NatSCA

Natural Sciences Collections Association

http://www.natsca.org

Care and Conservation of Natural History Collections

Title: Pest management, prevention and control

Author(s): Pinniger, D. B. & Harmon, J. D.

Source: Pinniger, D. B. & Harmon, J. D. (1999). Pest management, prevention and control. In: Carter, D. & Walker, A. (eds). (1999). *Chapter 8: Care and Conservation of Natural History Collections.* Oxford: Butterwoth Heinemann, pp. 152 - 176.

URL: http://www.natsca.org/care-and-conservation

8

Pest management, prevention and control

D. B. Pinniger
Entomologist and Pest Control Consultant, A.V.R. 83 Westwood Green, Cookham, Berkshire SL6 9DE. UK

J. D. Harmon
Manager and Entomologist, Urban Entomology Associates, 1008 North Hidalgo Avenue, Alhambra, San Gabriel, CA 91801, USA

Introduction

Pests in a museum, library or archive environment can cause serious damage to highly valuable and irreplaceable materials. Natural history collections are particularly vulnerable to pest attack because much of the collection is composed of edible plant material or animal protein. Mammal and bird skins and insect and herbarium specimens are frequently damaged by insects, and the risk of infestation is well known. However, many other objects in natural history museums and other institutions are also vulnerable to attack or may act as reservoirs for pests. Wool in carpets, wool felt in displays or door linings and dead flies in attics are as acceptable to insect pests as museum specimens and the risk to the collection from these sources must be recognized. The majority of facilities deal with pests in a reactive way, such as fumigating objects to kill the pests after the infestation has occurred or monthly spraying by a pest control company (Quek *et al.,* 1990; Spivak *et al.,* 1981). Such reactive approaches to pest control typically involve the application of some type of pesticide to control or prevent infestations. Although the routine application of pesticides to a museum will not prevent infestations of many of the pests, we are accustomed to this approach through tradition.

Pesticide chemical applications directly on to objects may damage or destroy these items and produce undesirable residues. (Zycherman and Schrock, 1988; Dawson, 1992). In addition, certain methods involving the use of non-chemical controls such as freezing or heating may also harm the materials if they are not used with due regard to the care of the objects. Therefore, a more preventive and proactive approach to this problem is needed to control and prevent infestations and reduce the possibility of damage to materials. Many other factors must also be considered such as hazards to humans, animals and the environment.

Integrated pest management (IPM)

In today's society, an increasing emphasis is being placed on environmental sensitivity and the reduction in use of traditional pesticides. Worker and public safety is also becoming a greater concern with the increasing likelihood of lawsuits and litigation over past exposures to potentially hazardous materials (Linnie, 1990).

Rather than decide to abandon all attempts to control the pests, less hazardous alternatives to the traditional methods should be considered.

Proactive approaches to pest problems are relatively simple and cost-effective over a long period of time. This requires the use of integrated pest management (IPM) principles and practices (Linnie, 1996). IPM involves the use of various types of control and management procedures to prevent pest invasion and to discourage insects from becoming established. Procedures may include improving buildings, modifying the environment, placement of monitoring traps, and training of staff to assist in the prevention of a pest im asion. IPM also uses control procedures, including pesticides, but these are targeted to specific problems and are only used when necessary.

IPM works with the environment, not against it, to protect valuable collections and to maintain a clean, healthy and safe working environment.

Principles

IPM principles use the understanding of pest biology and the museum environment to keep pests *away* from the collections and facilities and to prevent them becoming established. Typically, there are many facets to an IPM programme which are all interrelated. The success of the programme depends on each part of the programme being properly planned, adhered to and supported at all levels.

Cost versus benefits

The cost of an IPM programme may seem prohibitive at first. Initial start-up costs will be higher than a current monthly service from a pest control company which is where the largest amount of time and money is spent. After implementation, the cost for maintenance is relatively low and primarily consists of time spent inspecting and identifying pests. A typical benefit of using an IPM programme approach for the management of pests would be the discovery of a pest and implementation of control procedures prior to the development of a major infestation and subsequent damage. An IPM programme will also eliminate or minimize routine pesticide applications. IPM should be very flexible so that it can be modified at any time to suit each situation. It should also be practical and achievable as it is useless embarking on a grandiose scheme which then fails through lack of staffing, commitment or funding. A major point to remember is that implementation of only one of the control or management techniques will result in programme failure. To be successful, an IPM programme must include a multifaceted approach. which is specific to each situation and part of the collection in terms of control, eradication and, especially, prevention of pest infestation. Overall, a well designed IPM programme will be a major contributor to the efficient and environmentally conscious preservation of collections.

Basic IPM programme components

Looking at the IPM components separately, it is important to remember that each one is only a part of the whole programme and cannot stand alone. Each part of the programme must be carefully examined and planned to be effective. Different components may be selected depending upon the problems encountered, the use of a room, pests involved or administrative constraints. Different parts of the museum collection or institution may initially require different approaches depending upon the priorities. Other components can be added or deleted later as necessary.

Included within the discussion of each component will be recommendations to correct the problems. These recommendations are meant as guidelines or as a starting point to think of new remedial measures. The main objective is to correct current problems in order to prevent worse situations later.

The key stages in an IPM programme are as follows:,

- Recognizing and identifying priorities for action.
- Identifying responsible staff.
- Taking action on the high priorities.
- Establishing procedures for forward planning, financing and review.

Below is a list of the IPM principles that are employed in a typical programme. Each will be discussed separately in later sections:

- Knowledge of the pests.
- Surveys and inspections.
- Exclusion.
- Cleaning/sanitation.
- Vegetation removal.
- Pest monitoring.
- Environmental modification and manipulation.
- Education/training.
- Record keeping.
- Treatment.

Pest identification

Identification of the species of pest causing the problems is the cornerstone and the initial part of an IPM programme. Incorrect identification may result in large amounts of time and resources being wasted in controlling the wrong pest.

Some pests are general feeders whereas others will attack only a limited range of materials (Table 8.1). There are also major differences in pest importance and status depending upon the type of the collection and the local climate. Some pests are easily recognized by the damage that they have caused. Although a summary of the major pests and vulnerable natural history materials is given in this chapter, it is strongly recommended that the user makes reference to a good text on insect identification. Examples include: Mound (1989); Peacock (1993) and Smith and Whitman (1992).

Pests attacking wool, fur, feathers and textiles

Major destruction of mammal and bird skins and insect specimens can be caused by certain beetle and moth pests. A number of different species of carpet beetles, museum beetles and leather beetles (which all belong to the family Dermestidae) are widespread in many museums and stores throughout the world.

Carpet beetles and fur beetles

The most common carpet beetles found are *Anthrenus* sp. and *Attagenus sp.* There are

Table 8.1 Summary of pest risk to specimens

Specimen type	*Pest*	*Signs of Damage*
Dried insect collections, particularly large Lepidoptera and Coleoptera	*Anthrenus, Attagenus, Ptinus, Reesa*	Loose wings, fatty bodies eaten, frass, and larval skins in cases
Dried arachnids and Crustacea, particularly poorly cleaned decapods	*Anthrenus, Attagenus*	Loose legs, frass and larval skins in cases
Bird skins	*Anthrenus, Attagenus. Tinea, Tineola*	Stripped feathers, webbing and frass
Mammal skins	*Anthrenus, Attagenus. Tinea, Tineola*	Loose hair. webbing, cast skins and frass
Freeze-dried mammals and birds	*Anthrenus, Attagenus, Ptinus, Stegobium, Lasioderma Tinea, Tineola*	Loose hair, round emergence holes, webbing, cast skins and frass
Reptiles, pal1icularly poorly cleaned specimens	*Anthrenus, Attagenus*	Cast skins and frass
Bones and horns when poorly cleaned	*Anthrenus, Attagenus, Dermestes*	Cast skins and frass
Clean skeletal material	Not attacked	
Fish	Rarely attacked	
Spongse	Not attacked	
Dried plants, pal1icularly seeds and seed heads and some fungi	Stegobium, Lasioderma, Ptinus	Round emergence holes, globular silk pupal cases and frass
Cryptogams	Rarely attacked	
Fungi	*Liposcelis, Stegobium*	Dust and frass

many different species of *Anthrenus* which are similar in appearance and habits, including the museum beetle *Anthrenus museorum,* the varied carpet beetle *Anthrenus verbasci* (Fig. 8.1A) and the furniture carpet beetle *Anthrenus flavipes*. All adult *Anthrenus* are round, 2—3 mm long and covered with patterns of grey and gold scales. There are also many species of *Attagenus* including the fur beetle *Attagenus pellio* (Fig. 8.1E) the black carpet beetle *Attagenus unicolor,* the wardrobe beetle *Attagenus fasciatus* and the brown carpet

