castle following the major eighteen month external repairs programme. The presence of an infestation was not in dispute but the rise in adult insects detected on traps (hundreds) was new. In the past the family recounted having a wormy castle and it was common practice to annually bomb the castle with a fumigation ‘treatment’. The number of beetles collected and observed in 2010 and since was alarming for property staff as was the damage to floorboards and supporting joists (Fig. 3). Collections and panelling were affected but equally concerning were the structural implications. The puzzling explosion in infestation coincided with the end of a major project undertaken to improve the condition of the building.



Fig. 3: Damage to floorboards caused by *Anobium punctatum*. © National Trust for Scotland.

The issues caused by the increase in the *Anobium* infestation were presented by the member of property staff responsible to collecting the IPM data and the Group Conservator at the Trust’s 2011 annual IPM Pest Identification training day. Through discussion it became clear the answer could not come from the Conservators alone; the infestation was endemic, established in the structure of the castle as well as in the collections. In order to understand what treatments could be effective we had to understand the lifecycle of the beetle and also we had to understand how the building functioned. We therefore needed the help of an entomologist with expertise in heritage pests to advise on the beetle and the Trust’s Surveyors to understand what was happening in the castle.

Through the resulting Furniture beetle Study Day, where David Pinniger was invited to advise on the current beetle issue, its lifecycle and what the present level of infestation indicated and discussions and consultation with the Surveyors we were able to get a clearer picture of the problems the castle had suffered from in the past and from there we as conservators with David Pinniger’s help were able

to suggest explanations why the beetle infestation had increased and more importantly how the population could be managed.

1.4 Understanding the history of the problems

Major repair works between 2007 and 2009 were carried out on the exterior of the building. The castle was reharled with a traditional lime mortar to address structural issues caused by water ingress. Several of the ornate plaster ceilings were in imminent danger of collapsing- a direct result of rotting wood and increased insect infestation in the joists which supported the ceilings. Why did this damage happen then and not at any other time in the castle's 400 year history? Why also after the major repair project did the insect population increase?

1.5 1973 Harling

We understood from our Surveyor colleagues that the interior and the state of the collections were directly related to the harling- the exterior finish of the castle. Harling is an effective method of weatherproofing solid masonry walls. Many of Scotland's traditional buildings were coated externally with lime harling and finished with limewash to form a protective decorative finish. In 1973 there was a reharl of the castle for the best of reasons and the traditional lime mortar harl was replaced by cement rough cast, supported by grant from the Historic Building Maintenance Fund from central government.

The cement harl was dense, hard, brittle and prone to shrinkage and cracking, issues now better understood with this material than in the 1970's. Water was able to penetrate the cracks and then the underlying stonework of the castle. The cement also stopped evaporation of water and the water moved into the stonework. Lime mortar on the other hand is less dense, and crucially is porous. It may seem, at first, odd to allow water into a building but it allows for evaporation and the harl then keeps water away from the stonework and woodwork. The thick wall technology is intended to allow the moisture to penetrate the harl and to evaporate before penetrating the interior surface. The cement effectively prevented this wet/dry process and allowed moisture to build up in the stonework and increase the moisture content in the plaster lath and supporting structure (Davidson 2008). This problem with the cement harl came to light as several of the decorative plaster ceilings were in danger of collapse as the wooden support structure above had been damaged by this moisture. The building's internal environment was being directly affected by the failing exterior finish of the castle.

1.6 Removal of cement harl

A major project to address this was underway by September 2007, scaffolding was erected and the castle enclosed in protective sheeting. The cementitious harling was mostly removed by hand. The castle was reharled with lime mortar and lime washed by the spring of 2009. Harling with traditional lime mortar was the best solution to manage the moisture within the structure and encourage evaporation to ensure the building walls would remain dry. However, the internal consequences of the reharl were twofold; increased beetle activity and increased mould inside the castle (Fig. 4).



Fig. 4: Mould growth on wooden panelling, Great Hall. © Sarah Gerrish.

1.7 Environmental monitoring data

Figures 5 a & b show the environmental conditions in the castle in years preceding reharling project in one representative area, the Queens Room which has signs of active furniture beetle activity in the bed and in the floor boards and joists. In 2007 before the cement harling was removed the internal RH averaged at 78% after the major repairs were complete the internal RH had risen to an annual average of 87% (Bouwmeester 2010). The problem of the increase in the internal RH which occurred during the reharling project was due to a number of factors:

- Exposed stonework when the building was stripped of its cement harl and was then susceptible to the elements,
- Scaffold sheeting may have slowed down the rate at which moisture could evaporate from the building. This was intentional to help ‘cure’ the lime and help its setting processes.
- Reduced effects of solar gain on moisture evaporation.
- Trapped moisture within the castle due to lack of internal ventilation.

The Environmental monitoring data, gathered from 2004 onwards suggests that the internal conditions follow the external when it is able to (Bouwmeester 2010). When the castle was closed during the reharling project windows were boarded to protect the glass from impact during the works and this meant that they could not be opened to provide natural ventilation. The castle was also closed to the public, and as a result doors, normally open during the day were closed for 18 months restricting air and moisture movement. The absence of ventilation impeded the interaction between the external RH and internal RH, which tended to remain high as a result. This indicates the building is relatively free of natural ventilation, through chimneys for example, and draughts and has high buffering properties against external fluctuations. A consequence of this is that any moisture entering and getting trapped in the building is unlikely to find a way out during periods of no or limited ventilation.

The reharling process itself also may have added to the problem as a large amount of water would have been added to the stonework when the mortar was applied and it is also necessary to take into consideration the location of the building in NE Scotland, where the average RH is around 80% and the average annual temp is 8°C.

2. Discussion

2.1 Discussion of treatments

Application of chemical treatments were discussed in 1990's, but the issue of potential staining of ceilings and efficacy of chemically treating a building, access to joists, beams, and structural timbers was never satisfactorily resolved and the treatment did not take place. Small scale localized injection of permethrin solution had been conducted by conservators and property staff into flight holes but this was stopped as it had very little efficacy.

Trust IPM guidelines (Houston 2008) favour environmental control rather than chemical measures as the preferred option for controlling insect pest populations. Normal practice would be to introduce conservation heating by humidistatically controlled electric radiators. At Craigievar there were 5 power sockets in the building used regularly by staff for plugging in temporary lighting and vacuums for housekeeping. There is virtually no electric lighting in the castle and no heating other than two storage heater on the top floor and one at the entrance. This harks back to the wish to retain the castle's 'rustic charm' and the atmosphere of the castle. So it was not initially possible to introduce low level conservation heating as there were not sufficient electrical services to make this possible.

2.2 Natural Ventilation

To address the issue of excess water moisture trapped in the castle, a natural ventilation regime was reintroduced by the Conservators to the castle in 2010. The castle had suffered throughout the reharling project from a lack of escape routes for water moisture and the average RH inside castle was 85%. A protocol was put in place whereby if the external RH was up to 20% lower than the internal RH and it wasn't too windy (risk of dust from the gravel driveway entering the castle) then several windows at the bottom and top of the castle were opened to increase air movement through the castle. This protocol had a risk of increasing the internal RH fluctuations significantly and if the external RH was over 20% higher was not acted upon. The maximum average daily RH fluctuation was 6% in 2009 and the greatest average daily fluctuation recorded after the natural ventilation regime was implemented was 12%. This together with the reopening of the castle to the public has meant the ventilation of the castle has increased significantly and facilitated the extraction of excess moisture from the castle.

