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A brief guide to museum pests control and their management

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Abstract
It is estimated that there are 900 million insects that come under the category of pests, such as beetles, ants, bees, wasps, flies, moths and butterflies, etc. Pests have been pestering people since ancient times. Historians believe that cave dwellers might have used smoke to get rid of mosquitoes. In 2500BC, it is believed that people warded off insects and mites by using sulphur compounds. In 1200BC, the Chinese came up with a revolutionary idea of controlling pests, for instance, they tackle the problem of pests like caterpillars and beetles by using an army of predatory ants. Henceforth, it can be seen that humans have always found several ways to combat the genuine problems of pests, but sometimes we behave imprudently while misapprehending all the insects and other living organisms as pests, which usually we don't like or want around to be. The problem of pests is found everywhere from houses to even heritage sectors. Most of our heritage areas like museums, cultural centers, libraries or, archives have innumerable precious and irreplaceable collections which are persistently at higher risk due to the infestation of pests. To prevent these damages the components of integrated pest management (IPM) program should be materialized with more advance tools and techniques. Consequently, a holistic program should be developed according to the needs of the building and the collections it owns, as well as the variety of activities that take place within the building. This program should be always considered as a process of evolution rather than a revolution.

Keywords: archives, cultural center, heritage, integrated pest management, museum, pests

Introduction
Most of the artifacts found in museums are vulnerable to deterioration from biological, physical, and chemical sources. Artifacts that consist of organic materials, such as fur, hides, linen, plant material, wood, wool, etc., get easily infested by a range of insects. Most of the heritage buildings have huge collections which are at high risk, such as archaeology, prints and drawings, contemporary art, folk art, fine arts, ethnography, books and archives, industrial and technical heritage, and natural sciences. The main factors of deterioration are the biological agents such as mold, insects, and rodents along with the environmental factors are effects of temperature, humidity, and light [1-4]. Previously there was widespread use of many toxic or persistent materials, such as mercuric chloride, arsenic, and DDT to prevent textiles and natural history specimens from being damaged by pests. However, several irreplaceable treasures have been lost over the years to pests responsible were carpet beetle (*Anthrenus spp.),* common furniture beetle (*Anobium punctatum*), and webbing clothes moth (*Tineola bisselliella*), etc. [5, 6].
The pesticides are health hazardous and long exposure to it can cause acute symptoms such as nausea, vomiting and breathing difficulty, etc. It can also cause chronic effects such as seizures, skin and eye irritation, and memory defects. Sometimes, many pesticides are carcinogens or suspected carcinogens in nature [7]. So for the long-term benefit of staff, researchers, and visitor's safety, well-organized integrated pest management (IPM) program can help in mitigating the excess of pesticides employed in the museums. Not only to the staff or users, but pesticides may as well cause damages to the collections in long term. So the reduced or moderate use of pesticides will aid to lessen the risk of chemical deterioration to objects as well [8]. The damages that may occur in collections are the deterioration of inorganic materials such as metal, stone, etc, deterioration of organic materials such as skin and skin products, herbarium, wooden objects, color change of papers, textiles, inks, and pigments as well as the stain development on the object from the surface or due to humidity. The success of the IPM program depends on each part of the program being properly planned, adhered to

and supported at all levels. Hence, a well-executed and organized IPM program cannot only prevent problems in its initial stage, besides that it will also lead to the effective usage of limited human and cash resources [9].

Need of IPM in museum

Integrated pest management (IPM) strategies have been developed and also seen to be implemented by many small and large museums, historic houses, galleries, libraries, and archives worldwide with successful results [10]. IPM is a term originally adopted to describe the development of pest control methods for fruit and cereal crops that do not rely on the regular and systematic use of pesticides [11]. The approach is one of using non-invasive methods to prevent or at least minimize the risk of pest infestation. The principles of IPM are monitoring, discouraging pests, modifying the environment, and targeting treatments that have been adapted for use with museums and their collections. IPM principles rely on the understanding of pest biology and the museum environment to keep pests away from the collections and facilities and to prevent them from being established. Typically, there are many facets to an IPM program that are all interrelated. The success of the program depends on each part of the program being properly planned, organized, adhered to, and supported at all levels, shown below in

The approach has considerable advantages regarding health and safety, being less harmful to both humans and the environment, also likely to be more cost-effective than a passive or reactive approach [12].

