

Study on Population Dynamics, Occurrence Mechanism and Control Measures of Cultural Relics Pests in the Hall of Mental Cultivation of the Forbidden City

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Abstract

Insect infestations seriously threaten the safety of organic cultural relics and ancient buildings. Every year, the Palace Museum spends a large amount of money and time on the prevention and control of cultural relics pests, but there is still no systematic and targeted method. The Hall of Mental Cultivation is a representative and important building in the Forbidden City. Through three years of pest investigation, the species, occurrence mechanism and development trend of the main pests were discovered. During the investigation, more than 10 species of insects were trapped. Pests of cultural relics included carpet beetle (*Anthrenus picturatus hintoni* Mroczkowski and *Thylodrias contractus* Motschulsky), silverfish (*Ctenolepisma villosa*), powder post beetle (*Lyctus brunneus* Stephens), booklice (*Loposcelis bostrychophila*), spider beetle (*Ptinus japonicus* Reitter and *Gibbium aequinoctiale* Boieldieu) and clothes moth (*Tinea pellionella*), among which the *Anthrenus picturatus hintoni* Mroczkowski was the primary pests. Abundant resources of organic cultural relics, suitable temperature, humidity and light environment, and the existence of cypress are favorable factor for the occurrence of pests. Analysis of these triggers is helpful for Integrated Pest Management. The period with the largest number of active pests in the Hall of Mental Cultivation is July and August. April, May are the rapid growth period, and the influence of the carpet beetles on the overall change trend is significant. Combined with the living habits of main insect pest—carpet beetles, the killing time of different killing means can be effectively grasped: fumigation should be in July and August when the maximum amount, while chemical spray should be combined with the flowering period of trees (March to May).

Introduction

Pests are an important problem in the protection of cultural relics because of their large number, great damage and difficulty in extinction. Some cultural relic workers have been devoted to the research and control of cultural relic pests. For example, For example, Pascal Querner conducted a survey of cultural relic pests in central Europe^[1, 2]—the webbing clothes moths, the drugstore beetle, the development of carpet beetles, and silverfish were the main pests, and baker Peter^[3] surveyed 25 species of cultural relic pests in the United Kingdom—the book lice, silverfish, woodlice the largest number, followed by the carpet beetle, clothes moth, spider beetle, etc. Cultural relics of pest control methods also have a lot of research, both chemical method: pesticides spraying and fumigation method^[4], also physical method: frozen insecticidal method^[5], low oxygen insecticidal method^[6], microwave insecticidal method^[7], and other physical insecticidal methods, as well as biological protection methods such as application parasitic wasps^[8], and insect pheromone traps, etc. In addition, scholars are also exploring the changes of insect damage to cultural relics caused by climate change^[9, 10] in order to adopt more stable and effective methods to control the damage to cultural relics. Since the 1980s, the IPM concept has been widely adopted by museums in the prevention and control of pests^[11] and has begun to integrate a variety of control methods rather than a single sampling method. The study of the source and occurrence dynamics of pests is the basis of taking comprehensive control measures.

The Hall of Mental Cultivation was built during the reign of emperor Jiajing of the Ming dynasty. It had a very special status in the Forbidden City, mainly because from the Qing emperor Yongzheng, until the last emperor

Puyi abdicated, it was the political center of the country. Eight emperors lived and ruled here. Because of its special political status, there are lots of precious cultural relics in the Hall of Mental Cultivation. In the late Qing dynasty, the furnishings in the Hall were up to more than 780 pieces, including paintings, textiles, wood and other organic cultural relics. Although this area had been open to the public for many years, the interior of the hall had been closed, which was rarely visited by visitor. Because of the abundant resources of organic cultural relics and the quiet environment, causing the breeding of pests, resulting in the destruction of precious cultural relics. In order to reduce the damage of pests, the species of main pests of cultural relics, occurrence mechanism and population dynamics in the Hall of Mental Cultivation have been investigated and studied for nearly three years. The mechanism and population dynamics of major pests were analyzed, and comprehensive control measures were obtained for reference of cultural relic conservation workers. On the other hand, it can let more scholars know the pest population in Chinese historic buildings.

Layout of the Hall of Mental Cultivation

The Hall of Mental Cultivation is located to the west of the central axis of the Forbidden City, covering an area of 5000 square meters, the whole area has many rooms and functions. The main hall is an I-shaped hall, and the front hall is partitioned into six rooms (Ⅰ ~ Ⅵ), where the emperor govern, rest and recreat. The famous queen mother of the late Qing dynasty Cixi "Holding Court Behind A Screen" in the late Qing dynasty also happened here. Comparatively speaking, west warm pavilion is more complicated, partition is more. Divided into before and after room, the west of before room is the famous "Room of Three Rare Treasures" (Ⅲ), the original was the place where the emperor read and rest. The Qianlong emperor of the Qing dynasty named it, because of three famous calligraphy and painting –"Bo Yuan Tie" by Wangxun, "Kuai Xue Shi Qing Tie" by Wang Xizhi and "Mid-Autumn Tie" by Wang Xianzhi. The back room (Ⅵ) is called buddha room or fairy building as a whole, and it stores many beautiful Thangka and Buddha statues. On the first floor, there are Changchun book house and No Fatigue room, which are connected to Mei room (Ⅴ).

There are five rooms in the Back Hall, all with beds, where the emperor can live at will. Auricular chambers are on both the east and west sides of the back hall: the Hall of Swallows Happiness, the Hall of Manifesting Obedience, for the Queen and Concubine. There are still some enclosures rooms for concubines and other people live temporarily.

Methods

Insect Pests Investigation

This investigation concerns the quantity and species of pests. Purely trapping traps are passive and only trap passing pests in their active area, so the number of traps and control effect is limited. Insect pheromones can actively attract pests and make them more efficient. Even insect activity areas have migrated, it can also achieve trapping. Several studies have indicated that insect pheromones can induce target pests and significantly improve the efficiency of trapping^[12-14]. Therefore, the investigation using British Russell IPM pheromones production, which can trap the black carpet beetle, the varied carpet beetle, the case bearing clothes moth, the webbing clothes moth and the trap bait of silverfish.

Count and clean the pest species and quantity of the monitoring site every month, and replace the traps every two months to ensure the effectiveness of all kinds of pheromones.

Fumigation

Before investigation, serious pests had already existed in the Hall of Mental Cultivation. In order to better detect the source, mechanism and dynamic changes of cultural relics pests, and to explore the appropriate control time, after disease investigation and collection of pest samples, sulfuryl fluoride fumigation was conducted in the whole area from April 15 to 17, 2017. The concentration of sulfuryl fluoride is 50 g/m³, and the area with a large number of pests will increase by 10%.

Material identification

The most severely damaged relics in the Hall of Mental Cultivation are carpets, felts, and rafters used as partitions. It can be seen that these materials are the source of attracting pests, and identifying these materials can provide a basis for selecting alternatives. Fortunately, these materials can be identified by microscopic observation.

The wood samples were immersed in water for 24 hours and then immersed in PEG 1500 solutions of 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80% and 90% successively, at 60°C for 6 hours. Use melted PEG1500 embedding. The slices were dyed with Safranin.