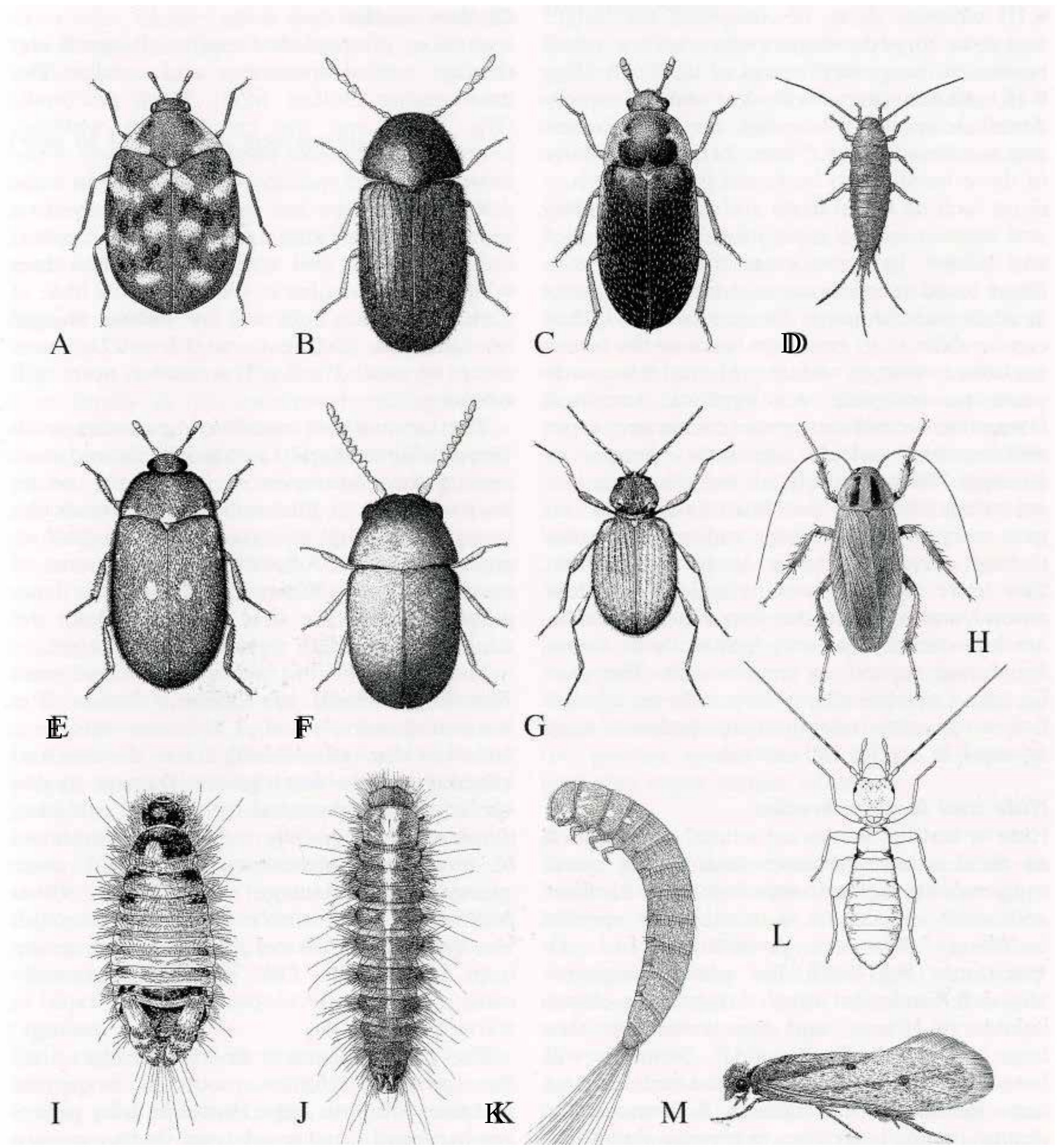


Figure 8.1 *(A) Anthrenus verbasci* adult; (B) *Stegobium paniceum* adult; *(C) Dermestes maculatus* adult;. (D) *Lepisma saccarbina* adult; (E) *Attagenus pellio* adult; (F) *Lasioderma serricorne* adult; *(G) Ptinus tectus* adult; (H) *Blattella germanica* adult; (I) *Anthrenus* sp. lar^{v}a; (J) *Dermestes sp.* larva: (K) *Attagenus* sp. larva; (L) *Liposcelis bostrychophilus* adult; (M) *Tinea pellionella* adult. NB Not to scale — size is given in text. Based on illustrations © The Natural History Museum.

beetle *Attagenus smirnovi*. *Attagenus* adults are more oval in shape and are very variable in size, from 3 to 6 mm.

All carpet beetle species have active. hairy larvae often referred to as `woolly bears'. Larvae of *Anthrenus* are short and fat (Fig. 8.11) whereas those of *Attagenus* are longer and more torpedo-shaped, often with a tuft of bristles at the posterior end of the body (Fig. 8.1K). All are voracious feeders and will rapidly demolish animal specimens, fur and feathers and woollen textiles (Plates 24 and 25). Many of these beetles can be found in natural situations such as birds' nests and animal burrows and they thrive on dead insects such as flies and wasps. In some museums they have a direct route into the premises from birds' nests in attics and chimneys. Once established, they can be difficult to eradicate because the larvae are able to forage widely and may take some years to complete development. Localized favourable conditions may encourage rapid development which increases levels of damage. When larvae hatch from the egg they are extremely small (less than 1 mm) and can gain entry to display cases and storage boxes through very small cracks. As the larvae grow, they leave empty cast skins which may blow around and indicate the first signs of attack. Adult beetles fly and may frequently be found wandering around on window sills. They can be found outside where they mate on flowers before returning indoors to lay batches of eggs secreted in cracks and crevices.

Hide and leather beetles

Hide or leather beetles eat animal protein such as dried animal carcasses and, as the name suggests, they will also attack untanned leather and skins. There are a number of species including *Dermestes pertaianus* and *D. maculatus* (Fig. 8.1C). The adults are generally dull black and much larger than carpet beetles (6—10 mm) and the larvae are also large and very hairy (Fig. 8.13). *Dermestes* will breed in poorly cleaned skeletal material and some institutions use cultures of *Dermestes* for cleaning animal carcasses to prepare skeletons. If dermestids are kept for this purpose, they must be well segregated with strict controls to prevent them invading vulnerable areas.

Other dermestid beetles which are found only in certain countries include the American wasp beetle *Reesa t.'espulae*, which is parthenogenetic and causes serious damage to insect collections in some European countries, and the odd beetle *Tylodrius contractus*, found in mammal and bird skins in the USA.

Clothes moths

A number of species of moth will attack and damage animal specimens and textiles. The case-bearing clothes moth *Tinea pellionella* (Fig. 8.1M) and the common or webbing clothes moth *Tineola bisselliella* are two of the most important species and they have a wide distribution. They are small, dull, grey-fawn moths, 5—7 mm long, which scuttle around rather than fly and when at rest fold their wings along their back. Clothes moths hide in dark areas, shun light and lay batches of eggs on fur (Plate 26), feathers (Plate 27), skins, wool or soiled silk. The larvae spin silk webbing.

The larva of the case-bearing clothes moth *Tinea pellionella* spins a `cocoon' around itself leaving the ends open so that it can use its jaws and legs. It then eats as it traverses the material carrying its case, leaving a trail of grazed textile or fur with some fragments of excreta or frass. When fully grown the larva pupates within the case and eventually the adult moth emerges to mate and lay eggs.

The common or webbing clothes moth *Tineola bisselliella* has different habits. The larva also spins silk but it leaves this as a tunnel or sheet of webbing across the attacked material under which it grazes. Damage by this species is accompanied by copious webbing tubes which frequently include large amounts of frass, and infestations appear far more `messy' than damage caused by *Tinea pellionella*. Adult moths can fly in through windows or open doors and can also originate from birds' nests. One generation normally takes a year but development is more rapid in warmer conditions.

The pelleted excreta or frass produced by the larvae of clothes moths is frequently mistaken for moth eggs. However, frass pellets are hard and opaque whereas moth eggs are very small and translucent and vulnerable to physical damage. Contrary to popular opinion, eggs will not remain dormant and then hatch many months later. Damage by moths is more concentrated in dark areas and in crevices or creases where specimens are stored touching a wall or on a shelf. Clothes moths occasionally attack large insect specimens. It has been noticed that textiles soiled with food or urine are preferentially attacked and that a stained area may be more damaged than an adjacent clean one. Clean cotton materials are not at risk from attack by clothes moth, or carpet beetles.

Pests of herbarium specimens

Some of these beetles are also important pests of the food processing and storage industries and can be introduced into the museum on specimens or food.

Biscuit beetles

The biscuit beetle or drug-store beetle *Stegobium paniccum* (Fig. 8.1B) belongs to the same family as the common furniture beetle or woodworm *Auobiitm piuictatum* but is much smaller (2—3 mm). Unlike woodworm larvae which only eat wood and paper, *Stegobium* will eat biscuits, nuts and dried plant specimens (Plate 28). Herbarium specimens with nutritious seed heads and a high starch content are particularly at risk (Plate 29). Biscuit beetles will also attack papier mache which has a high starch content, and there have been recent problems of damage to freeze-dried animal specimens. Adults are very active and will fly but the larvae are not very mobile or wide-ranging and live in tunnels inside the food, and when the adults leave they produce neat exit holes in objects. Development can be rapid at high temperatures of 30°C with generation times as short as five weeks. Biscuit beetles have an amazing ability to survive and breed on drugs and spices which would be extremely toxic to other animals.

Cigarette beetles

The cigarette beetle or tobacco beetle *Lasioderma serricorne* (Fig. 8.1F) is a very serious pest of tobacco but will also attack a wide range of dried plant and animal material (Plate 30) including freeze-dried animal specimens. It tends to be a more serious pest than *Stegobium paniceum* in hotter climates. The adult is similar in appearance to the biscuit beetle but is more hairy without distinct lines on the elytra The larvae tunnel in food leaving similar exit holes to the biscuit beetle.

General detritus feeders, mould feeders and scavengers

There are very many different kinds of insect species in this category. They generally cause nuisance and low levels of damage but occasionally populations of insects can build up to levels sufficient to cause serious damage.

Spider beetles

Spider beetles and particularly the Australian spider beetle *Ptinus tectus* (Fig. 8.1G), are widespread. They are common in birds' nests and general debris in attics, basements and stores where they will feed on a wide range of vegetable and animal detritus including dead insects. They have been recorded as causing serious damage to herbarium specimens, animal skins and insect collections. The larvae are similar in appearance to those of the biscuit beetle and they will also bore holes before pupating in a globular silk cocoon. The adults are 3—4 mm, hairy, superficially spider-like and generally slow moving. They will tolerate lower temperatures than many other beetles but at higher temperatures two or three generations a year may be produced and damage may be severe. Other species such as the white marked spider beetle *Ptinus fur* and the golden spider beetle *Niptus bololeucus* may also cause similar damage.

Booklice

There are a number of different species of booklice and *Liposcelis bostiychophilus* (Fig. 8.1L) is one of the most common and troublesome insects. The adult of this species is wingless and very small (less than 1 mm) and develops through a series of nymphal stages which feed on microscopic moulds on a range of substrates including flour, paper and cardboard. Booklice will attack some insect specimens and damage book bindings and prints by grazing the surface. Squashed bodies will also stain materials and booklice are a particular problem in stores which handle books and manuscripts. These insects thrive at high humidities which encourage mould growth, although *Liposcelis* can tolerate drier

Figure 8.2 Photograph and label damaged by *Lepisma saccharhina.*

conditions and will develop when the relative humidity is as low as 60%. Because it is parthenogenetic, *Liposcelis* populations can increase very rapidly at temperatures over 25°C and give rise to apparent population explosions.

Silverfish and firebrats

Silverfish *Lepisma* sp. (Fig. 8.1D) are always associated with damp conditions and they generally require localized humidity above 75–80% to breed and multiply. Firebrats *Thermobia* sp., on the other hand, are found in hotter, drier areas. They are primitive, scaly, wingless insects (10–15 mm) with forked bristles at the tail end. Silverfish and firebrats are general scavengers which feed on microscopic moulds on a wide range of foods including glue and ink on paper. *Lepisma saccharina* has been known to damage hooks, wallpaper, labels (Fig. 8.2), postage stamps, paper currency, herbarium specimens and textiles.