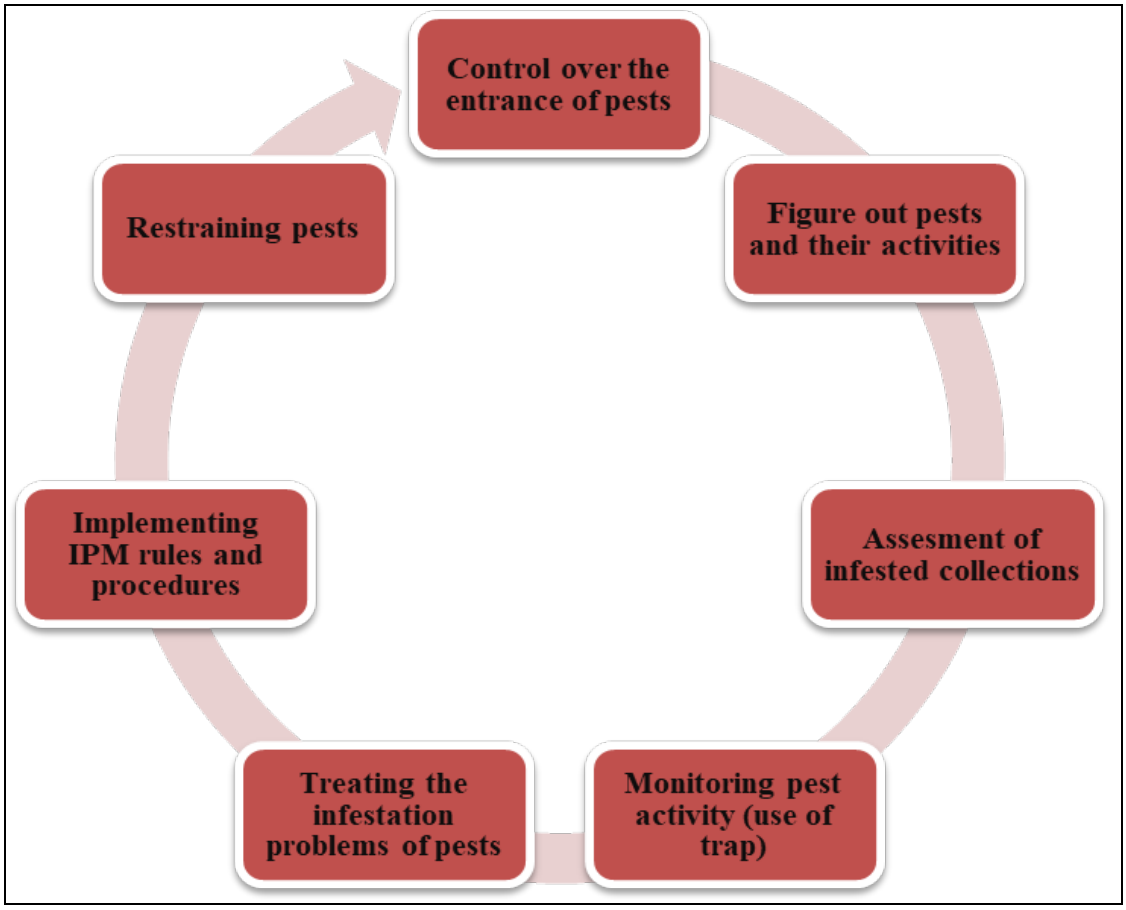

Fig 1: Represents the interrelation of principles of IPM for the control of insect pests in cultural heritage buildings