Technology of high performance liquid chromatography-time of flight mass spectrometer (Waters H-Class UPLC G2-XS QTOF MS) can analyze dyes and other organic components of dyed carpet ^[15]. Pre-treatment conditions for the test: Cut a small amount of carpet samples, put them in 1.5 mL liquid phase vials, and add 1 mL of methanol / formic acid / 10 mM EDTANa₂ (85/5/10, V / V / V) mixed solvent. After ultrasonic extraction at 75 °C for 45 minutes, transfer to a 1.5 mL centrifuge tube and centrifuge at 12000 r / min for 6 minutes. Pick up the supernatant, pass through a 0.22μm filter, and blow dry under nitrogen, then re-dissolved with 200 μL acetonitrile/ Water (1/1, V / V) mixed solvent, waiting for testing on the machine.

Since most dye components can obtain better ionization in the negative ion mode, the negative ion mode is selected and the LE correction is utilized, and its m / z is 554.2615. Specific parameters: Column BEH C18, column temperature 40°C, flow rate 0.3 mL/min, voltage 2.5 kV, injection volume 1μL. Mobile phase: water in channel A, acetonitrile in channel B. Gradient elution procedure: the initial concentration of 90% of A, 10% of B, after 8min, becomes 10% of A, 90% of B, keep for 2.5 min and return to the initial state, which lasts 13 min.

Record of temperature, relative humidity and illumination

Insects are poikilothermic animals, and there is not any mechanism for regulating body temperature. Therefore, pests can move and complete development and reproduction only when the ambient temperature meets their conditions. Humidity is equally selective for the types of pests. Under high humidity conditions, dry pests are rarely found, and vice versa. Light is also very essential for the survival of insects. Some insects avoid light, so some places where with sufficient light are not easy to find them. Therefore, the recording of physical factors such as temperature, humidity, and light can help find pest prevention measures. In the

investigation, HOBO UX100-011 was used to record temperature and humidity, and ELSEC 765 UV + logger was used to record light.

Results

Pests Situation in the Hall of Mental Cultivation

Species and population dynamics of cultural relics pests

Before the trapping, investigate the pest hazards in Hall of Mental Cultivation, record the degree of pest damage to cultural relics, and grasp the species of pests and their active areas. The previous investigation showed that the distribution of pests was uneven, as showed in Fig. 3a. As a whole, the damage to the west of the central axis was heavy, while the east side was relatively intact. Based on the damage of on-site woolen fabrics, silk fabrics, paper relics, and timber structures, it was presumed that the species of pests should be carpet beetle, silverfish, clothes moth, bark beetle, and powder post beetle. Based on this, trapping investigation plan was formulated, Fig. 2.

After fumigation, pheromone traps were utilized to monitor the pests. Monitoring began in July 2017 and completed in December 2019. The monitoring area included the main hall and the eastern and western side halls. Enclosure room and duty room are set as a buffer zone, Fig. 3b.

So far, our investigation results showed that after fumigation, pests can also appear slowly, even in the presence of buffer zones. There were more than ten species of insects, such as carpet beetle, booklice, silverfish, ground beetle, woodlice, scutigera, spider, spider beetle, Katydid, powder post beetles and clothes moths, among which the cultural relics pests were carpet beetle, booklice, silverfishes, spider beetle, powder post beetle and clothes moth. The rests were live herbivores or small carnivorous insects that do not directly harm cultural relics. However, the presence of their carcass will attract the carpet beetles to eat, increasing the security risk of cultural relics. Among the cultural pests, the quantity of carpet beetle was the highest, with a total of more than 1,300 in two and a half years, followed by the booklice, two of them make up 79% of the total. Silverfish, powder post beetle, spider beetle clothes moth appear infrequently, the quantity was still less than 10, as showed in Fig. 4.

The captured carpet beetles were mainly larvae, and adult seldom appears. Accordingly, this phenomenon suggest the potential that the pheromone of carpet beetles should be aggregate pheromone. Compared with the sex pheromone that only affects single sex and sexually mature individuals, the aggregate pheromone is secreted by some insects and acts to gather the different individuals for food and labor. The trapping number is more and it can be a better protection of cultural relics.

The distribution of pests was extremely uneven, the number of buddha room was the largest, and the number of carpet beetles accounted for a large proportion, more than 1000, while the remaining 300 carpet beetles were mainly distributed in the west warm pavilion, the main hall and the east warm chamber. The second was the central bay, the number of carpet beetle and booklice was at most. In the western side hall, the number of woodlice and ground beetle was more, while the proportion of woodlice in the western side hall is

larger. There were many species of insects in the back hall, the Hall of Swallows Happiness and the Hall of Manifesting Obedience, but the quantity is small.

There were two species of carpet beetle that been trapped, the first is *Anthrenus picturatus hintoni* Mroczkowski, which can be found in most provinces of China and mainly damages woolens, feather products, animal materials and specimens. The old mature larvae overwinter and the adults fed on pollen nectar, Fig. 5a. The second, *Thylodrias contractus* Motschulsky, is distributed in most provinces of China. The larvae can damage a variety of animal products and animal specimens, as shown in Fig. 5e.

The trapped booklice was *Loposcelis bostrychophila*, which is widely present in many kinds of storage. This booklice is extremely small and can reproduce at an amazing rate, making it difficult to eliminate—so it can destroy furnitures, clothes and books on a large scale. So—booklice should be killed in time if finding, Fig. 5b.

Lyctus brunneus Stephens is one kind of powder post beetle, that widely distributed in China. It feeds on dry, high-starch wood, furniture, bamboo and traditional Chinese medicinal herb etc. Both adults and larvae live in wood—but adults need to leave the wood when they mate, so we can capture it. Figure 5c.

Tinea pellionella mainly distributed in central China and Beijing, Tibet and other places. It damages textiles and causes regular holes. It also damages articles containing keratin such as rabbit hair, wool and chicken hair, as showed in Fig. 5e.

Two species of spider beetles were caught in the investigation, one was *Gibbium aequinoctiale* Boieldieu, Fig. 5f—the other was *Ptinus japonicus* Reitter—Figure 5 g. Both of them are distributed in most provinces of China, feeds on dried or rotting animal and plant materials, including flour, grain, seeds, fur, wool, Chinese medicinal herbs and animal specimens.

There is a wide food range of *Ctenolepisma villosa*, including grains rich in protein, sugar and trace elements, Chinese medicinal herbs, photos, paper, paste, cotton, animal fur, silk fibers, and even organic matter in indoor dust. It like dark and humid environment, mostly hidden in the gap of the host during the day, and comes out at night to forage, Fig. 5h.

Population dynamics of main cultural relics pests

After the fumigation, a large number of carpet beetles and booklice were trapped in August of that year. We consider the possibility that: there were still insect sources around the Hall of Mental Cultivation, so pest control should not only consider the isolated specific areas, but also consider the impact of the surrounding environment as a whole. Second, sulphuryl fluoride is a good fumigating insecticide, but several studies have demonstrated that sulphuryl fluoride does not work well on eggs^[16, 17]. Therefore, the failure to kill the eggs may be the cause for the short-term growth of pests.

Among all the cultural relic pests trapped, the number of them was very small, except for the carpet beetle and the booklice. Therefore, this paper focuses on the changes of the quantity of the carpet beetle and the booklice.