Cockroaches

World-wide, cockroaches are one of the most serious pests associated with humans and urban development and cockroach problems have spread to museums, other institutions and associated stores. The most common cockroach species are the German cockroach *Blattella germanica* (10–15 mm) (Fig. 8.1H), the American cockroach *Periplaneta americana* (30—40 mm) and the Oriental cockroach *Blatta orientalis* (20—30 mm). Although they are tropical in origin and require relatively high temperatures and locally high humidities, they are very common in heated buildings in countries with temperate climates. They are extremely active and the adults of many species will fly. They are also relatively large but, as they frequent heating ducts, wall cavities and other dead spaces, the centres of infestation may be hidden. The American cockroach *Periplaneta americana is* probably the most abundant insect in countries with tropical and semi-tropical climates and is commonly found outside buildings. All the pest species lay eggs in cases called oothecae and the tiny nymphs hatch from these. German cockroaches hatch immediately after the egg cases are dropped but American and oriental cockroach egg cases may remain dormant for some weeks or even months before they hatch. These cases can act as biological time bombs' which can be introduced unnoticed into stores on new or returned materials and give rise to subsequent infestation.

Infestations of cockroaches often spread from restaurant or catering areas and they will eat a wide range of materials and cause contamination by spreading smears of excreta. They will also feed in toilets and drains and as they are known to cause allergic reactions and carry a range of diseases, cockroach infestation can present a health hazard to staff. Cockroaches are active at night and the size of infestations can be underestimated if inspection is only carried out in daylight. Infestations may be difficult to eradicate even with the use of persistent pesticides and successful cockroach control usually requires close co-operation between museum staff, catering management and an outside pest control contractor.

Insects which damage wood

Pests which attack wood may cause problems in tree specimens, storage boxes, furniture, shelving or the building structure. Many of the most destructive pests are beetles, including the common furniture beetle or woodworm *Aiiobiuni punctatum*. Powder post beetles *Lyctus* sp, longhorn beetles such as *Hylotrupes bajulus* and bostrychid bamboo or auger borers such as *Sinoxylon* sp. However, some species of ants and termites can also cause serious damage in countries where they are endemic.

Ants

Most of the ant species which cause problems are associated with decaying timber but species of *Camponotus* such as the Hercules or carpenter ant *C. berculearnis* will gnaw tunnels to build nests in sound wood. The ants attack soft spring wood and so the tunnels follow the growth rings, leaving thin leaves of hard summer wood. Structural timber of buildings and specimens may be damaged in the tropics.

Termites

Termites or Isoptera, commonly known as `white ants', are the most serious and destructive pests of structural timber (Edwards and Mill, 1986). In many museums, infestation of the buildings can spread to display and storage furniture and artifacts where termites can cause serious damage. Termites are not a problem in cool, temperate countries and the most severe problems are encountered in countries with warm, temperate and tropical climates.

Termites are not ants although they live in large colonies that have a complex structure of different types or `castes' which may include workers, soldiers, kings and queens, plus the developing eggs, larvae and nymphs. The reproductive cycle of many termites involves the production of large numbers of winged reproductive alates which swarm from the colony and then lose their wings before establishing new colonies. There are many different species of termites and they are generally divided into three types with distinctly different life styles — dryw-ood, dampwood and subterranean. All three types can cause problems in museums and stores. Subterranean termites cause the greatest damage to buildings whereas dry-wood termites often cause the greatest damage to artifacts.

Drywood termites

Drywood termites, which include the species *Cryptoterines* sp. and *Kalotermes* sp., bore galleries and tunnels in many directions, frequently across the grain of the wood. Channels are connected by narrow passages which are clean and smooth. Although some faecal pellets or frass are scattered in the passages, they are often stored in chambers which are sealed off. Drywood termites can be identified by these pellets which are the shape of poppy seeds. The termites may bore small round holes in the surface of the wood and eject the frass through these `toilet holes'. Timber and wooden objects may be extensively damaged before infestation is noticed because a thin layer of undamaged wood may be left on the outside. The nests and colonies are constructed entirely within timber and they do not forage widely from infested material. Drywood termites will also attack and destroy other cellulosic material including books.

Dampwood termites

Dampwood termites, including *Zootermopsis* sp., are usually associated with wood which is already being attacked by fungus and their presence indicates advanced decay. The tunnels and galleries are similar to those made by drywood termites but the interior walls are not so clean and may be littered with pellets.

Subterranean termites

Subterranean termites need to live in contact with soil and some species build the classic `termite cities' with colonies in huge mounds or spires of soil. Colonies of some species, including *Reticuliterntes sp.*, *Coptotermes* sp. and *Macrotermes* sp., will spread from their natural environment of soil and tree stumps to the woodwork of buildings.

Many species require fungi in their diet, which is produced on decaying wood within the nest. They need to maintain high levels of moisture in the colony for the development of fungi and to prevent the desiccation of the nymphs and workers, and this leads to the characteristic tube-building habit of subterranean termites. These tubes. which may be some metres in length, are constructed of soil and faecal material and they protect the termites as they pass between nests in the soil to the food sources of wood or other cellulosic material. They will line their galleries with a mud layer which conceals holes and covers the wood which they are excavating.

This habit, together with the presence of connecting tubes, provides the main clue to distinguish colonies of subterranean termites from those of drywood termites with their relatively clean galleries. A further diagnostic feature of damage is that subterranean termite galleries are restricted to softwood and do not cross growth rings.

As their name implies, subterranean termites are found near or below ground level and seldom spread above the lower floor, and this means that basement areas are particularly at risk. In addition to damage to museum objects, the enormous amount of timber which can be consumed by subterranean termites can be sufficiently severe to cause structural collapse of buildings. The eradication of termites from museums and their subsequent exclusion can be extremely difficult and usually requires the services of a pest control contractor specializing in termite problems.

Rodents

Rodents are easily identified by their profuse droppings, gnaw marks and habits (Bennett *et al.,* 1988; Meehan, 1984) but expert advice should be sought if there are persistent rodent problems.

Infestations of brown rats *Rattus norvegicus* are usually only found in museums when the rats have considerable and easily accessible sources of food such as food stores near the museum or catering facilities with poor refuse disposal systems. When the sources of food are controlled, the rat problems will disappear. If there is a high risk of rat invasion, in an inner city area for example, then parts of the building can be proofed to prevent entry of rats through eaves and pipe runs.

The house mouse *Mus domesticus can* be a major cause for concern although in many museums and institutions the fear of infestation is greater than the reality. If mice are given undisturbed areas with access to food supplies then they will breed rapidly and cause serious damage by shredding paper and textiles to make nest bedding. They will not discriminate between valuable objects, packing and rubbish. Mice produce prolific quantities of small, pointed droppings as they run around and so signs of fresh infestation are easy to recognize if areas are kept clean.

Control of the food supply will control the mouse problem and particular attention should be paid to catering and eating areas. As with rats, buildings can be proofed to prevent entry although mice can gain entry through very small holes in air-bricks and under doors.

Facility and collection surveys

Although identification of the pest problem is the cornerstone of IPM it is only the first step of a programme. The second step is to conduct a survey commencing with the outside and then the inside of the facility. The aim is to gain a thorough knowledge of the facility so that action can be taken to prevent pest entry, and problem areas can be identified for intensified monitoring. Table *8.2* presents a suggested check-list for a survey.

Planning and priorities

A survey of a collection and facility is a very involved process. Before beginning, it is essential to know what to look for and what procedures to follow. The first priority is to look for ways that pests can enter the facility and to identify areas where they may become established. There are very large differences between the different functional areas in a museum such as galleries, stores, laboratories and offices. Given the huge number of specimens in most natural history collections, it is impossible to check each item on a regular basis. Therefore, an overall assessment of the collection must be carried out to identify high risk areas in the building and the most vulnerable parts of the collection. A scale diagram of the facility will be necessary during the survey. As problems are noted, they should be indicated on the diagram. Noting areas that could support pests prior to infestation will be helpful in preventing future problems. A thorough record with detailed notes of the survey will be crucial when instructing personnel in the resolution of these problems.

The following equipment will be required during an inspection: a strong flashlight for looking into corners and dark areas, a hand lens or magnifying glass for identifications, collection tubes and forceps and paper and

Table 8.2 Survey checklist: this list is a basic guide and may not include everything found in your museum or facility — look carefully and make additions (or deletions) to the list where necessary

EXTERIOR

Roof and walls:
- Roof type — flat, pitched or other
- Clean and in good repair
- Standing water
- Type of construction
- Cracks or crevices in walls (especially where two buildings meet)
- Ventilation air-bricks
- Chimneys — are they blocked off
- External heating, air-conditioning or other mechanical unit

Windows and doors:
- Glass complete and secure
- Screens in good repair
- Weather-stripping
- Seals tight
- Opened regularly

Rubbish/trash:
- Museum waste
- Office waste
- Catering waste
- Bin storage
- Skips dumpster storage
- Regularity of emptying

Loading-dock area:
- Clean
- Dock doors tight and sealed
- Doors left open regularly
- What part of building does dock lead into

Vegetation around facility:
- Proximity of the plants to the facility
- What is the ground material — soil, gravel, hark, mulch
- Are there flowering plants
- When do they bloom
- Are there wall-climbing plants
- Trees and leaves

Outside eating areas:
- Siting
- Cleanliness

Water sources:
- Drain-pipes and gutters
- Water pipes
- Good condition and not leaking
- Leaks, stains, water spots Erosion problems
- Standing water around facility

Rodents, birds, bats:
- Evidence of infestation
- History and what types
- Contributing factors to their continued presence, e.g. staff feeding them

External lighting:
- Type of unit used
- Mercury vapour sodium vapour other

INTERIOR

Windows:
- Sealed tight
- Glass complete
- Opened regularly
- Weather-stripping
- Screens — in good repair

Doors:
- In good repair
- Effectively seal off rooms areas
- Seal tight at sides. bottom, top
- Close properly

Walls and floors:
- Holes in walls, floors or ceilings
- Cracks at skirting baseboard junction
- Blocked off fireplaces
- Vents screened off to prevent animal and bird harbourage

Plant rooms:
- Standing water in rooms
- Evidence of pest presence, insect or rodent carcasses, insect or rodent faeces
- Pipes
- In good repair, leaks
- Pipe traces open or sealed
- Air conditioning/ventilation plant
- Mechanical rooms free from debris and water
- Cracks 'crevices holes in walls
- Openings to outside
- Signs of birds or birds' nests
- Vents screened off to prevent animal and bird harbourage
- Conduits and conduit lines open or sealed

Collection storage:
- Type of storage furniture
- Condition of doors and drawers
- How well sealed
- Space under/behind units
- How often inspected
- Cracks crevices in walls
- Temperature and humidity
- Monitored
- Normal daily range of values
- Environmental controls working
- Control of material moving into and out of area
- Are food and drinks allowed in stores

Loans/acquisitions:
- Route through facility
- Procedure for examining incoming materials
- Identification of pests damage
- Isolation of suspected materials
- Procedure for treatment of infested objects
- Location of freezers etc.
- Regular inspection and identification of materials with infestations
- Isolation of these areas from primary collection storage