Sources of pest infestation in museums

The environmental conditions generally found in museums are warm, dry, and undisturbed, which provide pests with a suitable environment to live and breed. The objects themselves provide the pests with a food source and material to live. Furthermore, museums often include cafés and offices that contain food and waste, which encourage pests to stay. Often pests are introduced into the museum by the objects that have come from outside, like object/s taken on loan from other institutions, or object/s donated by members of the public. Pests can be unintentionally moved around the museum and offsite when objects and packaging materials are transported.

Common museum pests

The pests that directly damage museum collections are mostly moths, beetle, and rodent. However, a small number of other insects, such as silverfish, booklice, and woodlice, may also harm the objects. In addition to the direct damage to objects caused by the aforementioned pests, other animals, such as birds can indirectly cause damage to collections. Bird's nests, which are often found in roof spaces or chimneys, can encourage and sustain the population of pests by providing a food source and living accommodation. Pests can spread from one area to other areas effortlessly, as a consequence, they can remain and breed for a long duration. One or two pests in the museum may not necessarily cause problem. However, if the population of these museum pests is allowed to grow significantly, then damage to objects is far more likely to eventuate. Whence, it becomes indispensable to spot signs of pest activity by doing the regular monitoring of the areas contain collections (both on display and in storage) to understand the minor action of normal residents (pests).

Indicators of the pest activity
The four indicators of pest activity in museums or museum-like institutions are given below:

Live pests
The pests can be seen flying around, crawling on the floor, or actually on objects within the collections. It can also be traced out through the cast skins (exuviae) that the larvae of insects left attached to the object or around the object.

Dead pests and cast skins (exuviae)
The dead insect pests (moths and beetles) can be seen on the floors or objects, or through the insect's molts. Molting is the process through which insects can routinely cast off their exoskeleton during a particular time in their life cycle can be easily tracked down from the collections. In the case of rodent pests, the poisoned bait boxes have been used to catch mice. The mice that have come in contact with poison become dead can be found easily in the collection area, which is usually supposed to be inaccessible.

Insect waste
Generally, the pests themselves cannot be easily seen, but the signs of their activity can be detected from droppings, frass, and shed skins. Frass is the finer powdery material that insects pass after digesting organic materials. This may be visible around the objects such as storage boxes and packaging materials.

Damage to objects
The first sign of having pests in any cultural organization can be understood as they begin to damage objects and packaging materials. For instance, the possibility of rodent pests can be easily identified by proper examining of the object or surrounding area. Usually, mice may have chewed up paper items for bedding, or gnawed on wood to sharpen their teeth. In the case of moths and beetles, damages can be seen to the items like fur, feathers, animal skin, hair, bristles, animal wool, felt, silk, yarn, velvet, carpeting, insect specimens, parchment, and vellum or stuffed animals, etc. Particularly the different insects are feeding on different object materials, so they may not be the same in every gallery/store throughout the organization.

Routine monitoring of sensitive areas
A routine checkup should take place so that any increases in the pest populations are identified at early stage, and measures can be taken to eradicate them accordingly. To monitor the areas containing collections, pest traps can be placed in the sensitive and risk areas, and should be observed regularly for identifying the pest type. Further, it will facilitate the indication of the pest population in an area for being further investigation. Blunder or sticky traps and pheromone traps are the two fundamental types of traps that can be use for such purposes.

Tools for the pest identification
There are some useful tools available for assistance with monitoring and analyzing every stage of the pest. The tools shown below can be used in the identification of different pests.

Insect identification poster:
A helpful guide can be created for the identification of insect pests found in the historic houses and museums. This poster contains information to help in the recognition of insect pests, such as images of the insects and larvae with their sizes. There are some useful tools available for assistance with monitoring and analyzing every stage of the pest.