Depending on the investigation data in 2018 and 2019, it was clear that the carpet beetles appeared in the earliest February, and the number increased rapidly from March to May. From June to August, the number of carpet beetle was the largest, and the peak reached in July. The change in the number of carpet beetle almost determined the changing trend of the total pests.

Insects pheromone has been a useful biological weapon for controlling harmful insects in recent years, but like other biological control methods, the effect appears slowly, and it is often effective in the second generation. Comparing the data of the carpet beetle trapped in 2018 and 2019, the number had dropped significantly, with the peak in July falling from 250 in 2018 to 137. It can be seen that the application of pheromone has a control effect on the carpet beetle.

More booklice appeared in 2017, compare to 2018 and 2019, and were found from March to October. The quantity fluctuations throughout the year are not significant. But beyond that, we cannot infer more information of booklice population dynamics, mainly because there are no pheromone substances of booklice in this investigation.

Occurrence Mechanism Analysis of Cultural Relic Pests

Food

There are numerous species and large numbers of pests in the Hall of Mental Cultivation, mainly because they have abundant food resources. Carpet beetles like woolen fabrics, while clothes moths prefer silk fabrics. Silverfishes and booklice are important pests of books and archives. Powder post beetles, bark beetles and anobiid beetles can cause serious damage to wooden buildings. Hundreds of woolen fabrics, silk fabrics, books, calligraphy painting and other cultural relics displayed in the Hall of Mental Cultivation have become food for these pests, and have a strong temptation to the pests. Tabel 1.

Table 1
Classification and quantity of paper and textile cultural relics (unit: piece)

	Paper cultural relics		Textile cultural relics					
	Calligraphies and Paintings	Books	Felts	Curtains	Lazybacks	Quilts	Bed sheets	Thangkas
Western warm chamber	0	0	0	0	0	0	0	0
Central bay	6	35	3	43	1	0	0	0
Eastern warm chamber	24	0	11	13	15	1	1	0
Back Hall	33	0	20	17	8	7	0	0
Hall of Swallows Happiness	6	0	8	1	8	2	1	0
Hall of Manifesting Obedience	17	0	11	4	0	2	1	0
Buddha room	6	0	2	1	6	1	1	17

The investigation results showed that a large number of carpet beetles were gathered in the Buddha room, the quantity of which was set at three times the sum of other areas. Unlike other areas, the entire second floor of the hall is carpeted, including red and yellow carpets. Both carpets were badly bitten by carpet beetles. Microscopic observation of the carpet fibers of the two colors has obvious scales and a black medullary cavity in the middle, consistent with the typical characteristics of wool^[18], Fig. 7.

In the court, Chinese medicinal herbs were usually employed to treat paper or fabric, which has achieved the purpose of insect repellent¹. In order to assess whether the carpets have been treated with Chinese medicinal herbs, they were analyzed by liquid chromatography. It can be known from the analysis that the two carpets were only dyed. Among them, Brazilian hematoxylin and protosappanin B were detected in the red felt. These components are typical components of sappan dyestuff. And the yellow carpet, safflower yellow A, a unique component of safflower yellow, was detected, so the yellow carpet was stained by safflower yellow, Fig. 8. No insect repellent component was detected in the two carpets. The above findings raised the intriguing possibility that the dyes don't have any insect repellent effect, however, it remains unknown whether the dyes attract pests.

In addition to woolen carpets, the most serious bites were wood grates employed as partitions. The buddha room and the western side hall are more serious. The growth cycle of the grates sample is obvious, and the early wood to late wood changed slowly. Lateral section tracheid are square, rectangular and polygonal.

Axial thin-walled tissues are scarce and scattered. Wood rays on the tangential section are small rows, 7–15 cells high, and some of the ray cells contain dark resin. The axial tracheids on the radial section have obvious bordered pits, and the cross-field pits are fir-shaped, with one or two. Synthesizing all aspects, the selection of the grates is Pinaceae Lindl (Pine Family) Abies Mill (Fir) ^[19].

Fir is an important coniferous material, that the bark beetle prefers. The bark beetles feed the bark or xylem and form a tunnel for branches. A large area of the grate surfaces of the buddha room and the west side hall showed trace bitten by bark beetles^[20].

During the investigation, it was found that the carpet beetles not only fed the silk and wool textiles, but also prefer the dead insects they collected as food, Fig. 10.

Environmental factors

Temperature, relative humidity and light

Beijing climate is located in warm temperate zone and semi-humid and semi-arid monsoon climate. The average annual temperature in the plain where the Forbidden City is located is 11°C~13°C, and the maximum annual extreme temperature is generally between 35°C and 40°C, which is appropriate for many kinds of insects. The interior of the Forbidden City is sheltered and buffered by buildings, so the temperature in winter is higher than that outside. According to the monitoring, the lowest temperature of the year is no more than -5°C. This low temperature contribute to pests survive the winter safely, Table 2. The high temperature in summer is higher than 25°C for a long time, which is conducive to the rapid reproduction of pests.

The distribution of pests is also intimately related to the light. Most cultural relics pests like to live in the dark, such as various beetles, and some have phototaxis in certain life stages, such as termites, which need to fly-off, mate and establish new nests in the breeding period. Because of the compact layout, the overall light is insufficient, especially the buddha room, the light is dim, most of the partition room is completely black, the number of carpet beetle in this kind of dark environment is more, because the larva of the carpet beetle is fond of dark environment, minimize this dark space is also an effective method.

Table 2
Environmental factor and the number of carpet beetle in main hall

		Temp/°C			RH/%			Light/lux		Number of carpet beetle
		Max	Min	Avg	Max	Min	Avg	Max	Min	
Central bay	1	33.3	-3.8	15.2	91.9	12.8	45.3	1.5	0.8	166
	2	32.8	-4.9	15.1	90.1	14.2	45.2			
Western warm chamber	1	30.8	-1.8	15.4	86.4	18.4	45.6	39.9	6.4	8
	2	29.2	-0.6	15.3	87.2	19.6	47.3			
Eastern warm chamber	1	29.9	-3.8	15.1	86.3	18.4	45.4	208	2.6	26
	2	30.3	-2.0	9.1	86.0	15.7	45.2			
	3	29.9	-1.5	15.4	85.1	16.4	45.1			
Room of three rare treasure	1	30.0	-3.1	15.1	86.4	15.9	45.6	5.5	0	1009
	2	31.7	-3.0	15.7	78.6	20.0	43.8			
	3	33.2	-3.5	15.6	82.4	18.2	43.7			

Trees

There are 16 cypress trees in the Hall of Mental Cultivation, of which ten are *Sabina chinensis* Ant, located near the duty room, and two *Platycladus orientalis* Franco are on both sides of the Gate of Mental Cultivation. Most importantly, four *Sabina chinensis* were planted in front of the Hall of Swallows Happiness, next to the buddha room, Fig. 12. Not only that, there are two *Pinus bungeana* Zucc in the courtyard of the Palace of Enternal Longevity behind the Hall of Mental Cultivation, and then to the west there are five cypress trees in the courtyard of Hall of Supreme Principle.