2.3 Furniture beetle Study Day

A study day organised in the castle in July 2012, chaired by David Pinniger, looked at the damage and the issues of an established significant structural and collections based *Anobium* infestation and allowed both Conservator and Surveyor teams to discuss how they could work more efficiently together to improve the management of the problem. It led to agreement to share information, such as IPM reports, environmental monitoring reports and structural surveys between the teams. Crucially, it also led to discussion and agreement to upgrade the electrical services where possible to allow for the introduction of low level conservation heating in a few key areas of the castle.

2.4 Further Actions

With a minimal extension to the electrical services it was possible for the Conservators to introduce humidistatically controlled heaters on several floor levels inside the castle. Trust guidelines for set points for conservation heating are generally set at 58%. This was deemed to be too low for

Craigievar, where the average internal RH was 85% in 2011. Set points for conservation heating at Craigievar were set to range between 72 and 76% for four main reasons:

- Graduated set points for conservation heating would facilitate increased air circulation through the castle and aid the escape of excess moisture
- Heating was to be kept to a minimum over concerns for increasing the risk from mould growth in a saturated building and the plaster ceilings were prone to efflorescence of salts
- Limited electrical service available
- Introducing warmer air in lower levels of the castle, rising to the next floor level would reduce the amount of time conservation heating would be employed and assist keeping energy consumption as low as possible.

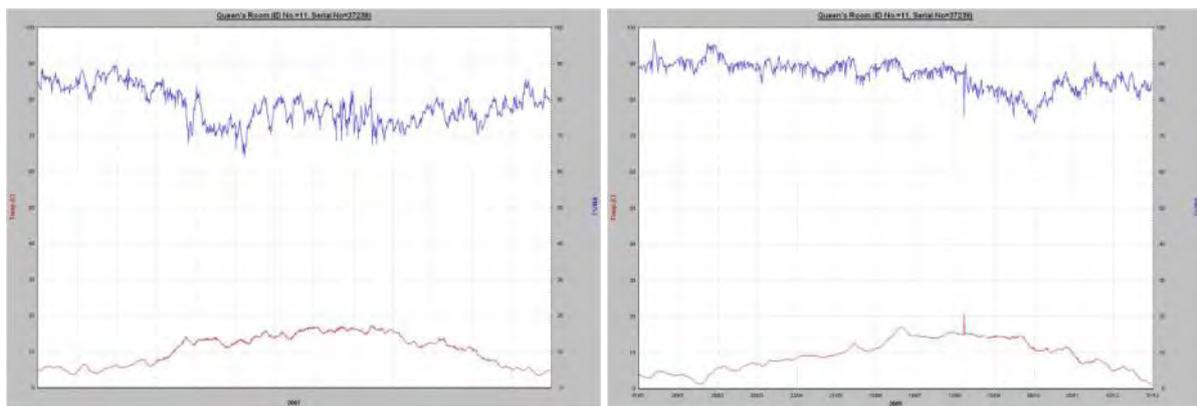


Fig. 5a & b: Environmental monitoring data graphs for the Queens Room 2007 and 2009 respectively. © National Trust for Scotland.

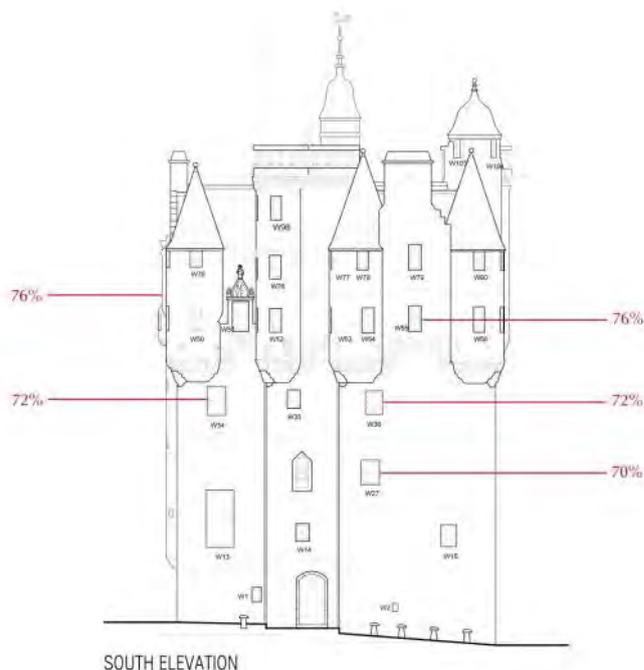


Fig. 6: South elevation of Craigievar showing RH set points for conservation heating © National Trust for Scotland.

Conclusion

The Trust's teams of Conservators and Surveyors are under no illusion that they have the problem solved yet. It is unlikely that there will ever be an absence of beetles in the house, given the high quality of sap wood in the pine flooring, panelling and roof structure.

The property staff at Craigievar has been assured that the problem is being addressed with the best advice and recommendations possible. A regular inspection regime is in place and the Trusts Annual Repair Grant programme will continue to support the control measures now in place. The environment is closely monitored, both through remote data loggers and well trained staff in the property to establish how the environment is changing with the actions taken and the hope is that it will be possible to bring the internal RH below the threshold where *Anobium* can flourish in affected areas of the castle.

This has been a valuable experience for the Trust, the Conservators and the Surveyors. It is perhaps unsurprising that issues such as those facing the building and their contents at Craigievar cannot be solved by one individual or by an individual team. It needs complete co-operation and understanding of all those involved for it to work effectively.

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IPM in the palace of Schönbrunn in Vienna, Austria

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Abstract

The large historic palace of Schönbrunn was built in 1743 as a conversion into residence by Fischer von Erlach, and lies together with its adjoining 160 hectare park in the Western part of Vienna, Austria. The large building contains a total of 85 rooms with historic furniture but also hosts over 30 rental apartments. Integrated Pest Management was first introduced in the historic palace in 2012. In that year and in 2013 a large monitoring concept with over 250 sticky blunder traps and over 100 pheromone traps for webbing clothes moths was put in place and checked five times per year. Traps were placed in the display area (about 40 rooms), the Children's Museum, the Crown Prince Apartment, the Bergl rooms, the reception areas (entrance, ticket area, toilets), eight staircases, eight storage depots, a small basement, a large attic, corridors and about 30 small private rented apartments. The tenants were included in the monitoring on a voluntary basis to locate infestations within the building. Various pest problems relating to the historic building and infested objects have been located since. Webbing clothes moth (*Tineola bisselliella*) is the most common pest in the palace with a total of 1.216 moths trapped in 2012 and 1.092 in 2013. Individual infested furniture objects were identified in the historic rooms, but the main source of the moths was found within the historic building: large numbers of moths were found in the staircases (299) and are expected to come from individual apartments (295) with a moth infestation. Only few objects were found with an active furniture beetle (*Oligomerus ptilinoides*) infestation (some historic furniture and a picture frame). In the storage rooms, where historic furniture and pictures are kept, a problem with varied carpet beetle (*Anthrenus verbasci*), black carpet beetle (*Attagenus unicolor*), biscuit beetle (*Stegobium paniceum*), silverfish (*Lepisma saccharina*) and also some webbing clothes moths were detected. Objects infested by beetles and webbing clothes moths were treated 2013 with sulfuryl fluoride; and a desiccant (diatomaceous earth) will be applied in cracks and dead spaces in the future.

Keywords: Historic building; apartments; webbing clothes moth; monitoring; pheromone traps

1. Introduction

Historic buildings are a big challenge for an Integrated Pest Management concept as most of those buildings harbour an insect pest population under wooden floors, in chimneys, shafts and other dead spaces (Singh 2001, Xavier-Rowe and Pinniger 2001, Pinniger 2004, 2008, Houston 2011, Houston and Davidson 2014). English Heritage is one of the large organisations in the UK where IPM has been implemented for 20 years. Infestations by insects found in historic buildings are mostly related to dust, other organic material, dead animals or bird nests (Lauder 2001, Xavier-Rowe and Lauder 2011, Lauder 2014). Objects displayed in historic rooms can be repeatedly infested by moths or beetles until

the source of the infestation is not found. Essential to these houses or palaces are (1) sealing the building for the prevention of pest entry, (2) regulating the climate and (3) cleaning, all being important parts of IPM.