USB microscopes
These microscopes are a convenient source for the identification of rare and unrecognized species of pests. It can be simply plugged into a computer, and provide digital images of any pest findings, later can be added to a reference kit, or if required can be shared with experts (when the identification of pest finds to be difficult).

Hand lenses/magnifiers
A hand lens is an essential part of any field of naturalist's kit. The small magnifying lenses can be used in the identification of different pests.

Binocular stereomicroscope
For studying insect specimens a binocular stereomicroscope is recommended. It can provide magnification from 10 to 120 times, suppose to be an excellent tool for entomological purposes.

Compound microscope
This can be used in examining the micro slides with the magnification of 100 to 200 times or more preferably having phase-or interference-contrast capabilities so that weakly sclerotized materials can be examined in detail without the need for staining.

Scanning Electron Microscope (SEM)
The SEM produces an exemplary detail of structure at high magnification by providing three-dimensional images magnified by over 1000 times. This provides helps for identifying the features of extremely tiny insects, or larvae and eggs (life cycle) of insects, generally that can't be seen by our naked eyes.

Insect storage boxes (Dried insect specimens)
Insect storage boxes with display cases are used to preserve dried insects, which aid in comparative study and for reference purposes.

Methods of pest control
Due to the negative effects of some chemicals on staff, objects, and the environment, have completely changed the attitudes of protecting institutions, towards the fulfillment of their crucial task by switching from persistent and toxic pesticides control methods, to some sustainable and reliable methods. The increasing emphasis is towards least, or no-toxic chemicals and non-chemical methods along with well-planned physical methods to protect the cultural and natural objects from deterioration and damage. This approach is called preventive conservation. Therefore it is an utmost need for integrating the below-given methods for pest control in terms of the safety of human being, their environment, and as well as for the museum's valuable collections.

Physical barriers
The most effective way to control pest populations is to prevent pests from entering to the museum primarily and discourage them from staying in. Inspection of building from

inside and outside has to be done periodically and has to be properly recorded. The possible places can be cracks on the floor, wall or ceiling, air vents, and ducts. If any of these are found, it has to be repaired immediately. It is also important to understand the other possible entry points of museum pests in the building, which are shown below in the following

There are several ways through which pest growth can be prevented and controlled are given as follow.

- Primarily, ensuring that windows and doors are well sealed by installing bristle strips in areas containing museum collections, which can help in reducing the number of rodents and insects such as moths and beetles that may easily access the collection areas. Flyscreens on windows will also prevent moths, beetles, and other insects from entering, and still, if any of the remaining insects succeed to come inside, would be caught into the sticky window traps.
- Storing and housing objects/collections in any secure cabinets or acid-free storage boxes will also provide a barrier to pests. When the size of an object is exceedingly large, it may be get damaged by transferring to some other box, in such cases a Tyvek cover can afford some protection, especially if it is made for a particular type of object, for instance, a coat cover for a costume (textile) object.
- One of the important methods of eliminating insect pests includes vacuum cleaning to diminish the spread of infections as well as to create disturbances in the life cycle of the insect pests.
- It is also important to have a good maintenance routine to ensure that any holes in the building are filled up. In case, if there is any air duct present in the building, filters should be appropriately installed. Sometimes small rodents can get through the tiny hole so even the smallest gap should be properly filled up.
- The maintenance routine should also extend to the exterior of the building including the removal of vegetation that is near to, or growing on the building, as this can shelter pests, and provide easy access from windows or air vents.

Fig 2: Demonstrate a schematic diagram to show key pest (insects) points in an older building

Temperature and humidity

It is of utmost importance to ensure the environment of stores and galleries of museums, which should be kept dry and cool for discouraging insect pests from breeding. In view of the

fact mentioned below:

- Moisture can damage not only the building but also the museum objects. Several insect pests like to feed on the objects that are affected by mold. Museums need to keep their facilities and collection areas free from any dampness and immediately deal with leaks or possible water damage. At 65% of relative humidity (RH%) germination of mold and fungus starts, and insects like beetles and moths also start their activities in such environments [13]. Some important insects often found in the museum are shown in the given below.