In Beijing, the flowering period of *Pinus bungeana* Zucc is from April to May every year, the flowering period of *Platycladus orientalis* is also from April to May every year, while the flowering period of *Sabina chinensis* is earlier, starting in March and ending in April. Comparing with the development trend of carpet beetles, this is somewhat surprising since that the flowering period of these plants just corresponds to the rapid growth period of the trapped number. Coincidentally, the *Anthrenus picturatus* hintoni Mroczkowski spend the winter in the form of mature larvae, and when spring comes, the adults go out to gather honey to mate^[21]. Then return to the indoor to lay eggs where food abundant. Thus, it can be inferred that the pine and cypress flowers around the Hall of Mental Cultivation provided a rich source of nectar for the *Anthrenus picturatus* hintoni Mroczkowski, and it's helpful for them to mate and reproduce.

In addition, cypresses are also important hosts of bark beetles, for example *Phloeosinus aubei* Perris captured in other areas in the palace museum, which is one of the most important destructive pests of

cypress, pine and fir in Beijing^[22]. It is also an important pest that damages the wooden members of the building.

¹Archives of the interior affairs office of the Qing palace 卷45 volume 1783 A.D.

Discussion

Population characteristics of cultural relics pests

The abundance of pests in an area is not determined by a single factor, but by the combined action of food, vegetation, temperature, humidity, light and other environmental factors^[23]. There are many organic cultural relics in the Hall of Mental Cultivation, suitable temperature and humidity conditions, many dark rooms, limited open areas, and several pine and cypress trees in and around the courtyard. All these factors jointly determine the diversity and quantity of pests.

There were more than ten species of insects been capped in the Hall of Mental Cultivation. As the dominant species, carpet beetle was also an important cultural relic pest. Other cultural relics pests were booklice, silverfish, clothes moth, powder post beetle, spider beetle, etc. but the number was limited. In addition, there were some species of sanitary pests: ground beetle, woodlice, katydid, scutigera, scorpions, etc.

The environment of the investigated area is complex, resulting in uneven distribution of pests. The front hall is spacious, but the back hall is dense. There are both trees and wells on the west side, which makes the western side more humid than the eastern side, so there are more insects in the western side hall, such as woodlice and ground beetles. On the eastern side, especially in the Hall of Manifesting Obedience and its enclosure, pests are rarely found.

The buddha room is a partition on the north side of the west warm chamber. There is only one window on the north side, what's more, because of the existence of the Hall of Swallows Happiness and the back hall, the interior is very dark. In addition, there were four cypress trees in the west side adjacent to the house, and no person entered for a long time, leading to a large number of pests, such as carpet beetles and bark beetles.

Insecticidal measures and control time

Various technical methods are available for killing cultural relic pests in ancient buildings. Based on the principles of safe and efficient, sulfuryl fluoride fumigation is still the main choice for Chinese cultural relic pest control. Through the investigation and research after the fumigation, it was found that, even in the serious areas to increase the sulfuryl fluoride dosage, check the active pests were killed, after a short time, the carpet beetle and booklice still appeared. The foremost reason is that the Hall of Mental Cultivation is not isolated, communicates with the surrounding environment. Without pest control measures, pests can still enter and forage. Secondly, fumigation time was not well chosen. The fumigation time was at the end of April, which was during the flowering period of cypress trees outside the hall, the adult of *Anthrenus picturatus* hintoni Mroczkowski were still looking for honey to mate. Moreover, April to May was the period of rapid increase in the number of trapped carpet beetle, which is the peak of egg hatching, and the eggs have a strong resistance to sulfuryl fluoride. Thus the surviving eggs were the source of active carpet beetles after

fumigating. Therefore, the appropriate fumigating time is critical. First, the number of adults that go out should be as few as possible. Second, we must make sure that the spawning and egg hatching periods are staggered. Third, we must do regional control to reduce the spread of surrounding pests. The analysis on dynamic of the number of active individuals in a year has important guiding significance for the control opportunity. In the Hall of Mental Cultivation, the number of active individuals (dominant pest: *Anthrenus picturatus hintoni* Mroczkowski) increased rapidly from March to April, and July and August were the biggest period. Thus, summer is the best time for fumigation (mainly for the carpet beetles). During this period, the eggs had hatched, larvae were the main stage, the quantity of activity individuals was the largest, and the best fumigation effect can be achieved.

Except the carpet beetles, silverfishes, powder post beetles, and spider beetles were equally trapped. The number of these pests was not large, but only sporadic. This was closely linked to their living habits. The above pests live indoors almost all their lives and rarely go out. Therefore, fumigation killed these pests relatively thoroughly. Under the effect of inventory of cultural relics and buffer area, a very small number of external individuals spread to the detection area. It also explained why the timber structures were seriously damaged by bark beetles, but they were not trapped.

Insect pheromones are information substances secreted by insects and acting on the same species of insects or other species of insects. Commercialized pheromones are mainly sex pheromones, aggregation pheromones and alarm pheromones. Sex pheromones and aggregation pheromones have lure effect, while alarm pheromones have repellent effect. The use of trap pheromone can not only monitor the situation of insects, but also have the effect of trapping and killing, so as to control the number of pests. However, it should be noted that the use of pheromones to control pest population is a long-term process, often showing effects in the second or third generation, and the longer breeding period is slower. The number of the main pest-carpet beetle was significantly reduced in 2019 compared with that in 2018, mainly because there was only one generation of *Anthrenus picturatus hintoni* Mroczkowski in a year. After the first generation was trapped, the breeding base of the next generation was reduced.

As mentioned above, the adult stage of the *Anthrenus picturatus hintoni* Mroczkowski needs to fly outdoors and to collect pollen and nectar, so except fumigation, it can also reasonably utilize this period to spray chemicals to the flowering plants from March to May. But it is necessary to pay attention to the selection of pesticides that are not sensitive to bees, so as not to kill bees by mistake and cause ecological damage.

Food

The Hall of Mental Cultivation is rich in organic materials, which are an important food source for pests. Cellulose and starch in calligraphy and painting, protein fiber of wool and silk etc are all the food that attract pests. In order to reduce the attraction to pests, we should try our best to put the silk relics, wool felts and carpets into storage and replace them with synthetic fiber fabrics. It is also possible to use pheromones that are more attractive than food, to decrease the contact chance between pests and cultural relics, and to check regularly to avoid damage.

In addition to the organic movable cultural relics, the wood grates were the most serious damaged inside the hall, especially the buddha room. According to the damaged symptoms, it can be judged that the grates were

bitten by the bark beetle. The material of grates was identified as fir, a kind of softwood that the bark beetles prefer. In the process of repairing, the seriously damaged grates should be treated with targeted pest control measures, or replaced with hardwood that the bark beetles do not like. However, it should also be noted that the powder post beetles were also trapped which like to eat hard wood with high starch content^[24], so should be replaced by wood with low starch content or treated with reduced starch content^[25].

One more thing to note, the existence of sanitary pests has no direct damage to the cultural relics, but their carcass can become an important food source for the carpet beetles^[26], indirectly damaging the cultural relics. It can be seen that the timely replacement of the trap is very important and necessary.

Environmental factor

First of all, insect activity is closely related to temperature, and the lowest cultural relic in the Hall of Mental Cultivation is -5°C, and the highest is not more than 30°C. The temperature not only satisfies the safety of pests overwintering, but also satisfies the rapid reproduction in summer. In addition, under high temperature conditions, the greater the consumption of pests, the greater the threat to cultural relics^[27].