Registration:
- Procedure for pest identification, isolation and who to contact
- Separate room from collection storage

Conservation laboratories and preservation offices:
- Separate room(s) from collection storage and other areas
- Treatment area
- Reference insect collection
- Reference collection maintained pest-free
- Specimens for identification in pest-free drawers or containers

Galleries:
- Cleaning schedules
- Are areas free of dust and dirt
- Types of display
- Do open displays contain vulnerable material more at risk
- Are materials going into and out of galleries checked for pests
- Are food and drinks allowed in galleries
- Are there catering areas in the galleries
- Are they clean

Gift shop:
- Standard of cleaning
- Materials checked for pest presence

Staff eating/rest areas:
- Where is food allowed
- Refrigerator clean
- Sink and counters in good repair and clean
- Presence of insects or rodents
- Microwave oven clean or filthy
- Rubbish bin 'trash can with liner
- Emptied routinely Washed regularly
- Floors regularly mopped, dusted or vacuumed
- Water sources, sinks/lavatories, leaks

Office areas:
- Carpets — wool or synthetic
- Standard of cleaning
- Live plants
- Supply cabinets
- Types and length of storage
- Food allowed
- Trash — where deposited
- How long in depository

Public catering areas:
- Standard of hygiene in food preparation areas
- Trash cans
- Where Regularity of emptying and washing
- Eating areas
- Regularity of dusting, vacuuming or mopping
- EFK fly control units, are they emptied regularly

Attic and basement areas:
- Lsed for `unofficial' storage
- Standard of cleaning
- Leaks
- Openings, holes to outside
- Birds and birds' nests
- Wasps' nests
- Pipe traces sealed
- Ducts screened off at top
- Damaged wood members

pencils for notes. It also helps to have a small screwdriver and pliers for opening things and poking debris out of cracks.

Prior to conducting the survey, several questions must be answered, to establish the history of the building and prior pest infestations.

- Where and when have there been pest problems in the past?
- Which pests were involved?
- What type of collections or other materials were infested?
- What was done to solve the problem?
- Who took care of these problems (e.g. pest control company, in-house department)?
- How often are collections surveys conducted and by whom?
- What is the current procedure for dealing with infested materials?

Exclusion

If pests could be prevented from gaining entry to the facility in the first place, then most of the problems would be solved. Information gathered in the survey will indicate where the entrance points are. An additional bonus is that some facilities have achieved up to 5% savings in their utility bills after sealing openings.

Windows which are never opened should be sealed but those which need to be opened need to be fitted with insect screening. This is not always possible, particularly on historic buildings where it may not be acceptable for aesthetic reasons.

Doors present special problems in excluding pests. Depending upon the door type (rollup, sliding, single or double doors) sealing all of the openings may prove extremely difficult. Gaps occur around most doors when closed and the bottom of the door is usually the most problematic area. This ineffective seal not only allows pests to enter the facility, but also allows heat or conditioned air to escape. All doors should close tightly with no openings around the edges. Problems can be corrected by installation of door seals or sweeps (rubber or brush) as necessary, depending upon the construction of the door and frequency of use. Weather-stripping, easily obtainable through most hardware stores, should be installed along the top and side edges of the doors to provide the needed seal.

Sinks and other pipes often have a much larger hole in the wall than the pipe itself, which leaves a ready-made highway for pests to enter the area. Gaps around pipes should be filled with steel or copper wool and caulking placed around the edges. All plumbing should be inspected and repairs made as needed. Any other openings should be sealed using fine copper wool or caulking.

Lighting

Outside lights should be positioned so that they are physically away from the building, pointing towards it. Lights attract many types of insects which, while they may not harm the collection, provide food for dermestid beetles and other scavengers. Diffusers on internal fluorescent lights may also trap flies and other insects which provide food for pests, and they should be regularly removed and cleaned.

Effective use of lights may include the placement of UV light-traps at loading-dock entry doors. This will stop the insects that are attracted to the light, such as flies and certain moths. The catch trays must be emptied weekly or more often if necessary.

New acquisitions

Collections and materials entering a facility can easily transport pests. Most facilities have a quarantine area devoted to new acquisitions and returned loans (see Chapter 9 on policies and procedures). There may be a specific registration area in some museums and in the receiving area in most libraries. Unfortunately, staff working in these areas are often not trained to inspect for insect damage or to respond appropriately if insect activity is found.

All staff should be trained in the recognition of objects that have been damaged by insect attack. Training should include recognizing signs of damage by biscuit beetle and cigarette beetle, silverfish, moths, dermestid beetles, wood boring beetles and rodents. The presence of frass (faecal pellets), webbing, old cocoons, insect carcasses and cast skins and various holes or tunnels will be key indicators.

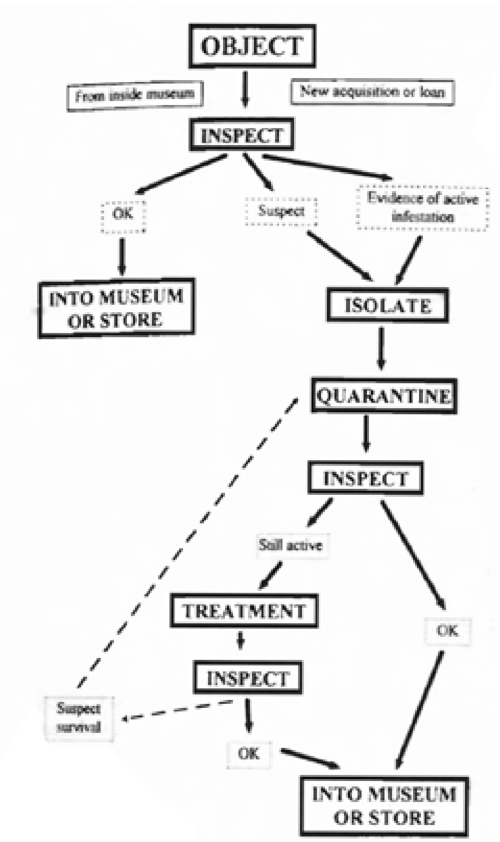


Figure 8.3 Quarantine strategy for a museum.

Staff should be given written procedures to follow if an infestation or damaged material is found. The instructions should be both simple and specific. An example can be found in Fig. 8.3.

Storage areas

As most collections have the majority of their articles in storage, this is the most important area for implementation of IPM. Material may remain undisturbed for many years and this provides an ideal haven for insect pests. Storage furniture may range from open wooden shelving to well sealed metal cabinets. It is important to remember that objects are more vulnerable to pest attack in open storage but they may also be damaged if pests are allowed to breed undiscovered and undisturbed on an object in a sealed drawer or cupboard. Some museums have devoted time and resources to the design of storage drawers and cabinets which preclude entry by invading insects. The results clearly show decrease or elimination of damage to specimens stored in these units compared to those stored in old and badly sealed units. Investment in good storage furniture is therefore a key component in I1'M and the care of collections (see Chapter 7 on the collection environment).

Storage areas are full of dead zones, such as corners, underneath bottom shelves and behind furniture, that insects and rodents love so much. These are areas which may be overlooked in routine cleaning schedules, as cleaning staff tend to miss them when sweeping and dusting. Particular attention must be paid to routine cleaning of storage rooms. Dust, dirt, hair, paper and other debris tend to accumulate in inaccessible areas. A good `spring cleaning' should be carried out every year and some climates may warrant such a cleaning every three months. Cleaning staff should be told where problem areas are located and how thoroughly they should be cleaned.

Shelving units are notorious for sheltering pests. Pest monitoring traps (see below) should be placed among the shelves and checked routinely. Infrequently used boxes of materials stored on shelves should be sealed in polyethylene bags and labelled. During a storage room inspection, checks should be made on, under and behind shelves for any piles of fine dust (indicative of wood-boring beetle adult emergence), shed skins of insects, casings and other debris, rodent faeces, and dead or live insects.

Conservation laboratories

The conservation laboratory and. or preservation office are of significant concern because these areas may hold damaged collections awaiting treatment, including insect eradication. Treatments on both uninfested and infested objects may be taking place in the same locality. The last thing that is needed are more pest problems.

Where feasible, it is best to have a `dirty' room isolated from collections for infested objects and a separate clean room. Those objects which are infested and/or undergoing treatment should remain in a different room from pest-free objects. Sticky monitoring traps should be placed in all doorways and windows. Weekly inspection of these traps should be conducted. While a stray insect may be found in the dirty room, nothing should be entering the clean areas.

Museum galleries

Museum galleries, which may have objects in cases or on open display, are potential sites for infestations to develop and transfer to the collections storage areas. They may also contain objects borrowed for an exhibition from outside the facility. Well lit objects will be less vulnerable to attack but darkened areas of the galleries will tend to encourage infestation and harbourage of pests. Exhibition openings and corporate entertainment functions with catered food services can introduce pests and result in food debris which may remain in the gallery to provide food for insects and rodents.

Sticky monitoring traps should be placed inconspicuously throughout the exhibits. All gallery staff should be briefed on the IPM programme (and given explanatory leaflets) to answer any visitor questions about the traps. Areas where mammal and bird skins are displayed should have moth traps around them. Areas where dried plant materials will be displayed should also be monitored with beetle traps. Inspections of the traps should be conducted on a monthly basis. Because some objects on display may be less accessible than collections in storage, regular inspection of the monitoring traps is essential.

Catering facilities

Most museums are under increasing pressure to provide food and eating facilities for visitors. As the requirements for this are almost in direct opposition to the provision of a safe environment for the collections, this has to be of major concern. When catering is provided is should ideally be in a separate building but, if not, it must be very carefully controlled.

There should be no consumption of food or drink allowed in gallery or collection areas. If galleries are used for corporate entertainment then all food residues must be removed after the event, otherwise the debris will provide food for pests.

Food preparation, handling and consumption areas must be kept scrupulously clean and monitored on a regular basis. All waste/trash disposal must be carefully controlled to prevent build-up of food waste. Caterers may have a separate pest control contract, and this must be checked and integrated with the pest policy in the museum.

Gift shops

Almost every museum has some sort of gift shop or book store housed within the facility. Such shops often contain objects and materials similar to those on display in the galleries, including textiles, basketry, wooden sculptures and other items. These materials may be stored undisturbed for long periods of time during transit to and at the museum and therefore the chance of pest infestation is high. Shops are often located directly adjacent to galleries, collection storage or food service areas, increasing the likelihood of an infestation spreading from the gift shop into the collections.

All gift shop managers and staff should be trained in the recognition of pest damage and given information about IPM and the danger of insects to the collections. All infested material should be refused if discovered before entrance into the facility, or bagged and removed immediately upon discovery.

Monitor traps should be placed discreetly throughout the gift shop, its office and the shop storage areas. Monthly checks should be conducted of these traps.