An IPM concept was introduced for the first time in 2012 in the historic building of Schönbrunn palace in Vienna, Austria and continued in 2013. Here we present results of two years of intensive monitoring, as well as the pests and problems discovered.

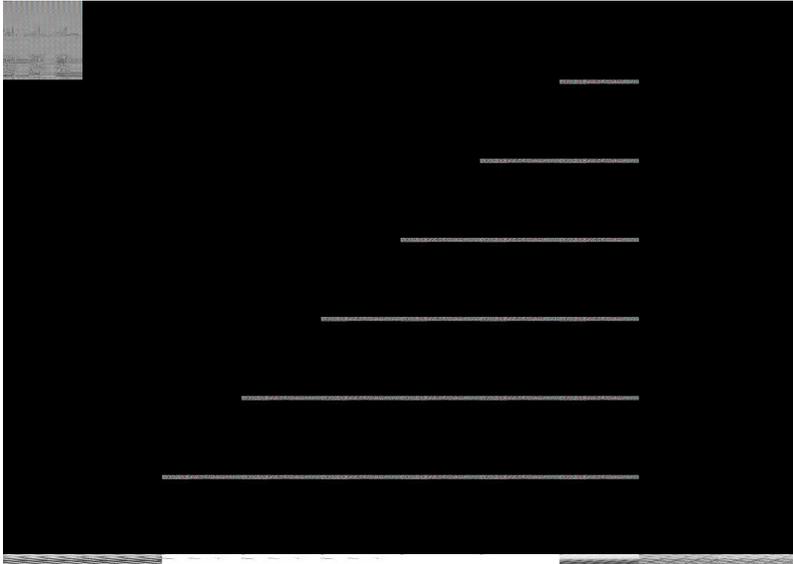


Fig. 1: Palace of Schönbrunn in the West of Vienna, Austria, © Gryffindor Wikimedia commons, https://simple.wikipedia.org/wiki/Schönbrunn_Palace

1.1 The building of the Schönbrunn Palace

The large historic palace was built in 1743 and lies within a 160 ha park in the West of Vienna. The building contains a total of 85 rooms with historic furniture. These rooms are divided into the display area (about 40 rooms), the Children's Museum and the reception areas (entrance, ticket area, toilets) which are open to the public (with up to 2 million visitors per year). The Crown Prince Apartment and the Bergl rooms also host historic objects, and are open for private tours. On the second floor of the palace there are eight where paintings, historic furniture and other artefacts of the palace are stored. On the third floor about 30 private apartments of different size are let to residents. Eight staircases and two large corridors connect all of these rooms as well as the historic display areas of the palace. The palace has also a small basement and a large attic.

No central heating or cooling climate control is in place and the historical rooms remain unheated in winter. Some parts of the historic heating and ventilation system are still in place and provide fresh air. Historic shafts are difficult to access and clean, and it was not known whether dust, dead animals or bird nests are present in these. Since 2002 a centralised system is releasing preconditioned cooled or warmed air from its base (the blue staircases of the palaces).

1.2 History of pest infestations in the palace

Objects of the palace have been infested in the past by wood boring beetles and webbing clothes moths. Some of them still have signs of this historic infestation, but this was from before the

monitoring was started, and no active infestation was noticed. A variety of pesticides have been used against the pests in the past, but no documentation is available.

2. Material / Methods

In 2012 and 2013 a large monitoring programme was put in place with over 250 sticky blunder traps and over 100 pheromone traps for webbing clothes moths checked five times per year (April to October). Traps were placed in the display area, the Children’s Museum, the Crown Prince Apartment, the Bergl rooms, the reception area, eight storage rooms, the basement, eight staircases and corridors. Traps were replaced twice per year. In 2013, the monitoring was extended to most of the rented apartments to include the tenants on a voluntary basis as a part of the IPM programme. Results of the monitoring were regularly discussed with the conservation department of the palace and searches for infested objects were conducted.

3. Results

3.1 Webbing clothes moths

Different pest problems in relation to the historic building and infested objects were discovered with the trapping. Webbing clothes moth (*Tineola bisselliella*) is the most common pest in the palace with a total of 1.216 moths collected in 2012 and 1.092 moths in 2013. Individual infested pieces of furniture, (see Fig. 2) were identified in the historic rooms, but also non-historic objects were found with an active infestation (emergency blankets, see Fig. 3). The main source of the moths was found within the building: large numbers of moths (466 individuals in 2012 and 351 in 2013) were found in the staircases. On the traps from the apartments, a total of 295 moths were captured in 2013 revealing some sources of the infestation.



Fig. 2: Two pupate cases of the webbing clothes moth underneath a chair, discovered in the first year of monitoring.



Fig. 3: Emergency blanket infested by webbing clothes moths, found in a room close to the exhibition space.

3.2 Wood boring beetles

Only very few objects, i.e. some historic furniture and a picture frame, and the wooden parquet floor in two rooms were found in the palace with an active furniture beetle (*Oligomerus ptilinoides*) infestation (Fig. 4a,b) (Hassler *et al.* 2015).



Fig. 4 a,b: Wood boring beetle infested objects.

3.3 *Anthrenus* and *Attagenus*

In the storage rooms where historic furniture and pictures are kept, several pests were detected in 2012 and 2013 including varied carpet beetles (*Anthrenus verbasci*), black carpet beetles (*Attagenus unicolor*), few biscuit beetles (*Stegobium paniceum*), some silverfish (*Lepisma saccharina*) and some webbing clothes moths. Objects were visually checked for an active infestation but none was found, suggesting that the insects were coming from below the wooden parquet floor and other parts of the building (chimney, shafts) where dust and dead insects were accumulating. As a treatment method for

this problem we applied Diatomaceous earth (or ‘Kieselgur’) in these spaces and tried to improve the housekeeping. In 2013 a chimney was discovered in the Great Gallery with a large number of beetles and moths on the trap, here we found a dead pigeon in the chimney.



Fig. 5: Chimney in the Great Gallery where a large number of *Attagenus* beetles were found in 2013.

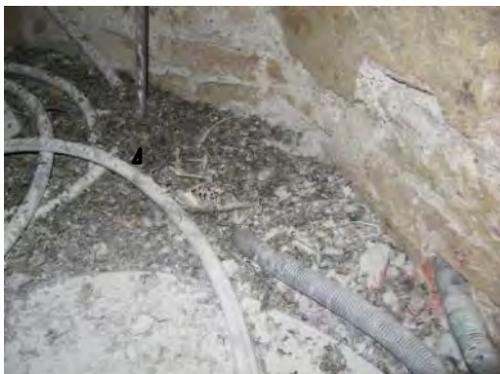


Fig. 6: Remains of a dead pigeon (circle) in an historic ventilation shaft in the Great Gallery.

3.4 Rodents

Some mouse activity was detected in the two years of monitoring and sometimes dead mice were found. They can enter the building through different doors and are attracted by the food sold to tourists in the palace. There are shops selling snacks and foodstuff, but no damage to objects by mice has been reported. Also food in the rented apartments might attract mice into the building.

4. Discussion and actions taken

In general very few problems / infestations were found in the last two years and most of the captured pests (moths) were not coming from the historic furniture or rooms, but from other parts of the building (40%). Active webbing clothes moth and wood boring beetle infestations were detected by the traps and the individual infested objects were quickly found based on the information of the monitoring. This shows how efficient the trapping is working, even in a very large and complex building such as the palace. Objects infested by beetles and moths were treated in the beginning of 2013 with sulfuryl fluoride (SF). SF was used because the palace management did not wish to present rooms without historic furniture over the 6 week period required for a Nitrogen treatment.