Secondly, the presence of wells increases the moisture in some houses, providing water requirements for wet-loving pests.

Thirdly, the existence of cypress trees provides a source of nectar for pests and an intermediate host for bark beetles, but also with the role of shading, reduces the indoor brightness, inhibits the loss of water.

But beyond all that, the buddha room and other areas are not open to the public for a long time, the quiet and dark environment is also conducive to the gathering of pests.

The emphasis study of these environmental inducements can help us to eliminate the factors that make pests accumulate, destroy the environment where pests live, and find reasonable comprehensive ways to prevent pests.

Conclusion

The Hall of Mental Cultivation played an important role in the Forbidden City. It was first used as a temporary resting place for the emperor. Since Yongzheng emperor, it replaced The Hall of Heavenly Purity, as the place where the emperor lived and governed. The hall of Mental Cultivation is not only a single building, but also refers to the whole area after entering the gate of Zunyi. In this area, there are side halls, back halls, enclosed rooms, wells and trees, which not only have a superior architectural layout, but also enrich the ecological environment, which is a good representative for studying the pest occurrence law in the Forbidden City. It also has definite reference value to the investigation, analysis and control of cultural relic pests in Beijing and even the ancient buildings in north China.

Generally speaking, the pests of cultural relics in ancient buildings are not single, but diverse. So we must adhere to the principle of Integrated Pest Management and adopt various technical means to control the number of pests. The Integrated Pest Management is based on the study of the source, dynamic and

environmental factors of pests. In this paper, the Hall Mental Cultivation in the Forbidden City as the object, analysis is carried out in the above directions, find the appropriate time for chemical control exactly, as well as other reasonable control methods. It is of great practical significance to the protection of ancient buildings and cultural relics inside the Forbidden City.

For example, it is best to choose the time when the number of pests is the largest, during that time fumigation can achieve the destruction of pests in the building, in order to ensure killing as many active individuals as possible, and stagger the egg stage, Chemical sprays, on the other hand, can be used to kill the adult insects for collecting nectar and mating during periods of rapid growth, the flowering season of outdoor cypress trees. A variety of organic cultural relics with a large number satisfies the energy needs of pests. They should be put into storage as far as possible to avoid undisturbed exhibition in the ancient buildings, if policy permits. Measures such as improving indoor temperature and humidity and reducing shade from trees can also reduce the risk of pests.

Abbreviations

IPM: Integrated Pest Management; PEG1500: Polyethylene glycol; UPLC: high performance liquid chromatography; QTOF : Hybrid quadrupole time-of-flight mass spectrometer MS: mass spectrometer; LE: Leucine enkephalin; Temp: temperature; RH: relative humidity.

Declarations

Availability of data and materials

All data generated during this study are included in this published article or are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Author contributions

Zhang Guoqing: the main person in charge of the investigation and analysis, responsible for the design and implementation of the investigation, the statistical analysis of data, and the identification of cultural relics.

Wei Le: participated in the organic component analysis of wool carpet.

Gu An: participated in the design and guidance of the investigation.

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Figures

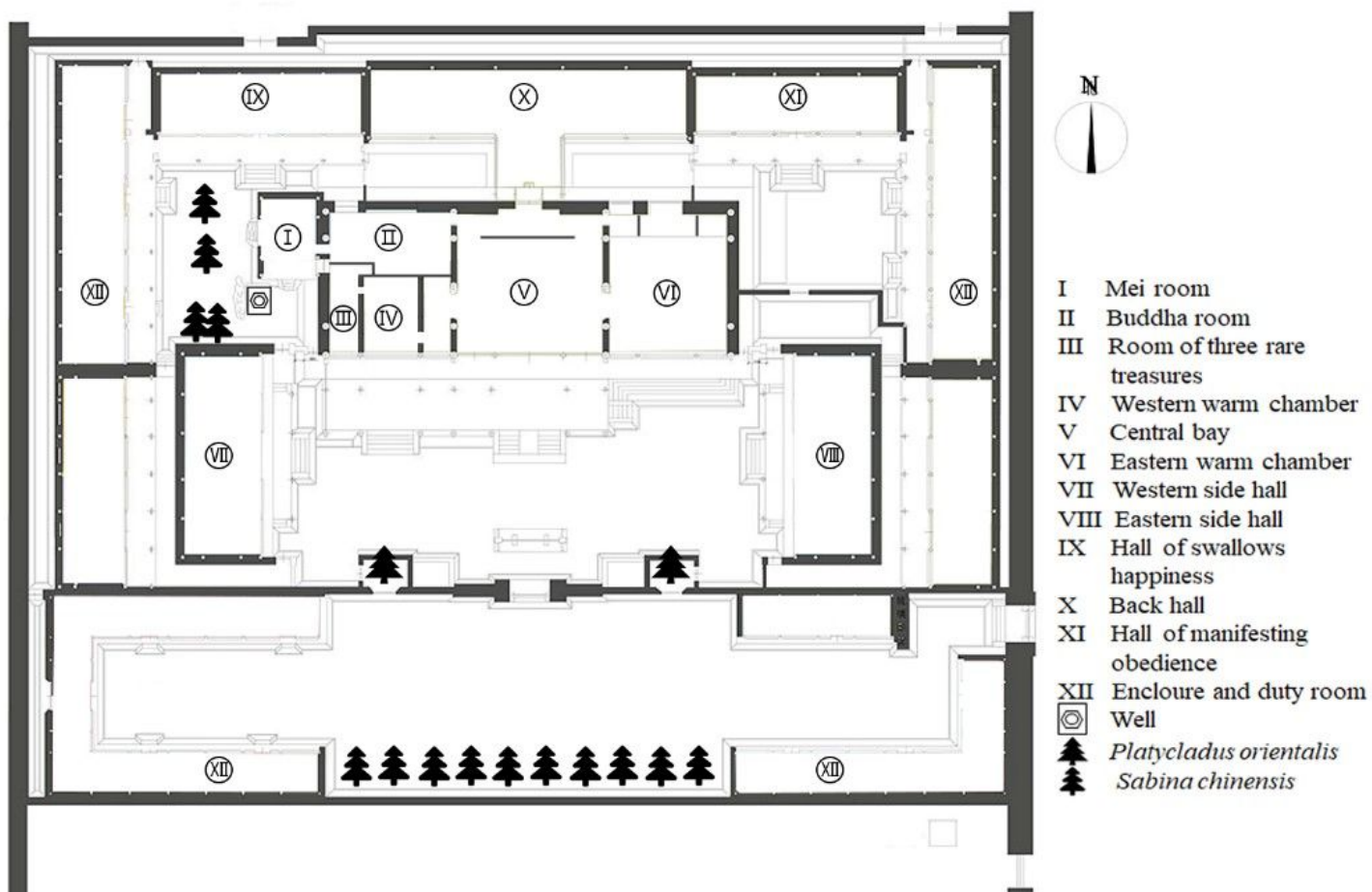


Figure 1

Overall layout of the Hall Mental Cultivation



Figure 2

Organic artifacts bitten by pests



Figure 3

Pest damage before fumigation (a) and monitoring area (b)