Vegetation

Plants are very comforting to have in and around a facility as they lend warmth and a sense of calmness to the work environment. Unfortunately, there are a number of pests that infest or are attracted to plants. Flies will often infest potted plants that are over-watered. Diseased or weakened plants are open avenues for serious insect infestations and healthy plants may also attract insects to their flowers or fruit.

Cut flowers and dried plant material should not be allowed in the facility under any circumstances. Many insects find their way into buildings by hitchhiking on plant material, especially plants and flowers brought in from home gardens or the outside landscape. Well-meaning staff members wanting to share their success at horticulture also share their pest problems. Carpet beetle adults feed on the pollen found in some flowers and, because they are very small, would probably not be noticed during picking or transport. Flowers from a commercial grower or florists shop for a temporary display usually do not present the same problems as they can be sprayed with pyrethrins before being placed in the museum. However, the water in flower vases can support the breeding of small flies and is a ready water source for cockroaches and other pests.

Dried flower arrangements are even worse for harbouring and transporting carpet beetles and other pests. Often the plant material is purchased already infested but, even if it is not, it will serve as a magnet for any future infestations and supply ample food and harbourage for pests.

Environment

Temperature and relative humidity

Collection storage areas should be kept as cool as is practically and economically possible. Temperatures lower than 20°C should slow insect growth substantially, although some insects such as spider beetles have adapted to lower temperatures. If storage areas which have climate control can be kept below 15°C, this will eliminate insect problems. Galleries are often very warm and large numbers of visitors may raise temperatures and humidities to even higher levels which encourage rapid breeding of insects.

Control of relative humidity is critical to the suppression of mould and mildew. If the relative humidity rises above 75%, then growth of mildew and other fungi starts. Mould and fungi are wonderful food for many insects and support a wide range of species. Damp areas caused by moisture migration and condensation should be avoided where possible as humidity above 65% will also encourage development of insect pests. Low humidity is not so limiting for some species such as biscuit beetles and carpet beetles, but relative humidity below 55% will prevent the development of pests such as silverfish. Good air circulation and consistent control of temperature and relative humidity will prevent mould and discourage insects.

Water sources

Important water sources include rest-rooms (sinks, urinals and toilets) and water leaking from outside, pipes or fire extinguishing systems. All of these areas should be investigated for leaks and any repairs made immediately. Standing water in the building can produce high humidity and subsequent mould and mildew growth.

The basement of a building is a common source of water. Often, collections are stored in basement areas due to space constraints or building design. As a temporary measure, dehumidifiers may be used to control humidity and objects may be sealed in polyethylene bags to prevent water damage (see Chapter 7 on the collection environment). However, the objects should not be bagged at high humidity as condensation can occur inside the bag and cause mould growth. In storage areas without climate control a packet of silica gel, encased in unbleached muslin and conditioned to 50% relative humidity, should be sealed in the polyethylene bag to keep the relative humidity constant. The silica gel will have to be checked periodically and reconditioned. A small hygrometer or humidity indicator strip can be placed in the bag to facilitate monitoring.

Hygiene

Depending upon the pest, food sources may be found anywhere in a facility. Most of the beetles may prefer a specific food but many are opportunistic and will eat anything. Discarded human food, breadcrumbs, hair, nail clippings, and even shed skin cells may provide a more than adequate food source. Special attention should be paid to cleaning in any kitchen and food areas.

Many insects prefer dark areas where they are undisturbed for long periods of time. An old display board covered in wool felt left in a side-room for years will provide a wonderful food source for moth and beetle populations to develop. Dead insects, birds' nests and debris under shelves and in old ducting will all sustain pest populations, and so the highest standards of cleaning should be aimed at everywhere.

Remember that insect populations can start from a very small source but will increase and then grow too large for the food source. When this happens, they will exit the area and seek out new food sources in the collection!

Garbage is to many pests what a grocery store is to us. The garbage area is typically a quiet zone, and pest populations can develop unnoticed. Decaying garbage presents a health threat: cockroaches and other insects will transport bacteria and germs on their bodies from the garbage area to human food. Food waste tends to support all types of pests but control of where the waste is placed and frequent removal of rubbish reduce the risk of infestations.

All rubbish bins/trash cans and recycling containers should be lined with plastic bags. The bags should be closed with a twist-tie or other such device at the end of each day and replaced regularly. The liner makes removal and transport of the materials easier and keeps the containers clean. If food is consumed outside designated catering areas then there should be bins designated for food waste only.

Monitoring and inspections

When to inspect

Inspections and surveys should be done as often as practically possible. They should be thorough and regular but the frequency will be determined by resources. As a general guide, a check of collection areas and traps should be carried out at least four times a year. Do not underestimate the time it takes to carry out a thorough survey. It is better to carry out a proper survey every year than to start off with the intention of doing it every month and then failing. During the initial inspection, each and every room in the facility must be checked. Too often, a pest problem will develop due to an incomplete inspection, allowing pests to build up their population without being noticed. After the first few inspections, certain areas that have proved to be free of pest problems and that do not contain vulnerable material, may not need to be surveyed each time.

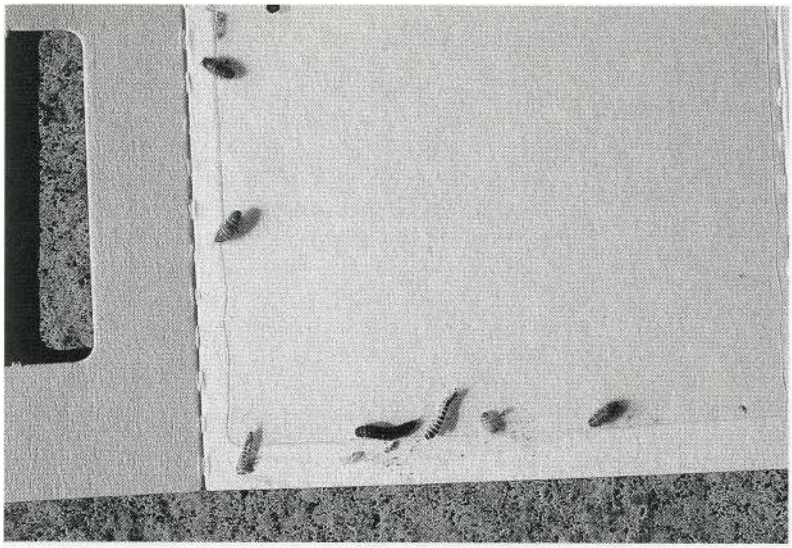
Traps and observations

Traps are used to monitor rooms and collections continuously. Pests will blunder into them as they move about the area in search of food, mates or shelter, and pests in the traps will indicate their presence in the area. Once pests are discovered, the number of traps can be increased to pin-point where the infestation is located. The correct identification of the pest will assist in decisions to continue inspections or implement control measures. Sometimes outdoor pests will be caught but seldom cause any damage to the collections and die before becoming established. During the building inspection and collection survey, it is important to check for any signs of pest presence, damage, droppings, carcasses, etc. Observations should be noted on the inspection/survey check-list.

Traps may be very successful in catching insects, but they *will not give control of insects*. They are only useful as a monitoring device.

Insect trap selection and placement

There are many types of trap available in different countries. Non-specific sticky traps should be used as basic monitoring devices for insects such as silverfish, booklice, cockroaches, crickets, ground beetles, carpet beetle larvae and other crawling insects. These traps do not have a pheromone attractant although some have a general food bait. Sticky blunder traps are good for monitoring the residual population of insects in a building to assess the risk to the collection. They will also indicate the level of ingress of crawling pests into a room or building. They should be placed in a regular grid pattern against wall/floor angles, preferably in corners where they will catch more wandering insects. Some traps are low in height and can be tucked under shelves and storage units. Numbers should be matched to the priorities of the collection and resources, and a trapping programme should not exceed the resources available to check the traps.



(a)

(b)

Figure 8.4 *(a) A. 1 r* and *Attagenus* larvae ,ught on a sticky trap. (b) Monitoring traps on a window-ledge.

Pheromone traps contain lures to attract a particular species of insect. They are therefore specific for the target pest. Traps and lures are available for the clothes moth *Tineola bisselliella*, furniture beetle *Anobium punctatum*, cigarette beetle *Lasioderma serricorne* and biscuit/drug-store beetle *Stegobium paniceum*. (Gilberg and Roach, 1991; Child and Pinniger, 1994; Cox *et al.*, 1996). Placement of these traps should be in areas where there is a high risk to valuable objects or where one of these species is suspected. Pheromone traps are also available for a variety of other stored food product pests.

Pheromone traps should be placed in a grid in the same way as blunder traps. Because the lure is more attractive to flying insects, the traps may be attached to walls or hung from units. The range of the attractive effect depends upon temperature and air movement. It is sometimes possible to pin-point sources of infestation by increasing the number of traps in the area

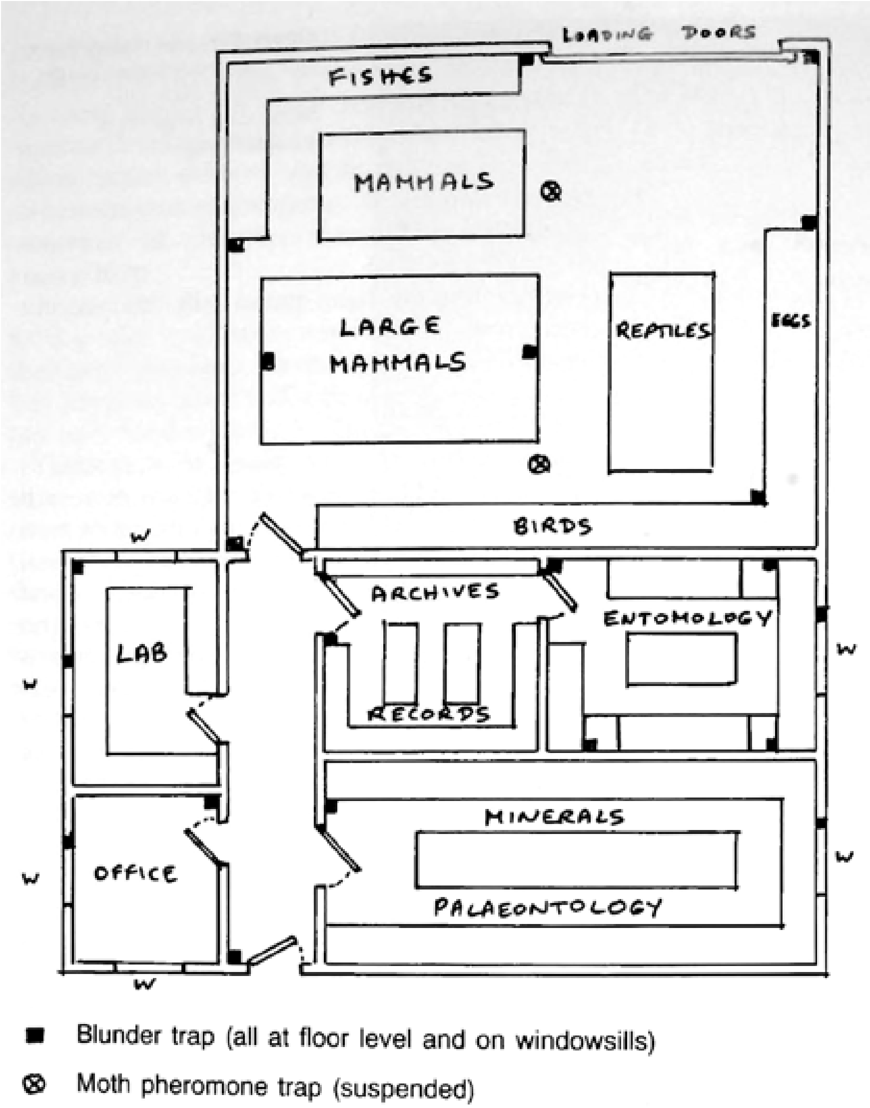


Figure 8.5 Typical sketch to show placement of traps in a museum store.