As most moths were collected outside of the historic display spaces, the inclusion of as many as possible apartments, staircases and other parts of the building was crucial for a correct interpretation of the monitoring data. This shows that complex historic buildings need complex solutions and that a resident population of pests might be present. Plans to improve the situation in the future include the mounting of insect nets (fly mesh screens) on windows and the sealing of the doors and windows with bristle strips, especially in the ground floor with direct access to the garden.

Large historic buildings are a big challenge for IPM and a large numbers of traps have to be used to cover all areas. Like English Heritage, Hampton Court Palace in the UK or National Trust of Scotland we found different pest species (mainly webbing clothes moths) not only related to infestation of historic furniture but also to the long term presence in the building itself. Cleaning is already an important part of preventive conservation in the palace with daily cleaning of all display areas and a yearly intensive cleaning under supervision of a conservator. The housekeeping can further be improved by including some shafts and chimneys in the concept to eradicate these sources of infestation. At the beginning of the IPM implementation programme, a presentation on IPM and the proposed monitoring program was conducted for all palace staff.

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Update on the IPM programme at English Heritage

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Abstract

Integrated pest management at English Heritage currently covers 71 sites and has been established since 1997. Managed and delivered centrally by the Collections Pest Control & Maintenance Manager since 2003, with assistance from staff, the programme has been instrumental in eliminating problems at the start and preventing major insect pest infestations since. Catch data recorded since 1997 also indicates that clothes moth activity is increasing. The main sources of insect pests, preventive and treatment approaches are outlined in this paper as well as the problems now faced through 'representation' or 'redisplay' projects using reproduced, loaned and historic items purchased for or associated with the sites.

Keywords: English Heritage; maintenance manager; clothes moth; training; historic collections; preventive conservation; monitoring; "What's eating your collection" website; exosex

1. Introduction

Integrated pest management (IPM) at English Heritage (EH) has been instrumental in preventing damage to significant collections displayed and stored at various sites over the past sixteen years. This has been a remarkable achievement as these sites display and store vulnerable materials including wool, leather, natural history specimens, paper and wood. This paper describes how and why IPM at EH has been so successful by looking at how problems when we started the programme in 1997 have now been eliminated, from early warnings given through the trapping data and the effectiveness of having a central Team Manager and how their staff training has helped in recognising problems at an early stage to prevent major infestations from occurring. Also the paper will look at the problems faced now through incoming presentation and interpretation projects at our sites.

2. Background

English Heritage is the United Kingdom government's statutory advisor on the historic environment for England. One of its key roles is the conservation and presentation of over 400 properties. 115 sites display or store collections of which 71 house vulnerable collections including wool based furnishings, natural history specimens, furniture, books and paper artefacts. The collections on open display in historic buildings are the most at risk from an insect pest attack.

IPM commenced at EH in 1997 starting with a sticky trap monitoring programme at Audley End House, a 42 roomed Elizabethan property, which displays and stores 22,478 objects. The developing EH IPM strategy at the time was outlined in a paper published by Xavier-Rowe and Pinniger (2001) for the Pest Odyssey Conference in 2001. Since 2003, the IPM programme has been centralised under the management of one person, the Collections Pest Control & Maintenance Manager, with great success.

In the EH *State of Collections Report* (Xavier-Rowe and Fry 2010) the risk posed by insect pests was deemed to be low in EH properties. The report was based on evidence provided from a collections condition audit and site-based risk assessment completed for 115 sites. As the overall risk of insect pest damage is increasing for historic house and museum collections in the UK, this confirmed the effectiveness of the IPM programme in EH. It is the opinion of the EH Collections Conservation Team that insect pests should be considered as one of the highest potential risks for historic collections as the density of vulnerable materials on display or in store provides an ideal environment for insect pests to thrive.

3. The IPM system at EH

The key elements that work together to produce a sustainable and effective IPM programme at EH are described below.

3.1 Insect pest trapping and interpretation

The foundation for success at EH is a systematic monitoring system delivered by a range of people trained and supported by the Collections Pest Control & Maintenance Manager. The monitoring system, based on sticky museum traps and pheromone lure traps, has been designed so that site staff, conservators and collections care assistants can monitor them. Keeping the number of traps to a realistic number and checking them two to four times a year has proved to be achievable. Results are logged onto an Excel spread sheet and house plans using a standardised key chart. These were created to enable staff to electronically send in the results by email every quarter (spring, summer, autumn and winter) instead of posting paper returns (Lauder 2009).

However, an element of quality control is required with 17 site-based staff currently completing the returns. All quarterly or bi-annual returns are checked by the Collections Pest Control & Maintenance Manager to remove errors and quickly spot any unusual insects or potential insect pest problems. High catch numbers are investigated either over the telephone or through a site visit. Annual insect trapping and monitoring reports are prepared for each property which highlights trends in terms of insect pest numbers and actions needed to reduce the likelihood of an infestation. The annual site report is circulated widely to both inform and raise awareness of insect pests and the on-going actions being taken to control them.

Annual results have been gathered and recorded in this manner since 1997 providing useful trend data which has directly informed collections care practices. At Audley End, for example, the data relating to the varied carpet beetle (*Anthrenus verbasci*), webbing clothes moth (*Tineola bisselliella*), and case-bearing clothes moth (*Tinea pellionella*), flagged up issues relating to housekeeping and chimney cleaning (Fig. 1).

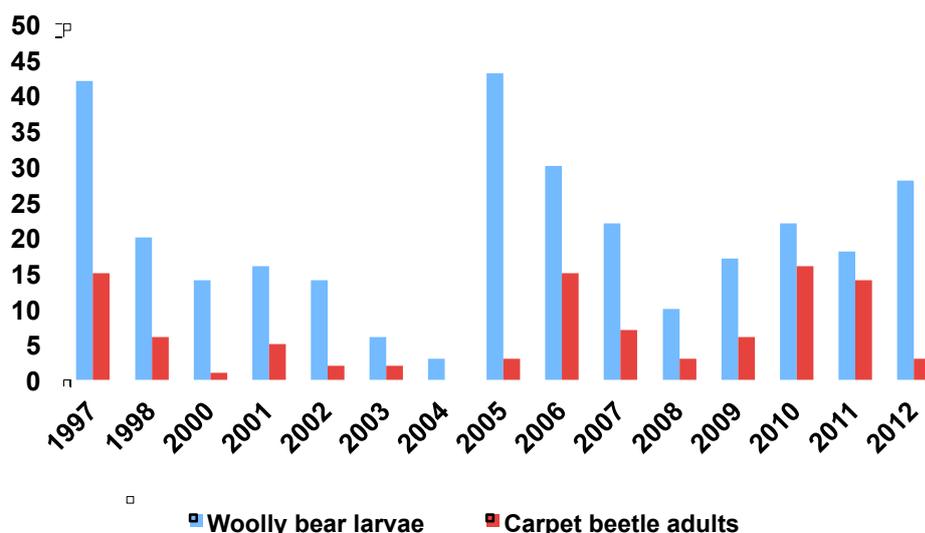


Fig. 1: Audley End House *Anthrenus* adults and larvae catch results 1997-2012.

Anthrenus verbasci numbers had decreased over seven years until 2005 when numbers suddenly increased. Upon investigation, it was established that housekeeping standards had dropped due to staff changes. Whilst the impression was given that all was well, the deep cleaning of the vulnerable rooms and collections was not being targeted effectively. The monitoring results provoked a change to the housekeeping schedule and recognition by the conservator and collections care assistants that certain areas and collections in the house needed to be checked and deep cleaned more frequently during the year. The new schedule was implemented during 2006 and the catch numbers decreased. However, recent monitoring has again shown an increase in numbers particularly being found on traps placed in fireplaces throughout the building and a programme of chimney cleaning is now being put in place to target them.