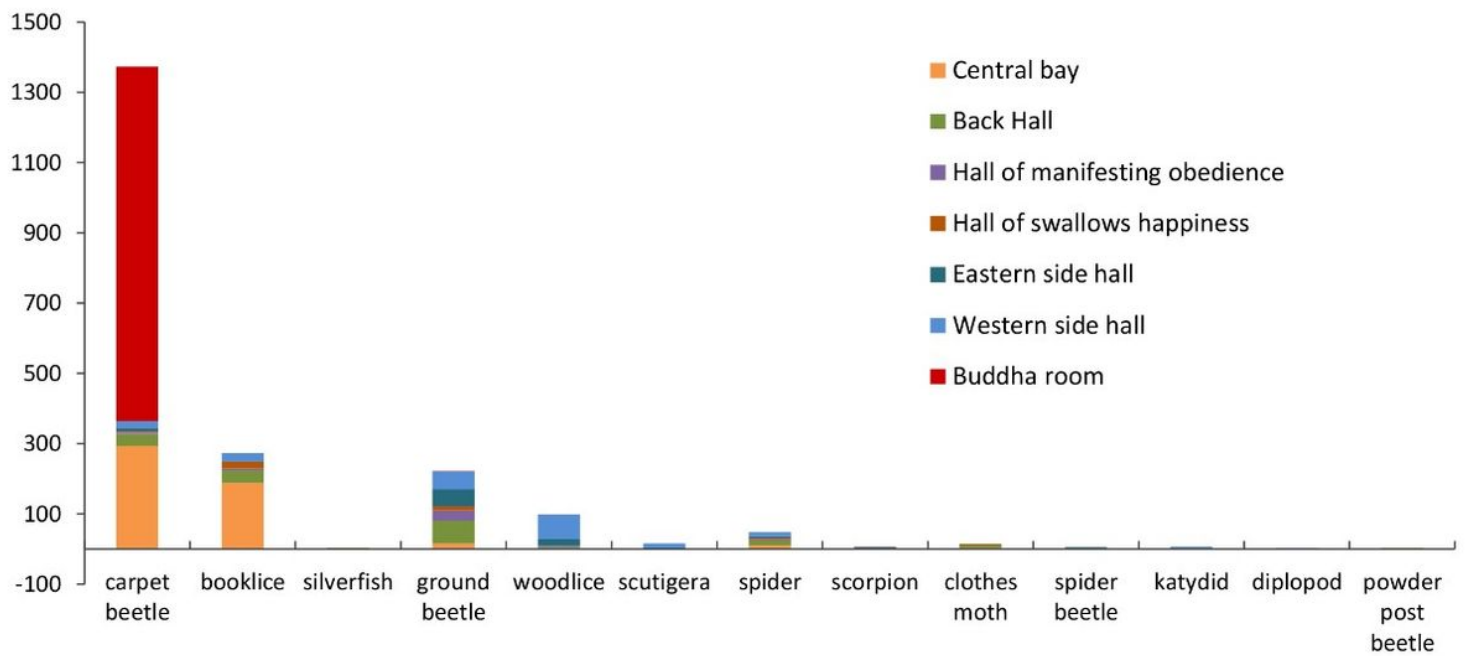


Figure 4

Quantity and distribution of pests



Figure 5

Main pests of cultural relics

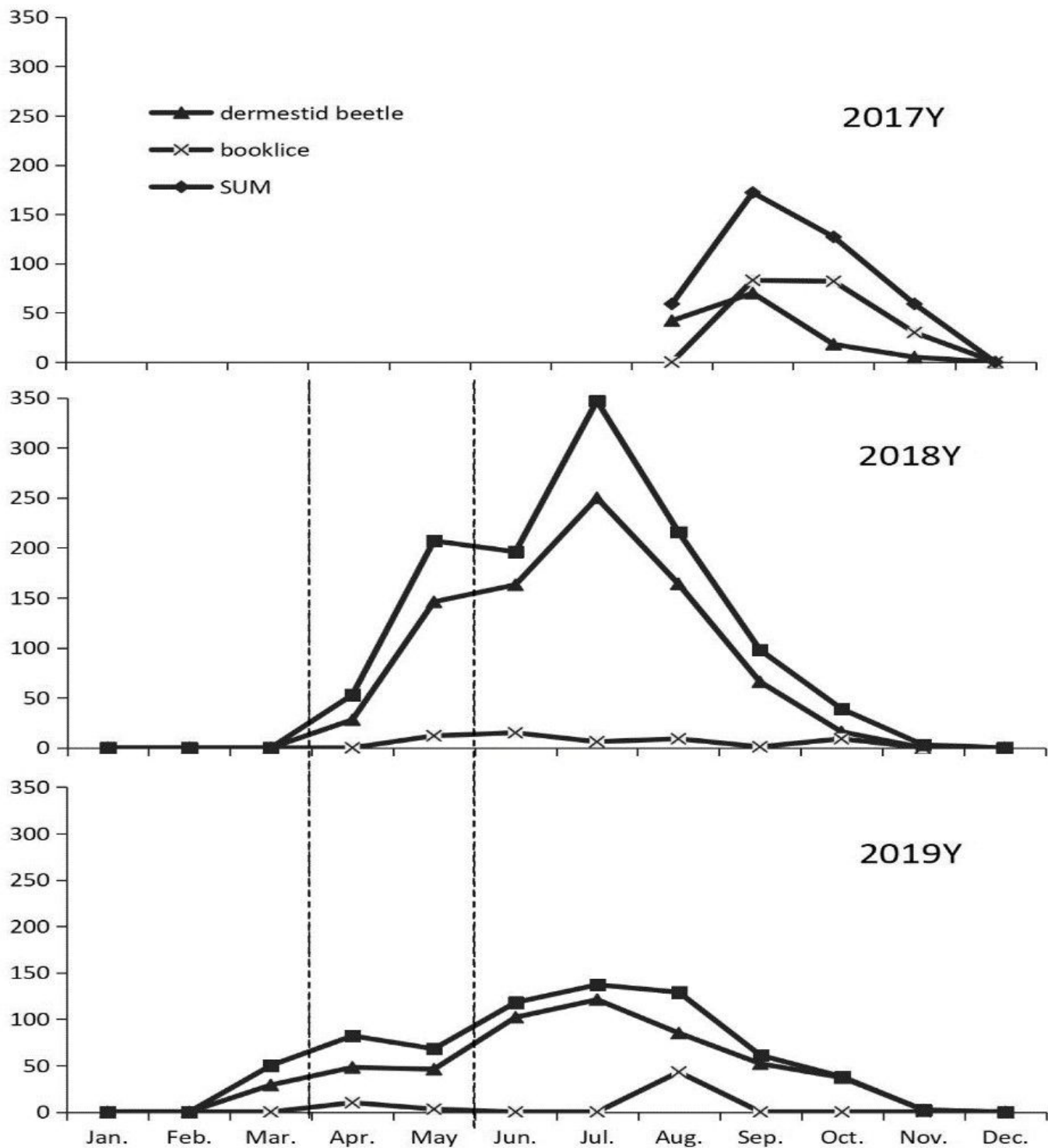


Figure 6

Monthly trapping quantity of main pests: 08. 2017 ~ 12. 2019

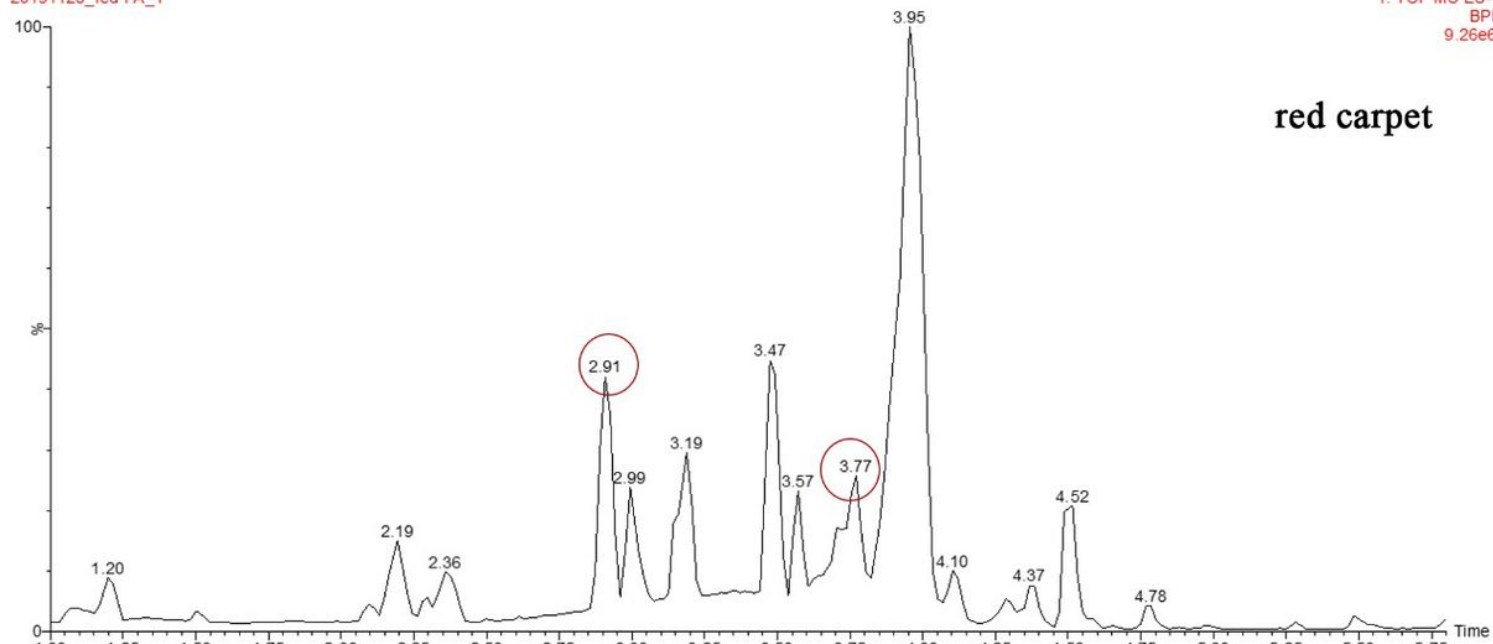


Figure 7

Carpets and their fibers 200× (a. red carpet; b. yellow carpet)