immediately adjacent to where the pest was caught, to narrow down the area where the pest originated. For larger populations of pests, increased number of traps may actually exert some control of the pest, by confusing the males and catching them before they get a chance to mate. However, this is of no real practical value as considerable damage will be caused by the remaining insects. As some insects may only fly for short periods each year it is necessary to consult the manufacturer's recommendations for timely trap replacement.

With all sticky traps, once an insect is caught (Fig. 8.4), the trap (or sticky surface, if removable) should be removed and the specimen recorded and discarded. Numbers of. dead insects on traps are food for other insects such as dermestid beetles. Replacement of the trap will also simplify recording of later trap catches and reduce confusion.

Keep track of where you place the traps and what type they are. It is helpful to have a schematic diagram of the floor plan with displays and the furniture drawn in. Add all trap locations to this diagram. Keep an extra copy of the master drawing in a safe place. An example of such a diagram can be found in Fig. 8.5.

Record keeping

Record keeping is crucial to the success of IPM programmes. Accurate and complete records of pest presence and activity will allow the programme co-ordinator to modify the programme as needed, identify seasonal occurrences and devote attention to problem areas.

The most important information to record is the correct identification of the pests found. Secondly, the number of individuals caught per trap and life stages of those individuals should be recorded. This information should be kept in a log hook or spreadsheet. Plans should also be used to record the distribution and presence of pests; these will be useful as references in future surveys.

Comparisons of trap catches over time can enable trends in pest emergence and invasion to be tracked. In addition, `hot spots' (areas that consistently show pest activity) will become evident. These active areas are where you will want to concentrate control activities. Comparisons of inspection observations will show what is going on, how effective the controls are, and what modifications need to be made to the control programme. A simple spreadsheet programme on a PC will allow easy production of tables and bar charts to show trends in trap catches.

Treatment strategies for pest removal

Choosing the pest control method best suited for a particular problem can be a difficult decision. Prevention is better than cure and all the points made in the section on preventing pests should be the first priority. However, when pests are found in objects or in the building then some remedial action may be necessary. Remedial action when pests are found is as follows:

- Isolate any objects suspected of being infested to prevent spread of infestation to other objects.
- Clean infested areas and destroy insect bodies and debris.
- Decide on the most appropriate treatment for the object and environment.

Remember, once the treatment is completed, care must be taken not to allow the material to become re-infested. Keep treated and pest-free objects separate from actively infested materials or storage areas. Placing of infested materials in plastic bags and sealing the bags is one of the best ways to achieve this goal. In environmentally controlled storage areas, clean objects which are particularly susceptible to insect attack can be placed in clear polyethylene or heat-sealed bags to prevent them from being re-infested.

Treatment of objects

Consideration must be given to the object's general condition and composition. Each control method should be evaluated and, if there is any question about whether a control method is appropriate for a certain kind of object or material, a conservator should be consulted. Consider the materials the object is made of, the pest and its biology (life cycle and behaviour), and the different control methods available before selection. The use of an inappropriate method can cause damage to collection materials and serious health hazards to the staff and public.

Freezing

Freezing kills insects by exposing them to a rapid temperature change. This technique is now widely used for treatment of natural history specimens but unless proper procedures are observed then some damage can occur to specimens (Nesheim, 1984; Florian, 1986, 1989, 1990; Strang, 1992). Temperatures in the freezer should be around -18 to -40°C. It is better to use a deep-freeze unit rather than a common household freezer, and self defrosting freezers should never be used. The freezer should be capable of reducing the temperature in the objects very quickly, within 24 hours, to be effective. If the items have been stored in a cold climate and are frozen very slowly, some insects will become acclimatized and will not succumb to freezing. It may take much longer for the cold to penetrate large objects or tightly rolled skins and the temperatures in the centre of test materials should be recorded to check that the target temperature has been achieved.

The objects must be sealed in plastic bags to prevent damage by relative humidity change and moisture migration. An absorbent organic buffering material such as paper-towels can be added to the bag to help control the relative humidity. Place the object in the freezer for at least two weeks at -18°C or for at least three days at 30°C. It is not advisable to freeze wet specimens unless this is to prevent decay.

After freezing, objects must not be unsealed until they have regained room temperature to prevent condensation problems. Buffering materials will help prevent condensation.

Heating

Heating will kill insects much more rapidly than freezing but it is essential to ensure that elevated temperatures do not harm the objects involved. In the past a number of museums have used ovens to `disinfest' insect collections and this often resulted in brittle specimens and cracked drawers. Recent work has shown that damage due to shrinkage and distortion can be eliminated by controlling the humidity around the object (Strang, 1996). The Thermo Lignum process uses a special chamber in which the humidity is accurately maintained at a set level of, for example, 55% during the entire eighteen-hour cycle from ambient temperature up to 55°C and back. Many objects, including books, furniture, textiles and natural history specimens, have been successfully treated (Child, 1994). Strang (1.996) has demonstrated that if objects are bagged when they are heated, then humidity in the enclosure is stable and the object is not damaged. This offers possibilities for rapid and safe treatment of natural history specimens. There are some questions regarding the effect of heat treatment to 55°C on plant and animal DNA and, if this is of prime importance in the specimen, then heat treatment would not be advisable.

Microwaves have been used for rapid treatment of herbarium specimens but there can be undesirable side-effects as the heating may be uneven and localized and overheating may occur (see Chapter 3 on Vascular plants). In addition, unnoticed metallic objects such as paper-clips may cause sparking and ignition of specimens and paper.

Gamma radiation

Gamma radiation will kill insects at high doses and is used in some Eastern European countries for treatment of museum specimens. The drawbacks are the high cost of the radiation unit together with the stringent safety precautions necessary for its operation. There is also evidence that gamma radiation has deleterious effects on some materials such as plastics and glass and may therefore adversely affect natural history specimens.

Nitrogen

Nitrogen has proven to be very effective and safe for treatment of sensitive objects (Reichmuth *et al.*, 1991; Rust *et al.*, 1996; Valentin and Preusser, 1990; Valentin, 1991; Gilberg, 1990: Hanlon *et al.*, 1992). The procedure relies on exclusion of oxygen which then kills insects by anoxia and is relatively simple to conduct. Oxygen levels must be very tow, less than 0.1%, and this can only be achieved in a special chamber or in individual bags made of an oxygen-barrier film. Large objects can be treated using nitrogen from cylinders. Small objects can be treated in sealed bags using an oxygen scavenger such as Ageless*.

Building a nitrogen treatment chamber may be expensive because of the need for absolute gas-tightness. Conversion of an existing fumigation chamber used for ethylene oxide or methyl bromide is feasible but can also be expensive because of the need for additional sealing and pipe-work. The cylinder and hag method is cheaper to set up initially although an accurate oxygen meter must be purchased and gas cylinders must be stored in compliance with local fire and safety regulations. An important consideration is that the relative humidity of nitrogen gas is extremely low, between 5 and 10%, which ss ould he detrimental to the materials being treated. It is therefore essential to add a humidification system to the gas supply-line (Rust *et al.*, 1996). The speed of the treatment in killing insects is dependent upon temperature, at temperatures of 25°C and above, two to three weeks should be sufficient to kill pests. However. at temperatures of 20°C or below, very long exposures of four or five weeks may be needed to kill some species such as woodborers.

A number of museums now use Ageless, a scavenger of gaseous oxygen, for treatment of

---

Ageless is the trademark of the Mitsubishi Gas Chemical Company.

individual specimens (Gilberg, 1989, 1990, 1991; Lambert *et al.*, 1992; Valentin *et al.*, 1990). Ageless is composed of moist, active iron oxide powder encased in a porous packet. Oxygen in the atmosphere penetrates the packet and further oxidizes the powder, forming iron oxides and hydroxides. A slight amount of heat is produced by the reaction but, if the packets are spaced for enough apart and kept out of contact with objects, this never builds up enough to damage the material being treated. Ageless will work effectively only if there is a finite amount of oxygen to be absorbed. This is achieved by enclosing the object to be treated in a clear oxygen-barrier film bag. The bag should be big enough to accommodate the object to be treated, with 3 to 4 inches spare. The excess space will become the seam of the bag and also provides extra room for the Ageless packets. The number of packets to be used is calculated from the type of packet and the volume of the bag. An indicator called Ageless eye can be used to show that levels of oxygen below 0.1% oxygen have been achieved. Objects should be left for at least three weeks at 25°C. With this system, set-up costs are lower than with the cylinder treatment but costs of Ageless may be high if large objects are treated. Ageless will also slow any degradative processes requiring oxygen, such as mould growth or oxidative chemical reactions. Thus, this system has applications for collection care other than insect eradication.

Carbon dioxide

Carbon dioxide treatment has been widely accepted in the stored grain industry for many years. Grain in bins and other structures has been routinely treated with carbon dioxide to eradicate insect infestations. The insect will open up its spiracles when exposed to high levels of CO_2 and this decreases the time to death, probably due to rapid dehydration.

The procedure used for CO_2 is similar to that used for nitrogen in chambers or bubbles (Valentin and Preusser, 1990; Valentin, 1991). As with nitrogen, the gas works slowly, particularly at low temperatures, and some treatments add slight heating of the chamber to 30°C to increase insect metabolic rates. This method also requires the use of a meter to monitor the percentage of CO_2 in the chamber during the exposure period. Levels of CO_2 need to be about 60% and, unlike for nitrogen, some leakage of oxygen into the enclosure will not make the treatment ineffective. Because of this, CO_2 is used for large objects and enclosures. In some countries CO_2 is registered as an insecticide and can only be used by professional operators.