In order to keep the monitoring programme sustainable, properties have been divided into four categories. This has ensured that effort is focused on the important and vulnerable collections. Category A (currently 28) and B sites (currently 6) are seasonally monitored four times a year. Category a sites house the most important objects whilst B sites may have less important collections that are still vulnerable to attack. Category C sites (currently 5) are monitored twice a year, during the spring and summer months, whilst D sites (currently 32) are annually deep cleaned and visually checked. Category D sites do not have an annual site report written up as there are no monitoring records. Most of these sites are 'buildings related' where, for example, there has been a history of wood borers in the structure or just a few vulnerable items on display such as pews and traceries in churches. Problems detected are relayed to the Collections Pest Control and Maintenance Manager who targets and ensures that effective practices and communication is agreed upon and carried out by the Collections Conservation staff and the Technical Buildings Managers with the approval of Curatorial, Historic Properties and Estates Teams.

Annual site reports are written up, based upon the quarterly trapping information over the past year, and are either emailed to the individual sites and staff concerned or compiled together into a published report 'Pest Management in EH Properties' (Lauder and Pinniger 2011). This is circulated to all the managers involved, including senior management, with the purpose of raising awareness of IPM as a long-term collection care activity. The annual site reports have been produced as a standard practice at EH since 2003.

3.2 Centralised management

The sustainability and effectiveness of the EH IPM programme is due to the centralisation of its management under one person supported by senior management. In many organisations, pest management duties are usually undertaken as an add-on to a job description. Until a dedicated post was created in EH in 2003, progress had been inconsistent and difficult to sustain. At EH, the conservators and collections care assistants mainly assist with IPM but they do not have the time to focus on monitoring, reporting and dealing with potential problems before they turn into an active infestation.

The other key advantage of a dedicated post is that this person can keep up to date with key developments in monitoring and control as well as health and safety regulations and other legislation, for example, biocide legislation, treatment practices and protected species. Whilst the focus of the Collections Pest Control & Maintenance Manager is on insect pests, vertebrates and the baits left by contractors are an increasing problem to collections as they provide a food source for the insect pests.

3.3 English Heritage IPM strategy

The EH IPM strategy was written in 2006 and last updated in 2011 (Lauder 2011). It is used widely by staff involved with monitoring as well as senior management as the formal set of standards for implementing IPM at our sites.

3.4 Training

At the heart of the influencing, coaching and training programme is the EH poster recently revised to include new pest species (Pinniger 2009). This simple publication has been very effective at both raising the awareness of IPM and as an insect pest identification tool.

The EH IPM training programme consists of four courses. Our 'Introduction to IPM' course is taught over two days and concentrates on insect pest identification and gives an understanding of how pests become established in historic houses and collections. An important learning outcome is to correctly identify insect pests and the damage they cause. The EH monitoring and recording system is then introduced through practical sessions. This can then be set up and established with staff over the following year through one to one coaching by the Collections Pest Control & Maintenance Manager. To date we have trained 230 members of staff.

The 'IPM Master class' is a follow-up course designed to provide EH house staff with updated information which advances the knowledge they have all previously gained by attending the 'Introduction to IPM' course. It introduces new pest species and also any updates to our IPM procedures. Other topics covered include protected species, for example bats and legislation, and other insect pest trapping techniques currently available. The presenters provide instruction, practical sessions and advice. Since 2001 we have trained 39 members of staff and one person from the National Trust for Scotland.

The 'Pests Master class' is co-presented with vertebrate consultant Ed Allan and is aimed at EH conservators, site curators, IPM-trained staff, Estates staff and the Technical Building Managers. Updates are given on current insect pest species and issues and their implications for the collections and buildings but the main topics covered include vertebrate issues, protected species updates and also new low-hazard/non-chemical treatments and prevention methods. All current legislation and Health and Safety issues are also covered. We also advise on pest control companies or consultants who are

experienced in working in the historic house context. Since 2008, we have trained 45 members of staff and two external members of staff from Historic Royal Palaces.

Lastly, an ‘Insecticide Treatment’ training course is co-presented with Bob Child of Historyonics. Aimed mostly for the Collections Conservation staff, attendees are trained in the safe use of treatment methods such as freezing, using desiccant dusts and Constrain insecticide applications using pump sprays and ‘fogging’ equipment. The training also covers all current Health and Safety and legal requirements such as the current Biocides Directives. Since 2005 we have trained 22 members of staff and 12 members of staff from other heritage organisations.

3.5 National trends

On reviewing the national data over the past 15 years, we have a picture of which insect pests are most likely to be found in our historic properties and are on the increase. Looking at the results for webbing clothes moth (*Tineola bisselliella*), numbers have increased sharply since 2008 (Fig. 2). The introduction of more effective moth pheromone lures in 2008 explains an increased catch but they cannot account for the steady increase in numbers since then. With the annual trap numbers of other species remaining at steady levels, the increase in numbers of clothes moths being caught currently presents the greatest potential risk to EH collections.

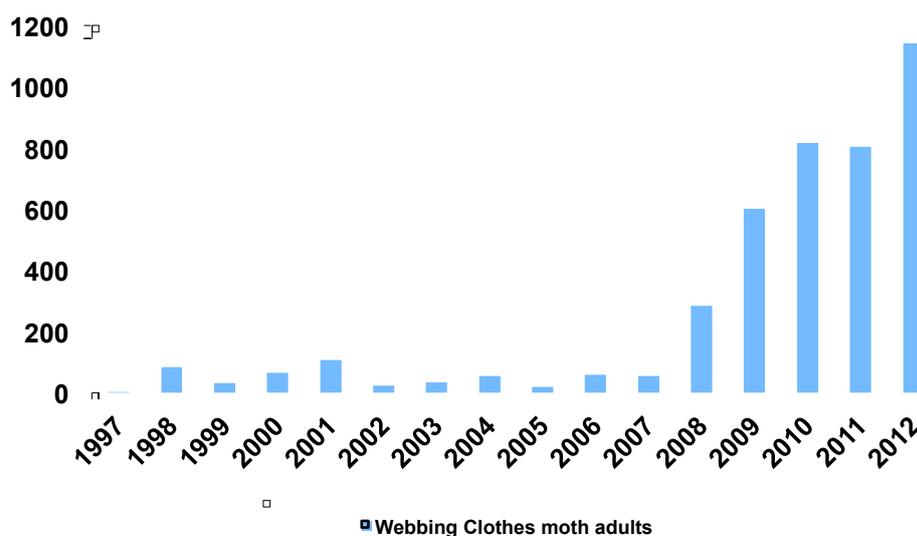


Fig. 2: EH properties *Tineola* clothes moths catch 1997 to 2012.

This type of long-term data analysis can both provide a warning to the risk level and also help with securing and targeting resources for research into control methods. To this end EH has worked with David Pinniger and Jane Thompson-Webb at the Birmingham Museum and Art Gallery in providing data for the online ‘What’s Eating Your Collections’ database (www.whatseatingyourcollection.com). This can then be used to highlight risk levels by region and towns. Other heritage organisations have also recently started to provide their data as well. A good baseline with data from a wide range of reliable sources can be used to show changes in UK distribution and frequency of insect pest populations and how they are affected by climate and other factors.

4. Sources of insect pests in English Heritage sites

Through maintaining an IPM database, on which all information relating to IPM issues for each site is logged, we can confirm the main sources of insect pests.