20191128_red FA_1

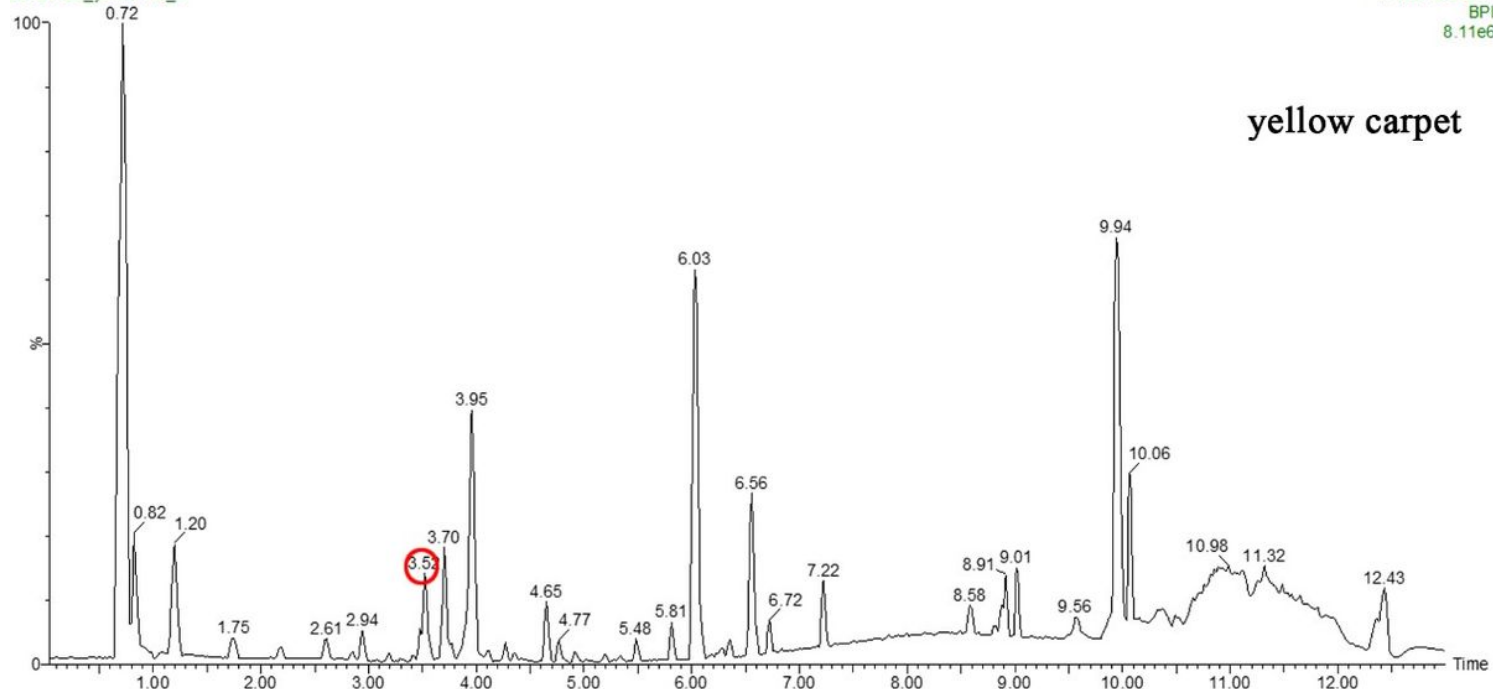
1: TOF MS ES-
BPI
9.26e6



red carpet

20191128_yellow FA_1

1: TOF MS ES-
BPI
8.11e6



yellow carpet

Figure 8

Liquid chromatography of organic components of wool carpets

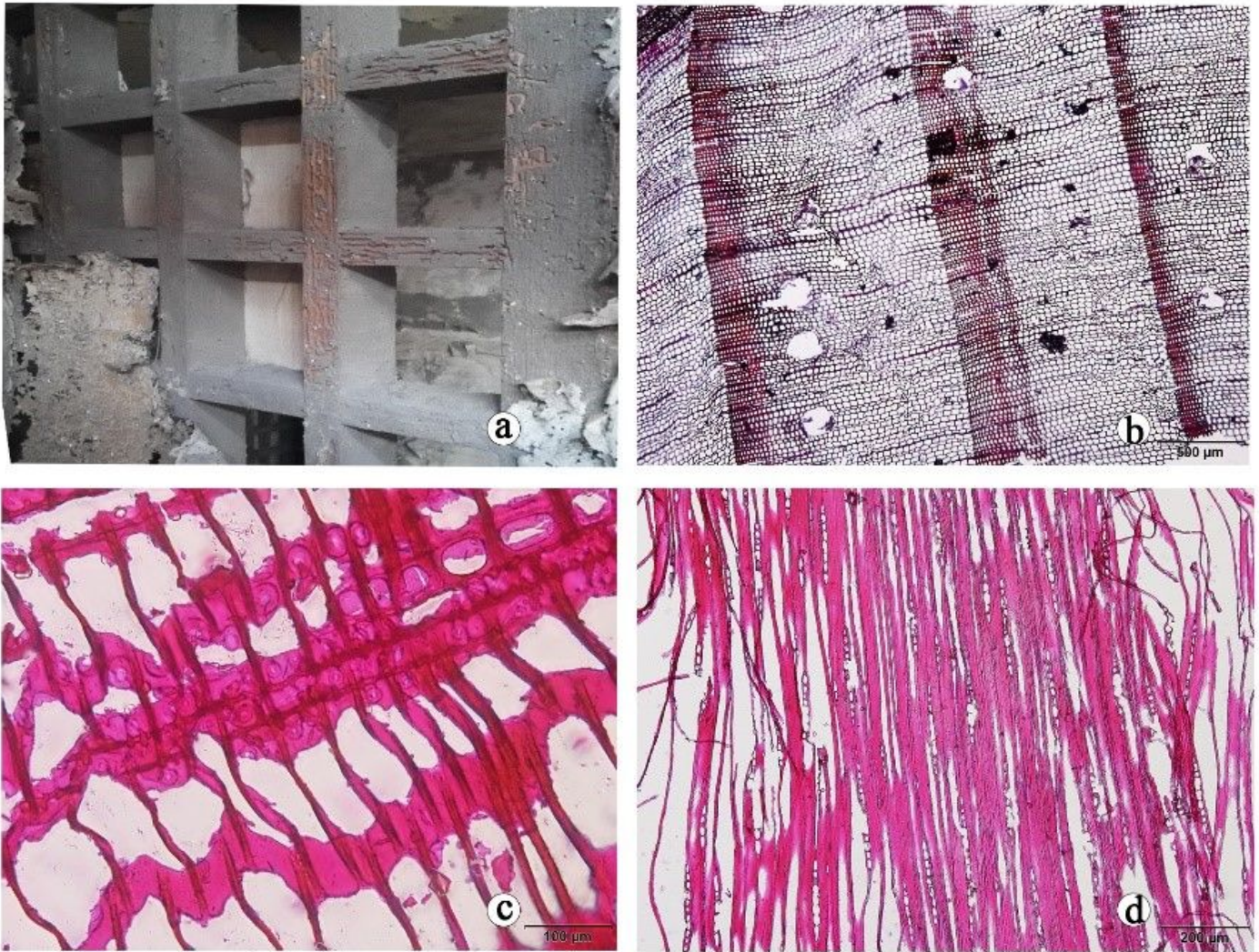


Figure 9