Other gases

Argon and other inert gases have been used with varying degrees of success but, because they are more expensive than nitrogen or carbon dioxide, it is difficult to justify their use.

Fumigation

Fumigation involves the introduction of a toxic pesticidal gas into an enclosed space. Fumigant gases will penetrate materials and will kill all insects within the target objects but the treatment provides no residual protection. Because of the hazards associated with fumigants, only trained and licensed professionals must conduct this type of treatment. Many of the products in the fumigant category such as ethylene oxide, carbon disulphide, carbon tetrachloride and ethylene dichloride have been abandoned, phased out or made illegal due to safety and environmental concerns.

Specialized equipment must be used in conjunction with fumigation, including some type of gas containment equipment such as a gas-proof sheet or bubble or a gas-tight chamber. Chambers are commercially available but the price is too high for most institutions to consider buying one. The use of a vacuum chamber greatly increases the efficacy of the treatment through increased penetration of the fumigant. Also required are gas detection devices to test the concentration of the fumigant in the enclosure and in the atmosphere during aeration. High-powered fans are needed to move the gas and evacuate it once the fumigation is complete. In some countries regulations forbid the venting of gas directly to the atmosphere and traps or scrubbers must be used to clean the exhaust air.

Sulphuryl fluoride or Vikane

Sulphuryl fluoride or Vikane is a fumigant which is widely used in some countries for the treatment of termites. It has also been used for museum objects and archival materials (Derrick *et al.,* 1990). There is some concern over deleterious effects of Vikane such as etching of glass and tarnishing of silver, brass, bronze and copper. In addition, sulphuryl fluoride reacts with strong bases, and will dissolve slightly in certain organic solvents and cooking oils. There are further concerns that the material may deposit residual fluorides in and around leathers and oiled stains, but definitive evidence is not yet available (Dawson, 1992).

Methyl bromide

Methyl bromide has been used world-vvide for many years as a fumigant in the food and agricultural industries as well as in museums. Because of its effect on the ozone layer it has been targeted for restrictions and will soon be phased out of use in North America and Europe, but many museums had already sought alternative treatments because of the hazards and residues associated with methyl bromide. Liquid methyl bromide will react with a variety of sulphur-containing materials such as leather, wool, rayon, vinyl, rubber, hair, feathers and photographic chemicals. This reaction produces a sulphurous or rotten egg-like smell from materials, which is impossible to remove.

Phosphine

Phosphine gas is evolved slowly from solid aluminium or magnesium phosphides in the presence of moisture. Because of this it does not require the use of complicated delivery apparatus or measuring devices. The gas must be contained in a gas-proof sheet or chamber and exposures must be longer as it kills insects more slowly than other fumigant gases. Five clays may he sufficient at temperatures of 25 C but at lower temperatures of around 15°C, two weeks may be needed. Although it has been used successfully for treatment of mammal and bird skins, there have been reports of phosphene causing corrosion of metalwork at high humidities.

Vapona, DDVP or Dichlorvos

DDVP typically comes packaged in a plastic resin strip. The strip contains the active ingredient 2,2-dichlorovinyl dimethyl phosphate which slowly vaporizes into the atmosphere. The concentration builds up slowly until it is high enough to kill insects and this means that the strips are most effective in enclosed cases or cupboards and are ineffective when hung in ventilated areas. DDVP is not a penetrative fumigant and is unsuitable for control of insects such as wood-borers, which live inside materials (Williams and Walsh, 1989). The strips will eventually exhaust their supply of DDVP in three to six months depending upon temperature. As the DDVP vaporizes, the resin strip starts to break clown and produce a discharge. This discharge is yellow in colour and may cause discoloration or staining of objects in direct contact with the strip. If used, DDVP must be used at the correct dosage and the strips should be wrapped in cheesecloth or muslin to prevent direct contact with objects.

Dichlorvos is animals and its very toxic to humans and use is being reviewed and restricted in some countries.

Repellents

A number of chemicals such as camphor, naphthalene and para-dichlorobenzene have been used for many years as repellents and passive fumigants. They are crystalline solids which slowly vaporize and, to be effective in killing insects, the vapour must be contained at a high concentration in a storage case, drawer or bag. At lower concentrations there is some repellent effect on booklice, moths and beetles. Due to the rate of volatilization, vapours tend to move out of the enclosed air-space to contaminate the surrounding areas. The health hazards to humans from these chemicals are high enough that it is advisable to investigate alternative methods.

Para-dichlorobenzene (PDB)

PDB will kill insects at high concentrations but is known to adversely affect articles containing such materials as zinc white, lithopone, scarlet pigments and some dyes used on cellulose acetate. It will severely shrink polystyrene foams and plastics and will structurally weaken resins. PDB will also discolour the ultramarine pigment and contribute to the yellowing of paper and fading of ink. Dawson (1992) states that this is caused by the chlorine in PDB. The use of PDB is being phased out as it is now regarded as a health hazard and long-term exposure may cause serious health problems.

Naphthalene

Naphthalene is still widely used in homes and museums to repel and control fabric insect pests. Although there is some repellent effect on adult moths and beetles at lower concentrations, the levels required to kill insects are high. High concentrations may be encountered during the initial placement of the chemical or upon opening of containers such as storage bags, boxes or chambers. Naphthalene will produce discoloration in wool and may dissolve fats in biological specimens (Dawson, 1992).

Camphor

Originally obtained from tree resin but now synthesized from pinene, camphor has been used for many years as a moth and beetle repellent. Although effective at high concentrations, there are concerns relating to safety of use because of its toxicity. The short-term and long-term occupational exposure limits in the USA and the UK are lower for camphor than for naphthalene or para-dichlorobenzene.

Plant-derived repellents

Plant products such as lavender seed heads and cedarwood oil have traditionally been used to protect objects from attack by moths and beetles. With the demise of many synthetic pesticides, attention has again been focused on these products. Certain oils derived from lavender and cedarwood do have repellent effects on insects, but it must be remembered that many are also quite toxic to humans and may have deleterious effects on objects. More research is needed before they can be recommended as safe alternatives to protect collections.

Treatment of the collection environment — contact insecticides

An important part of the IPM strategy may be insecticide treatment of a part of the building to stop the spread of insects from infested objects or to attempt to eradicate them from harbourages in the storage furniture or in the structure of the building.

Applications of contact pesticides, both natural and synthetic, have been used for many years, often in the form of the routine application of a pesticide by a pest control company to kill any insects in the area. Although some treatments have a value, all pesticide use in collections should be questioned and only used if appropriate and targeted on the pest (Pinniger and Child, 1996).

Pesticides may present a hazard to objects in the collections due to undesirable side effects (Dawson, 1992) and many pesticides have been withdrawn due to health and environmental concerns. These include arsenic compounds and dusts, hydrogen cyanide, mercuric compounds, lindane, chlordane, heptachlor and other organochlorine insecticides.

Pyrethrins and pyrethroids

Pyrethrins or pyrethrums are natural botanical derivatives of the chrysanthemum flower-head. Only a specific variety of this flower can be used to yield the desired commercial grade of the material. Pyrethrins are a combination of different chemical constituents (pyrethrums) derived from this process. Some of these components cause rapid knock-down of insects and others cause the death of the insect. Although safe, their usage is very limited due to the rapid degradation of the material when exposed to ultraviolet light.

Pyrethrins are usually dissolved in a petroleum distillate base solvent system and applied as an aerosol. The particles that are produced are approximately 80—100 pm (microns) in diameter. While this sounds very small, the particles will stay suspended in the air only a few hours. The pyrethrins are also very photosensitive and degrade rapidly in sunlight due to the UV rays. A realistic lifetime for pyrethrins applied in a room is about twenty minutes and this means that they have little value in museums except as an emergency treatment for invading insects such as flies or wasps. The petroleum distillates in the solvent systems are a disadvantage as they can damage by staining or by dissolving oily and fatty substances.

The pyrethroids, which include permethrin, cypermethrin and deltamethrin, are synthetic analogues of pyrethrins which are much more stable in the environment, but are also more toxic. These are very effective insecticides against a wide range of insect pests and are widely used as residual sprays and dusts to control crawling insects.

Other residual insecticides

A number of other insecticides are used as residual treatments in museums. These include carbamates, such as bendiocarb, and organophosphates, such as chlorpyrifos. The effectiveness of these depends upon the siting of the treatment and the type of formulation used. Sprays are more useful for treatment of walls and floors, and dusts may be more appropriate for treatment of dead spaces in ducting and under units.

Most dust formulations have a true insecticidal effect but desiccant dusts also have another effect on the insect by removing the waxy coating on the exterior of the insect's body. The waxy coating is used to retain water and, without it, the insect dies from dehydration. These dusts are safe and long-lasting and can be very effective for treatment of wall voids, under cabinets and shelving units and in other dead air-spaces. The dust may sometimes be impregnated with natural pyrethrins to speed up killing of the insects.

Effects of treatment on objects and staff

Many treatments may have some undesirable side-effects. These may be from the insecticide's active ingredient or the other chemicals used in the formulation. Such effects include damage to objects and books from water- or oil-based sprays and fogs. Colour changes, staining and loss of structural integrity can all result from careless application of a pesticide. Some formulations such as micro-emulsions have been designed to have minimum impact on materials (Pinniger *et al.*, 1994). Others such as micro-encapsulated formulations have been developed to adhere to structural surfaces and then release the pesticide only when it is picked up by the insect.

Some consideration must be given to the possible contamination of objects by previous treatments. In the past, many objects were directly sprayed or dusted with insecticides such as lindane and DDT. In addition, many herbarium specimens were treated with mercuric chloride and mammal skins with arsenic. It is always advisable to take precautions when handling old specimens which may have been treated, to prevent absorbence through the skin and inhalation of toxic dust (Linnie, 1990) (see also Chapter 9 on policies and procedures).

Whenever the use of pesticides is contemplated it is essential to ensure that the product is registered for museum use and that it is appropriate for the pest and the environment and will have no undesirable effects on the collection.

Implementation of IPM

An IPM programme should not be set in tablets of stone at the beginning but is essentially an evolving process which should apply local knowledge and respond to changing needs and priorities (Rossol and Jessup, 1996).

Implementing an IPM programme in a large museum or collection can be a daunting task. It is therefore important to identify priorities and plan to cover the museum or institution in achievable steps. In many cases it has taken some years to develop and implement a programme in a large national collection (Hillyer and Blyth, 1992). This has been achieved by initially selecting one department or collection area, demonstrating that IPM is effective and achievable in that area, and then adapting the programme for other areas until all parts are covered.