4.1 Poor housekeeping

Poor housekeeping is by far the biggest contributor to increases in pest activity. The build-up of dead insects including flies, wasps and ladybirds and of dirt, dust and litter has been responsible for increased pest activity.

4.2 Chimneys

Chimneys, which are nearly always found in EH sites, are the principal source of significant rises in moth species. Dead birds and their nests trapped in chimney flues are a natural habitat for Tineid moths and Dermestid beetles larvae that can fall down into the fireplaces and lead to an infestation within the building. Chimney flues have been largely missed from cyclical maintenance schedules as they are no longer used, but this situation has changed at EH through the IPM programme and chimney cleaning and effective capping is now recognised as a core maintenance activity (Fig. 3).



Fig. 3: Fireplace clean in the Duke of Wellington's Room, Walmer Castle, Kent, UK.

4.3 Forgotten rooms

Rooms not open to the public are often left off cleaning schedules. This can lead to a build-up of dirty rooms with dead insects and even vertebrate carcasses which can lead to the insect pests spreading and causing an infestation problem in other areas of the building.

4.4 Lack of building maintenance

The lack of building maintenance related to downpipes, guttering, roof spaces, window and door proofing, and roof repairs have all been responsible for damp ingress resulting in death watch beetle (*Xestobium rufovillosum*) and furniture beetle (*Anobium punctatum*) activity in the wooden fabric of the building. Poor chimney proofing encourages birds gaining access inside them and roosting. Birds nests can accumulate and lead to an insect pest infestation inside the building from debris etc. falling down into the fireplaces and insect pests gaining access into rooms housing vulnerable collections.

4.5 Vertebrate pests

Birds, rodents, bats and other protected species, squirrels, rabbits and moles have also been responsible for insect pest activity through nesting materials, droppings and dead bodies.

5. New Projects

New projects involving loans, 'reproduced' items and collections brought in for specific sites are also presenting a major source of concern due to the potential of bringing an insect pest infestation into a site housing collections.

For example, the Dover Castle Great Tower project installed in 2009 presented two major problems. The first was from using reconstructed red dyed wool hangings as well as fur and woollen bed covers and hangings in most of the rooms along with new reconstructed oak furniture. As a result, 18 moth pheromone lures had to be deployed and checked 4 times a year to give us early warning of any potential major clothes moth infestations. The rooms are also targeted at least once a year with a thorough deep clean and a fogging treatment using Constrain carried out as a preventive control measure.

The second problem happened in 2012 when powder post beetle bodies *Lyctus brunneus* and fresh frass were detected on and underneath the reconstructed oak barrel stand which was installed in the kitchen area on the Ground floor. Weekly visual checks, clearing away the dead bodies and frass over the summer months and treating the stand and barrels as a precaution proved that the stand was the source of the infestation which resulted in it being removed from display, disposed of and a replacement installed in March 2013.

With more projects for various sites rolling out each year there is the increased worry as to whether IPM procedures are being considered in the early stages and undertaken. Examples include condition checks of vulnerable items, whether brought in from one of our stores or another property, loaned or newly acquired items which are intended as part of the itinerary and taking the advice given as to the suitability before items are agreed upon as part of the new display scheme. For example, do we use traditional dyed woollen fabrics and wood containing sapwood or which has not been pre-treated to make reconstructed furniture? Do we loan or even buy collections from other properties which may be infested?

All the factors highlighted raise problems for our Team. They can overtake us in our main priority to safeguard the historic collections already in our care as a result. For us to effectively cover all of our sites housing vulnerable collections throughout England without the help from trained site staff which we used to have, additional projects which involve our Team attending meetings, agreeing to what can be realistically installed, carrying out condition checks, overseeing and implementing in the final stages, more sites being included to the insect pest trapping programme and also carrying out more

cleaning duties and visual checks is decreasing the amount of time we realistically have to carry this out as well as impacting on the limited budget we already work with.

6. Prevention and control

Producing an annual report for each IPM site provides the key information for prioritising actions over the coming year and is fundamental to preventing damage.

There are about 600 chimneys in the 34 Category A and B sites that require cyclical cleaning. Chimneys that are linked to rises in insect pests are prioritised for cleaning using a budget that has been ring-fenced for collections maintenance. Requests for chimney sweeping are logged on the Estates maintenance database system to ensure that jobs appear on cyclical schedules using agreed specifications produced by us. Establishing a close link with our Estates teams through engaging with their system and staff means that this relatively simple and cheap task has a major impact protecting our vulnerable collections and is dealt with in a methodical and timely manner. We also alert our technical maintenance teams to a range of building maintenance issues noticed through insect pest monitoring.

Housekeeping schedules are regularly reviewed and revised in response to annual results and targeted deep cleans are undertaken either when required or on a yearly basis.

Birds and rodents are also an increasing problem for collections often due to the increased consumption of food and frequency of functions at many sites. We therefore aim to influence EH practices relating to vertebrate control through a standard specification for the appointment of contractors and advocating a central cyclical contract carefully monitored to ensure effective control and value for money.

7. Control Treatments

Temperature treatments (freezing and heating) are the preferred methods when dealing with infested objects. For the treatment of multiple objects we prefer a heat treatment using the Thermo Lignum (UK) Ltd mobile treatment chamber due to the short treatment time and proven efficacy, particularly for wood borer infestations (Strang 2001).

For local treatments *in situ* the insecticide Constrain, a permethrin micro-emulsion, is used for textiles (for example carpets, curtains, upholstery), plant fibres and wood.

Fogging using Constrain and an IP Mini Fogger has also been used to treat rooms and objects both as a preventive measure and for control of insect pest outbreaks. This control measure has been mainly used for large recreated interiors where wool and wood has been used. It has also been recently used in rooms where there has been a wood-borer outbreak.

Following the successful trials of Exosect Ltd's Exosex CLM and CL moth confusion pheromones lures at Marble Hill House in London since July 2007 (Lauder 2009), we can now consider deploying it at other sites to control webbing clothes moths numbers to acceptable levels. This is a non-chemical 'pest confusion' treatment designed specifically to reduce the numbers of the highly destructive larvae of the webbing clothes moth. Each pheromone lure tablet uses a synthetic female pheromone to attract male clothes moths into a dispenser where the 'Entostat' powder combined with the pheromone is situated. Males are lured to the dispensers and upon contact with the powder; it coats their bodies (Fig. 4).



Fig. 4: An Exosex CL dispenser and pheromone lure in the Great Room at Marble Hill House, London, UK.

The senses of the coated moths are overwhelmed and they cannot detect females as a result. As they leave the dispenser, they then attract other male clothes moths and so spread the confusion effect even further. Female moths do not mate, lay very few fertile eggs and as a consequence there are far fewer larvae produced. The twenty-four lures currently dispensed around the house are changed every eight weeks. Since 2006, when thirty-six webbing clothes moths were caught on sticky museum traps situated around the house, the numbers have since have depleted to only four moths being caught in the house in 2012 (Fig. 5).