Section of wood grate (a sample, b lateral section 40×; c radial section 200×; d tangential section 100×)



Figure 10

Carpet beetles fed insect carcass

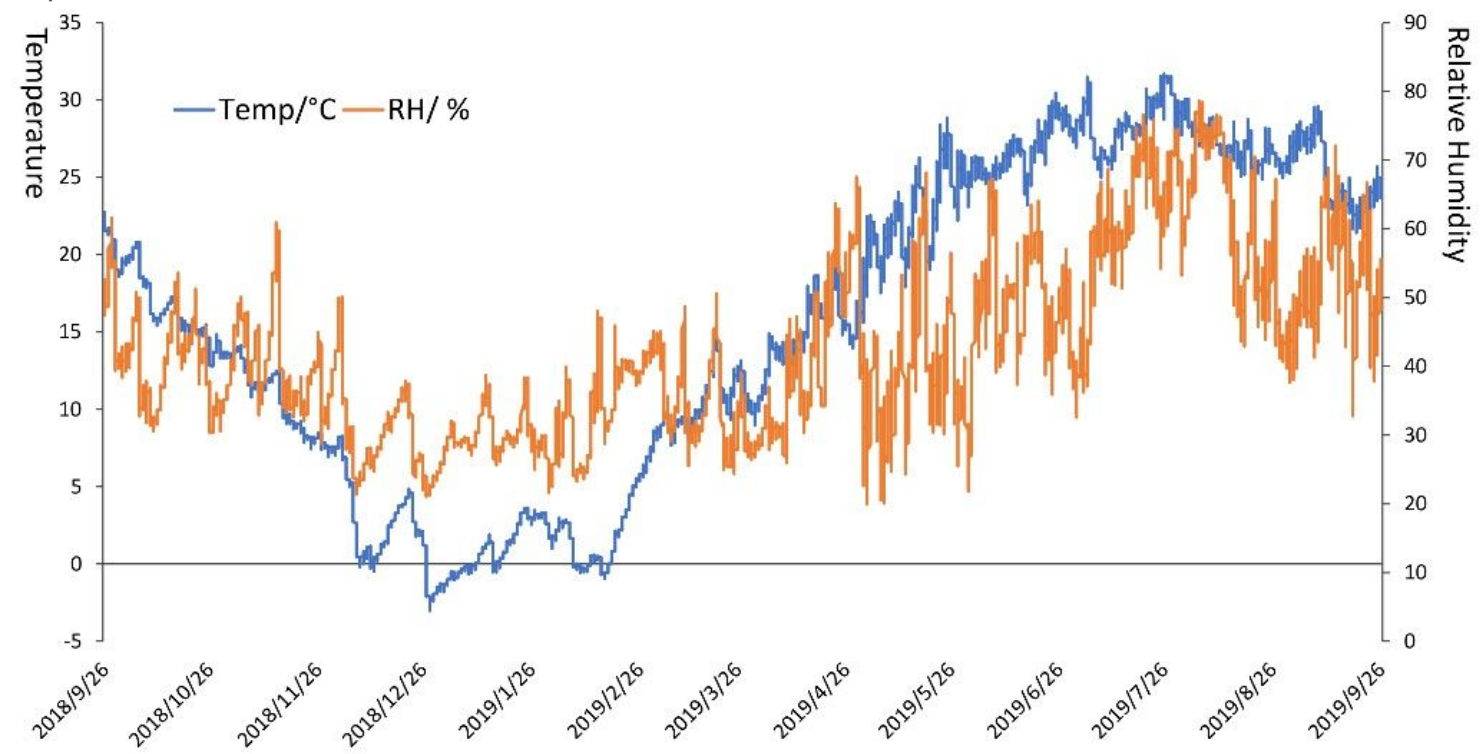


Figure 11

Annual temperature and relative humidity changes of buddha room



Figure 12

Cypress trees in the Hall of Mental Cultivation (b *Sabina chinensis* Ant, c *Platycladus orientalis*)