The following list gives a summary of IPM procedures:

- Obtain a plan of the building or collection or make sketches.
- Carry out a preliminary survey to identify high-risk areas and objects.
- Include the outside of the building, galleries, stores and all other areas.
- Place monitoring traps in a grid.
- Plan a detailed inspection schedule.
- Check cleaning regimes.
- Check existing pest control contracts. Examine the movement of objects in and out of the museum.
- Plan a quarantine strategy if one is not in place.
- Explain to key people the objectives of IPM.

- Form a small team to aid communication and spread the IPM load. This can, for example, include conservation, collection management and buildings management.
- Examine training and awareness needs.
- Write an outline strategy for short-term and long-term IPM.
- Identify budgets that may contribute funding for IPM. For example, training, buildings maintenance, collections care, storage furniture etc.

Because of the effects of some chemicals on staff, objects and the environment there will be increased pressure to move away from persistent and toxic insecticides. As you implement and maintain an IPM programme in your facility, staff will begin to work with you once they see the merits of the programme. The development of an IPM programme based on the principles outlined in this chapter will enable collections to be cared for in ways which are safe and effective.

References

Bennett, G.W.. Owens J.M and Corrigan R.M. (1988). *Truman's Scientific Guide to Pest Control Operations*, 4th edn. Purdue University/Edgell Communications.

Child, R.E. (1994). The Thermo Lignum process for insect pest control. *Conservation News*, **72**, *9*.

Child. R.E. and Pinniger, D.B. (1994). Insect trapping in museums and historic houses. *IIC 15th International Conference on Preventative Conservation. Practice, Theory and Research*. Ottawa.

Cox, P.D., Pinniger, D.B. and Mueller, D. (1996). Monitoring populations of the webbing clothes moth, *Tineola bisselliella*, using pheromone lures. Second International Conference on Insect Pests in the Urban Environment, Edinburgh.

Dawson, J.F.. (1992). Solving museum insect problems: chemical control. *Canadian Conservation Institute Technical Bulletin*, **15,** 1—26.

Derrick, M.R., Burgess, II.D., Baker, M.T. and Binnie, N.E. (1990). Sulfuryl fluoride (Vikane): a review of its use as a fumigant. *journal of the American Institute of Chemistry*, **29**, 77—90.

Edwards, R. and Mill, A E. (1986). *Termites in Buildings*. Rentokil Ltd, West Sussex.

Florian, M.-L. (1986). The freezing process — effects on insects and artifact materials. *Leather Conservation News*, **3**, 1-13, 17.

Florian, M.-L. (1989). Freezing for museum insect pest eradication. *Collection Forum*, **6,** 1—7.

Florian, M.-L. (1990). The Effects of freezing and freezedrying on natural history specimens. *Collection Forum*, **6,** 45-52.

Gilberg, M. (1989). Inert atmosphere fumigation of museum objects. *Studies in Conservation*, **34**, 1—84.

Gilberg, M. (1990). *Inert atmosphere disinfestations using Ageless oxygen scavenger*. Ninth Triennial Meeting of ICOM. Committee for Conservation.

Gilberg, M. (1991). The effects of low oxygen atmospheres on museum pests. *Studies in Conservation*, **36,** 93—98.

Gilberg, M. and Roach. A. (1991. The use of a commercial pheromone trap for monitoring *Lasioderma serricorne (F.)* infestations in museum collections. *Studies in Conservation*, **36,** 243—247.

Hanlon, G., Daniel, V., Ravenel, N. and Maekawa, S. (1992). Dynamic system for nitrogen anoxia of large museum objects: a pest eradication study. *Second International Conference on Biodeterioration of Cultural Property*, Yokohama.

Hillyer, L. and Blyth, V. (1992). Carpet beetle — a pilot study in detection and control. *Conservator*, **16.**

Lambert, F.L., Daniel, V. and Preusser, F.D. (1992). *the rate of absorption of oxygen by Ageless: The utility of an oxygen scavenger in sealed cases*. Getty Conservation Institute, Marina del Rey, California.

Linnie, M.J. (1990). Conservation: pest control in museums — the use of chemicals and associated health problems. *Museum Management and Curatorship, Professional Notes*. **9,** 419—423.

Linnie, M.J. (1996). Integrated pest management: A proposed strategy for natural history museums. *Museum Management and Curatorship*, **15,** 135—143.

Meehan, A.Y. (1984). *Rats and Mice*. Rentokil Library, Rentokil Ltd, West Sussex.

Mound, L. (1989). *Common insect pests of stored food products. A guide to their identification*. British Museum (Natural History) Economic Series No. 15, London.

Nesheim, K. (1984). The Yale non-toxic method of eradicating book eating insects by deep-freezing. *Restaurator*, **6,** 147—164.

Peacock, E.R. (1993). Adults and larvae of hide, larder and carpet beetles and their relatives. *Handbooks for the Identification of British Insects*, Vol 5. Royal Entomological Society, London.

Pinniger, D.B. (1994). *Insect Pests in Museums*, 3rd edn. Archetype Press, London.

Pinniger, D.B. and Child, R.E. (1996). Insecticides: optimising their performance and targeting their use in museums. *Third International Conference on Biodeterioration of Cultural Property*, Bangkok.

Pinniger, D.B., Morgan, C., Child, R.E. and Lankford, W. (1994). A novel micro-emulsion formulation of permethrin for the control of museum insect pests. *TIC 15th International Conference on Preventative Conservation, Practice, Theory and Research*. Ottawa.

Quek, L.M.. Razak, SI. and Ballard, M.W. (1990). *Pest Control for Temperate vs. Tropical Museums: North America vs. South America*, Vol. II, pp. 817—820. ICOM Committee for Conservation.

Reichmuth, C., Unger. W. and Unger, A. (1991). The use of nitrogen to control wood destroying insects in works of art. *Restaurator*, **4**, 246—251.

Rosso], M. and Jessup, W.C. (1996). No magic bullets: safe and ethical pest management strategies. *Museum Management and Curatorship*, **15,** 145—168.

Rust, M.K.. Daniel, V., Druzik, J.R. and Preusser, F.D. (1996). The feasibility of using modified atmospheres to control insect pests in museums. *Restaurator* **17**.

Smith, E.H. and Whitman.R.C. (1992). *Field Guide to Structural Pests*. National Pest Control Association, London.
Spivak. S.M.. Worth. J. and Wood. P.E. (1981). Assessing the effects of pesticidal chemicals on historic textiles. In *Preservation of Paper and textiles of Historic and Artistic Value II,* pp. 333—343, Advances in Chemistry Series 193. American Chemical Society. Washington. DC.
Strang. T.T.K. (1992). A review- of published temperatures for the control of pest insects in museums. *Collection Forum*, ***8,*** *2*.
Strang, T.J.K. (1996). The effect of thermal methods of pest control on museum collections. *Third International Conference on Biodeterioration of Cultural Property*. Bangkok.
Valentin, N. and Preusser, F. (1990). Insect control by inert gases in museums, archives and libraries. *Restaurator,* **11.** 22—23.
Valentin. N. (1991). Controlled atmosphere for insect eradication in library and museum collections. *International Seminar on Research in Preservation and Conservation*, Arden House.
Valentin, N., Lidstrom, M. and Preusser, F. (1990). Microbial control by low oxygen and low relative humidity environment. *Studies in Conservation, 35*. 222—230.
Williams, S.L. and Walsh, E.A. (1989). Developing chemical pest control strategies for museums: effects of DDVP on pests and materials. *Curator,* **32,** 3-i 68.
Zycherman. L.A. and Schrock, J.R. (eds) (1988). *A Guide to Museum Pest Control*. Association of Systematics Collections.
Hanlon, G. (1992). *Progress in project on the feasibility of using modified atmospheres for museum pest eradication: An overview*. J. Paul Getty Museum. Malibu. California.
Harmon, J. and Coleman, C. (1993). Pest management and disaster preparedness. *Conservation Administration News,* ***52,*** 6—7.
Mallis. A. (1982). *Handbook of Pest Control*. Franzak and Foster Co.
Morgan, C.P., Pinniger, D.B. and Bowden, N.S. (1993). The effectiveness of residual insecticides against the varied carpet beetle *Anlhrenus verbasci* and the implications for the control of this pest in museums. *International Conference on Insect Pests in the Urban Environment,* Cambridge.
Parker, T. (1988). *Study on Integrated Pest Management for Libraries and Archives*. Gen. Info. Prog. and UAISIST, Paris, UNESCO.
Pinniger. D.B. (1996). Insect control with the Thermo Lignum treatment. *Conservation News*, ***59.***
Pinniger, D. and Winsor, P. (1998). *Integrated Pest Management*. Museums & Galleries Commission, London.
Smith. R.D. (1984). The use of redesigned and mechanically modified commercial freezers wetted books and exterminate insects. *Restaurator,* **6**, 165-190.
Webb, E. A. *et al.* (1989). Integrated pest management at the Denver Museum of Natural History. *Collection Forum*, **5**, 52-59.

Further reading

Berkouwer, M. (1994). Freezing to eradicate insect pests in textiles at Brodsworth Hall. *Conservator,* **18,** 15—20.
Brezner, J. and Lunen, P. (1989). Nuke 'em! Library pest control using a microwave. *Library Journal*. **Sept. 15.** 60-63.
Daniel, V. and Hanlon, G. (1996). Non-toxic methods for pest control in museums. *Third International Conference on Biodeterioration in Cultural Property*. Bangkok.
Ebeling, W. (1978). *Urban Entomology*. University of California.
Florian, M.-L. (1987). Methodology used in insect pest surveys in museum buildings — a case history. *Eighth Triennial Meeting of ICOM* Sydney.

Suppliers

We recommend that when seeking advice about pest control companies or products, pesticide regulation authorities such as the Health and Safety Executive in the UK or the Environmental Protection Agency in the USA should be contacted.

Monitoring traps

Agrisense-BCS Ltd. Treeforest Industrial Estate, Pontypridd, Mid Glamorgan CF37 SSU, UK.
Museum Trap, Historyonics, 17 Talbot Street. Cardiff CF1 9B NV, UK

Monitoring traps are also available in most large suppliers catalogues.

Plate 24 Insect specimens damaged by *Anthrenus verbasci* (David Pinniger).

Plate 25 Reptile damaged by *Anthrenus sarnicus* (David Pinniger).

Plate 26 Lioness severely damaged by *Tineola bisselliella* (David Pinniger).

Plate 27 Feathers damaged by *Tinea pellionella* (note larval cases) (reproduced with kind permission of the Central Science Laboratory, York).

Plate 28 Dried manioc cake eaten by *Stegobium paniceum* (reproduced with kind permission of the Central Science Laboratory, York).

Plate 29 Herbarium specimens damaged by *Stegobium paniceum* (David Pinniger).

Plate 30 Parrot damaged by *Lasioderma serricorne* (reproduced with kind permission of the (catral Science Laboratory, York).