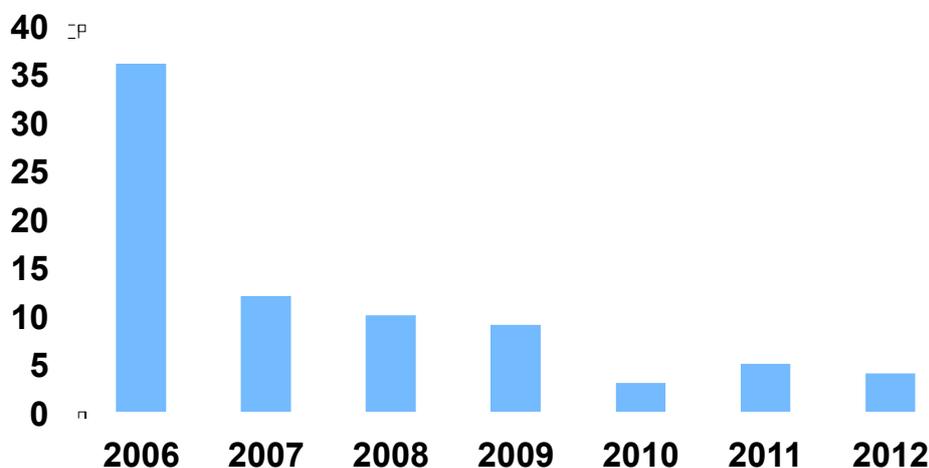


Fig. 5: Marble Hill House *Tineola* clothes moths catch 2006-2012. For each quarterly return in 2012, 24 Exosex CL lures, 5 low-dose bullet lures and 27 blunder traps were used.

The system appears to remain effective in continuing to keep populations of clothes moths at low levels and has remained steady in the last three years which has produced an encouraging result.

The introduction of wool-based materials as part of new representation schemes is carefully managed. Where possible wool is avoided, however this can be challenging when authenticity, texture and drape of textiles are essential to the successful historic interior scheme. Where no acceptable material can be

found to replace wool, the method of installation is controlled to ensure easy access for removal and cleaning. In some cases we have also implemented an annual fogging programme using Constrain insecticide to prevent a clothes moth outbreak.

A significant proportion of the EH collections are in kept in stores (87%) (Xavier-Rowe and Fry 2010). We are developing new storage facilities at some of our sites and in spring 2013 our first new store became operational. This has given us an excellent opportunity to dispose of accumulated materials, check vulnerable collections as they are packed and also design the new stores so that relative humidity can be kept below 55% for most of the time. Quarantine areas and procedures for receiving goods and collections have also been incorporated.

8. Raising the public profile of IPM

The insect pest story can be very successful in attracting public interest through the media. When we have released a press release relating to IPM the press response has been strong. Examples are the in-depth interview of the author by BBC Radio 4 as part of a programme titled ‘What’s Eating The Museum?’ about pest control in museums and historic properties housing collections and an interview given to ITV Meridian’s South East news about our IPM programme in late 2011 (Fig. 6).



Fig. 6: Dee Lauder from English Heritage interviewed by ITV Meridian News about insect pests at Dover Castle and its historic collections.

Conclusion

Government cuts to grants in recent years means that the risk of major damage to the nation’s heritage from insect pests is increasing. The experience at EH over the past 16 years has demonstrated that Integrated pest management successfully mitigates this risk. A further challenge could be the effects on pests through climate change and EH will have to adjust its IPM strategy to deal with this. There is no doubt that an efficient, manageable and effective strategy at EH is due to one staff member being responsible full-time for the programme.

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Everyday struggles with insects at an ethnological museum

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Abstract

A review of the history of IPM at Weltmuseum Wien is followed by a discussion of the methods of pest eradication which are currently in use. After ten years of practicing IPM methods I realized that most pest infestations occur due to failures in complying with the quarantine rules. Therefore I will concentrate on this topic and how to deal with it. Despite many struggles and a permanent lack of money, a comprehensive insect-trap-system was installed and cheap recyclable traps were developed. In a nutshell: IPM is an effective, economic and simple method for the prevention of pest attacks in museum collections.

Keywords: insect-trap-system; sticky trap; quarantine; *Dermestes maculatus*; *Trogoderma angustum*

1. History of IPM at Weltmuseum Wien

Weltmuseum Wien (WMW) is a very big and famous ethnological collection which comprises more than 200.000 ethnographic objects, 25.000 historical photographs, lots of archive material, and much more properties on the history, culture, art and everyday life of non-European people (Fig. 1). As in most ethnographic collections the use of pesticides to prevent or kill pests was formerly very common. For the purpose of pest and mold eradication Weltmuseum Wien was equipped with its own ethylene oxide fumigation chamber. For pest prevention – especially in the textile and leather collections – a variety of products containing pesticides was widely used. Some textiles of the collections were treated with EULAN (a deterrent preventing insect damage by coating the fibers and fabrics).



Fig. 1: Weltmuseum Wien, Vienna, Austria.

In the early 1990's repellents were employed for the protection of the textile collection. Especially one product was used, consisting of a small metal box containing an absorbing pad soaked with essential oil. After a few years of usage, however, a yellowing on the cotton cover around the repellent boxes

was observed. As an alternative, tea bags containing plant materials rich in essential oils were applied. Nevertheless, after some years, moth cocoons were found directly on some of the lavender bags. From the literature we learned that moths can get used to odors, so the use of repellents was discontinued from then onwards.

In 1996 the first sticky traps were installed but only in areas where insects occur very often. This is because the museum could not afford to buy a bigger quantity of traps. At the same time, pheromone traps for webbing clothes moths were applied.

A turning point in the history of IPM at the WMW was the preparation of objects for an Afghanistan exhibition in 2003. As the damage of some objects due to past pest attacks in this collection was very bad, we opted for an intensive use of sticky traps as well as pheromone traps for monitoring insects during the exhibition. The traps were checked regularly and all findings were documented. At the same time, a growing interest in Integrated Pest Management brought me in touch with Bob Child and David Pinniger at an IPM course for students in Vienna. Their enthusiasm inspired me and I was fascinated by the complex nexus of pests, climate and housekeeping.

Being more aware of pests, we detected a large pest attack (*Dermestes maculatus*) in our leather collection. All objects were transferred to an external nitrogen fumigation chamber, and the infested storage room was cleaned very carefully.

When trying to implement Integrated Pest Management at Weltmuseum Wien, I encountered considerable difficulties due to the lack of collegial support and a missing appreciation of the necessity of IPM. The lack of funding did not make things easier. Nevertheless, a comprehensive insect-trap-system was installed in all storage facilities in 2004. With this trap system practically all pest infestations have been detected until now.

Performing IPM in addition to my work as a textile conservator became too time-consuming; therefore, the work was shared with one of the collection assistants, who checked the traps on a monthly basis. For easy understanding of IPM, a booklet with guidelines was prepared. With the assistant looking for flying insects every morning when switching on the lights, many pest attacks could be detected at a very early stage. Hence, I realized that all storage staff should be involved with IPM, because no one is more familiar with storage location and conditions.

Monitoring report sheets were prepared for the different storage departments and kept in folders accessible to the IPM team. The following details were completed: date of monitoring, information on the room climate, variety and number of flying insects, insects recovered from the window sills, detailed records of the insects caught on the pheromone and sticky traps.

For the lack of funding we had to design our own insect traps, important aspects being recyclability and the possibility to reopen them and place them under the microscope for a more detailed investigation of the insects trapped.

In order to avoid problems with identifying beetles that lie backwards on the trap, transparent foil was applied, which can easily be turned when the insect is upside down. We experimented with different adhesives and tried a number of attractants, including vanilla, ketchup, and butter. An adhesive was chosen that is common in fruit-growing and very inexpensive; no further attractants were added. The foils are renewed on a yearly basis to ensure that the traps are sticky enough to trap insects (see Fig. 2).



Fig. 2: Self-made sticky trap. Fold the cardboard. Apply adhesive on a transparent foil. Clip it together.

2. Pest eradication / pest prevention methods at WMW

For pest prevention, all incoming objects as well as all infested objects are treated by the following methods:

2.1 Freezing

At Weltmuseum Wien most objects are treated by freezing, especially textiles and paper. For this purpose, two big domestic freezers are available that are able to cool to -26°C . Before freezing, the objects are prepared as follows: At first they are wrapped in some layers of acid-free tissue paper, tightly put in a polyethylene foil and firmly sealed by tapes. Then they are wrapped in blankets or towels and the whole package is afterwards put in a box in order to facilitate safe handling and stacking. After two weeks of freezing, the boxes are allowed to return to room temperature for two days. Objects are then retrieved from their packages in another room to make sure they do not get re-infested.