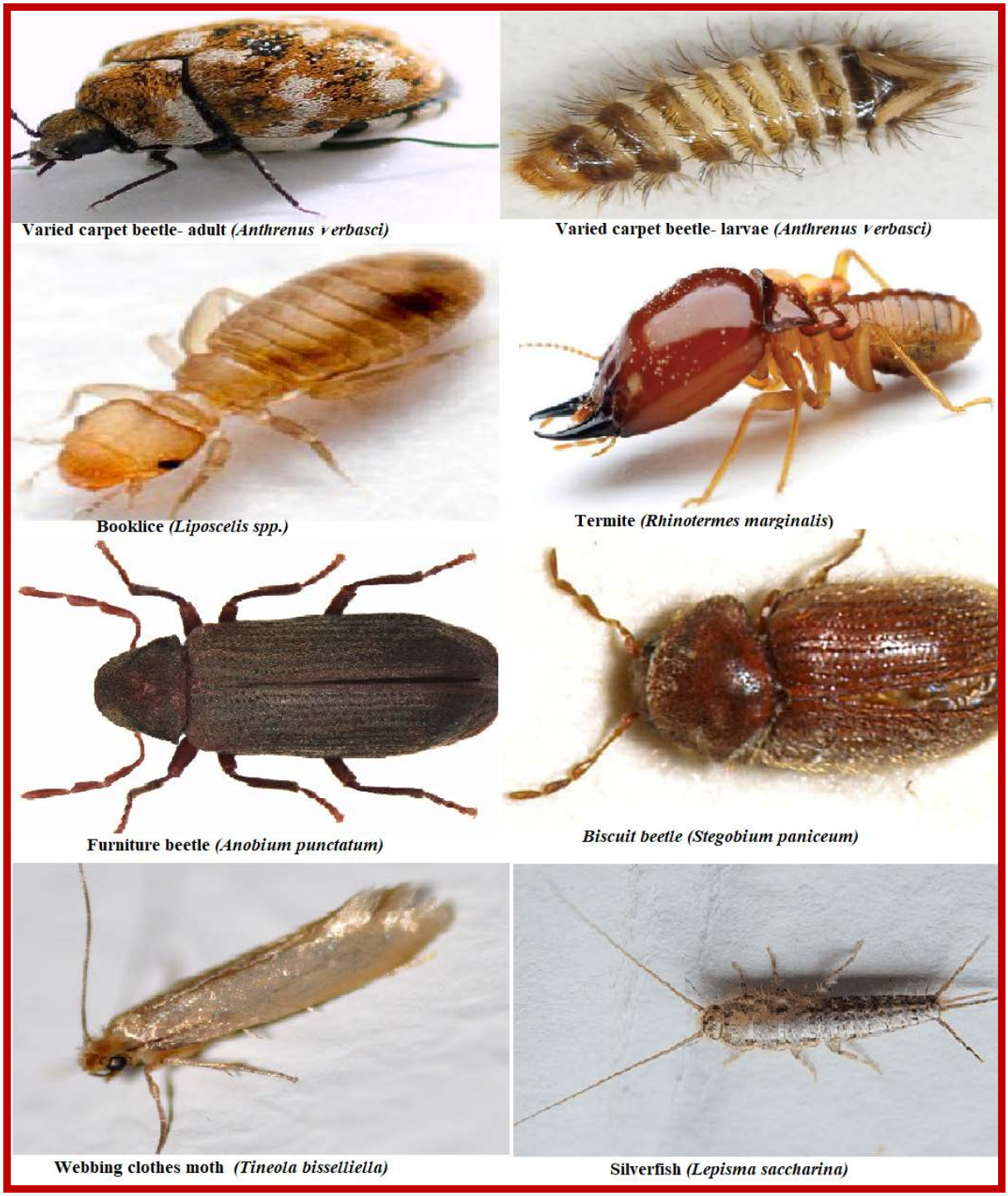

Fig 3: Demonstrating museums common insect pest found in museums, libraries and archives

- As well as being preferable for most museum objects a lower temperature can help to slow down the pest activity, so this has to be maintained as far as possible.