2.2 Nitrogen fumigation

Very big objects and materials that cannot be put into the freezer, such as synthetics, metal applications, paintings and material compounds, are sent to an external nitrogen fumigation chamber. Currently (Autumn 2013) two big nitrogen fumigation tents for pest eradication are operated by an external company in our museum. One tent (200 m^3) contains our textile collection (15.000 textiles), which has to be treated for pest prevention before being relocated to a newly built storage facility. The other tent (50 m^3) houses objects that just returned from an overseas touring exhibition.

2.3 Anoxia with oxygen scavengers

Very fragile objects that cannot be frozen and transported are treated by anoxia with oxygen scavengers. For this purpose, we use Styria Bar foil, which a research project at Kunsthistorisches Museum Vienna had identified to be most suitable. Starting out with ATCO oxygen scavengers, we now use ZerO₂. To regulate the climate during the treatment, Prosorb and cotton cloth are used together with acid-free tissue paper.

For effectiveness, only a small number of small objects should be treated at a time. For the treatment of larger numbers of objects, a tent (5 m^3) ready-made out of aluminum compound foil (Fig. 3) was used. Such large volume tents are no longer used, as they required excessive quantities of oxygen scavengers. The reason for the leakage became evident after the treatment when I discovered that all

foldings and bents in the metal component of the gastight foil had developed into cracks (giving the impression of a starlit sky when looking up from the inside). Indeed, this type of tent is suitable only for the use with nitrogen, but not with oxygen scavengers.



Fig. 3: Large tent used for anoxia with oxygen scavengers. We do not use such big volumes anymore; the smaller plastic foil bags are more effective with oxygen scavengers.

3. Common struggles with IPM

3.1 *Cleaning after pest eradication*

If insect remains are found on an object after previous pest eradication it is unclear, whether or not the object is subject to a re-infestation (Fig. 4). In addition, dead insects are good food for other pests. Therefore, it is important to clean the objects after every pest eradication treatment. We clean the objects with special medical vacuum cleaners under the guidance of our conservators.



Fig. 4: This felt-carpet was preventively pest treated but not cleaned on its return from an external storage in 2007. When we opened the cover of the object in 2013 we were not sure, whether the textile was infested again. So we had to treat the felt carpet again.

3.2 *Forgotten rooms*

Following our attendance of the IPM Conference in London 2011, we adapted our IPM system to all rooms of the museum, including staff rooms, offices and all “neglected” rooms, such as rooms for

building equipment and appliances. The traps in these areas are checked at least once a year. When visiting these rooms I came to realize that one of the weakest links in IPM is the building itself. I detected various sources for insect infestation, including bird's nests and other more appalling discoveries, all to do with poor housekeeping.

3.3 Poor housekeeping

Many problems occur because of bad housekeeping. Poorly kept storage rooms are the best homes for insect pests, who love dark, filthy environments with little air circulation. Dust itself is a good food source for insects, because it contains lots of fibers and tiny organic particles. Additional problems arise if waste bins are not regularly emptied. Brooms and other cleaning equipment, too, needs to be cleaned after each usage. One moth infestation was caused by a vacuum cleaner, which had not been emptied for a long time.

3.4 Sticky barriers (see Fig. 5)

Sometimes, when we cannot identify the source of infestation we set up sticky barriers for detecting the way insects are moving. This happened in the course of a large *Anthrenus* larvae attack at the so-called 'Melanesia storage' in 2006. Only after installing a grid of sticky barriers we realized that all insects entered through a small door, outside of which a dead pigeon was lying in a ventilation shaft. After removing the source of infestation, the door was sealed properly and a pigeon net was installed over the ventilation shaft. The floor of the store was cleaned thoroughly, including the spaces under the selves. We did not treat any objects, because we found only larvae but no adult insects. Following these measures no further insects were found in this storage area.



Fig. 5: Sticky barrier made out of a long transparent foil. With this barrier lying underneath a window, we can detect how many insects are attracted by the natural light outside. Adult *Trogoderma angustum* on the strip.

3.5 Pest prevention – quarantine rules

The most difficult area of IPM is the prevention of pests. After ten years of practicing IPM methods, I realized that most pest infestations occur because of failures to comply with quarantine rules. Problems kept occurring in spite of the usual museum instructions "no smoking, no eating, no plants, no living animals, no taking of handbags or other personal belongings into museum storages and exhibitions", mostly because these very instructions were not being followed by everyone.

But simply obeying general museum rules is not enough. My experience with IPM taught me that some additional quarantine rules are warranted:

1. No object should be allowed to enter the storage without strict quarantine;
2. All materials and tools that are used need to be controlled;
3. Staff should wear special clothing: working coats and gloves to be worn only in the designated area.

3.5.1 Inspection of all objects

All new objects, both arriving for or returning from exhibitions and those that were on loan before entering the storage, need to be checked. In the course of visual inspection of incoming objects I have found many moth pupae on and inside glass, ceramics or metal objects, because larvae often leave their substrate before cocooning. Therefore, it is absolutely necessary to control objects regardless of the material – even inorganic material may carry pests!

3.5.2 Transport materials in storages

Many materials used in storages can be the source of an insect infestation. Once we had problems because of wooden pallets that were regularly used for transportation, but some of which were left in the storage. Care should be taken with transport boxes – they are unsuitable for the long-term storage of objects. I also advise staff to be cautious with blankets made out of recycled textiles often used for protection against breakages: These blankets typically contain a lot of wool.

3.5.3 Short-term loan

One twilight zone of IPM relates to the ‘short-term kidnapping of objects’, as I would call it. In our museum it is common that objects are removed from the storage to be studied and discussed during a lecture elsewhere in the museum. But often short-term periods turn long-term, and the object then returns into the storage without any quarantine to check for possible infestation.

3.5.4 Photo shooting

When objects are photographed for exhibition catalogues or other publications they often leave the storage. At Weltmuseum Wien we have an extra room for photo shooting, but there is no separation of objects from the storage, new objects and objects on loan. This is another twilight zone of IPM.

3.6 Touring exhibitions

We had a big problem with *Lyctus* infestation within wooden transport boxes from Africa in 2011. All objects and transport boxes had to be treated before the exhibition started. Afterwards we also had to put under quarantine for a year the room where we unpacked the objects, because it had a wooden floor and cross infestation by the contaminated objects could not be ruled out beyond any reasonable doubt. In this instance, we monitored the occurrence of beetles with a self-made UV-trap.

Another incident occurred in the course of opening the transport boxes for an exhibition coming from America. We organized everything for pest prevention concerning the objects, but were unprepared for living insects (Cockroaches) emerging from the transport boxes.

3.7 No quarantine – because of former pesticide treatment?

In March 2013 we discovered an unusually large number of beetles on our sticky barrier on the windowsill in one of our Africa stores (see Fig. 5). It turned out that the insects originated from wrapped objects. Two years earlier, infested objects had come into our storage without quarantine, because it was known that they had undergone an intensive treatment with pesticides. Nevertheless, these objects turned out to be infested. After detecting the source, we evacuated the objects and froze them. This infestation is the best example for why absolutely no object should come into storage facilities without strict quarantine.

Conclusion

No matter what obstacles have to be overcome, IPM is an effective, economic and simple method for the prevention of pest infestation of museum collections. Sometimes it is a hard way to go, but judging from my personal experience I can state that it is worth it. In the hope to have encouraged other museum staff to start with IPM I will be happily available for a future cooperation with ethnological museums and other institutions.

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