Dirt and dust

- Good housekeeping routines are essential in mitigating pest infestations. Regular cleaning of collection areas to minimize dust will ensure that insect food sources are kept to a minimum.
- Policies that prohibit eating and drinking in stores, (except bottled water) should be introduced for all areas where collections are stored. This will prevent discarded or dropped food from being available for pests to survive on. Other areas in the building should have specific design food waste bins that are small rodent-proof and emptied regularly.

- Implementing the strict policy of supervision and quarantine for the objects coming from the outside. It can help to prevent the spreading of pests into the main collections from external sources. There should be an arrangement of separate areas away from the collection area for proper checking of all objects while entering the museum. In case if any of the objects is suspected to contain pests should be sealed immediately and treated appropriately (freezing or heat/humidity treatment can be applied).
- Properly training the staff to identify the first signs of pest activity and providing profound information regarding the expected common pests. So that immediate actions can be taken on behalf of it, before that a minor problem may change to a critical issue.

Non-chemical methods

The past variety of insect repellents were used for the elimination of insects were such as cedar oil, naphthalene balls, paradichlorobenzene crystals, and camphor, etc. However, with more experience and study it is found that these repellents do not remove insect pests completely. Some museums and libraries are regularly using insecticides such as methyl bromide and ethylene oxide. These insecticides are generally effective in killing pests but they also possess great health hazards to humans. In India too, there have been lots of insecticidal chemicals have been used for terminating insects in the fumigation chamber. Moreover, these insecticides are also not completely effective in killing insects. Many of these chemicals are carcinogenic or suspected to be potentially carcinogenic. To solve these problems, there has been constant research and technique evolved in conservation science [14]. Some recommended methods for controlling insect pests are given as follows:

1. Exposure to freezing environment
2. Exposure to anoxia environment
3. Exposure to nitrogen (N2) environment
4. Exposure to carbon dioxide (CO2) environment
5. Biological control
6. Radiological control
7. Least-toxic chemical control

The most commonly accepted treatment for pest infestation is freezing, which can be successfully and safely used on most types of museum collections. There are various types of freezers such as upright type and chest type that can be set to different extreme low temperatures. The treatment time and temperature play a crucial role in controlling insect pests. Initially, the objects need to be bagged in plastic that is properly sealed to prevent dehydration, and after the process of freezing, allowed to return to room temperature still keeping it in the bag, so that the object retains its moisture. The general guide of freezing that can be applied to all stages of the insect life cycle is given below:

- Freezing for 48 hours at -40ºC.
- Freezing for 72 hours at -30 ºC.
- Freezing for 7 days at temperatures above these levels.

Chemical methods

When all physical methods for the prevention of pests are in place, but still a problem arises, then it becomes necessary to use chemical methods in order to eradicate them. The Pesticides Regulations Act 1986 and the amendment in 1987, state that, the training of the staff must be under a competently trained person in order to use most of the toxic chemicals against the pests. So it has to ensure that training is completed under expert supervision, otherwise, he/she will breach the law. The chemicals used for the eradication of pests tend to fall into several categories are mentioned below. It is a health and safety requirement that risk/COSHH assessments are carried out before any of these chemicals are used.

Dusts

Agrodust are desiccant dust that kills insects by dehydrating them. The regulations for use are slightly unclear but it is advised that professional training should be received before its application.

Sprays

There are many sprays available in the market, which have been tested on museum collections for the safety aspect, are mainly Permethrin-based sprays. It kills insects by poisoning them through contact mode of action. The object and the area can be safely handled after a few hours of applying because no residue is left at all. One must have received professional training before applying these sprays.

Chemical release agents

Chemical release agents are transfluthrin-based chemicals that are also known to be fumigants. Fumigants are the most important mode of action which acts or may kill the target insect by producing vapor, and are supposed to be used in an enclosed area. Transfluthrin is a rapid-acting pyrethroid insecticide with low persistency, acts as a contact and inhalation agent. It is a relatively volatile substance that produces poisonous gases when applied against insects. The vapor formed from insecticides enters the body of insects via their tracheal system through spiracles and causes death by poisoning.

Smoke bombs

Smoke bombs are a form of chemical release agent. The problematic areas are sealed off and permethrin is released into the area in the form of smoke for killing insect pests.

Professional help

In cases where physical and chemical methods of pest control have proved insufficient then any expert or professional help should be taken. It is very important to understand the rules and procedures of using pesticides especially for controlling the pest in cultural heritage sectors, without having sufficient knowledge and training, one should never come forward to use such chemicals.

Gender confusion systems

Gender confusion is a relatively new technique that is used to eradicate moths and beetles infestations. This pioneering technique confuses the male beetle which is obliviously attracted to another male beetle that has been coated with female pheromone, in consequence, breaking the mating cycle.

Tools for the pest management

The IPM program is a risk management program that focuses on prevention and employs a combination of pest management strategies to reduce the risk of pests and related damage. Two tools that can prove very helpful are floor plans

and databases. These can be either paper or electronic-based.

Floor plans

Floor plans can be used to identify high-risk areas within museums where collections are stored. It can be highlighted with red color, and symbols can be employed for indicating the locations of pest traps. Adding pest data to floor plans can comprehend precisely about the problem areas where dwells.

Databases

Databases can be used for analyzing the pest trapping data in order to monitor the pest problem over time. Classic and simple versions of these are available on the internet without any charges, or even a basic spreadsheet can be also maintained by using Microsoft Excel. The database must have retained all information such as, where the pest traps are located when they were examined, and what was found in them (insect types and insect numbers). This can be used to create statistics for further analysis.

Environmental data

Environmental data usually assists in order to ensure that collections are stored at appropriate environmental levels. However, this data can also be useful as an aid to pest management. Many museum pest species require specific environments, such as humid, warm, or undisturbed areas for breeding insects like silverfish, booklice, moths, and beetles, etc. Environmental data collated from recording devices can be relatively used to support the identification of varied pests that are found inside a particular area. For example, if there is an increase in silverfish, the environmental readings may show increased humidity. The locations of the environmental monitors can be schemes on floor plans for the cross-reference of the restored data. It may be useful to incorporate the environmental data with the pest trapping data. This helps to understand any unusual effects that may be caused by leakages, unexpected weather conditions, private events serving food, or other situations leading to potential fluctuations. Later, the acquired data can be beneficial in analyzing the sensitive areas for future plans.

Conclusion

Pests are unwanted organisms that are a nuisance to man or domestic animals and can cause injury to humans, animals, plants, structures, and possessions as well. Pest management is the process of making decisions in a systematic way to keep pests from reaching intolerable levels. Nowadays, there is advancement in the tools and techniques accessibility for the detection, prevention, and control of museum pests. The application of pesticides to control pests in cultural heritage buildings is associated with undesirable effects on humans as well as on valuable collections. Modern conservation ethics is determined about any negative effect on artifacts must be minimal or reversible. It is also determined about the safety of the person who is applying chemicals as well as the person who is handling the artifacts after the treatment and also for the person who visits museums. Pesticide regulations are constantly being revised to restrict or ban the application of many toxic chemicals, which leads to depends the conservators or museum staff on some other alternative methods. Therefore, the alternative strategies prompted the non-chemical treatment methods for several years in pests control and management.

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