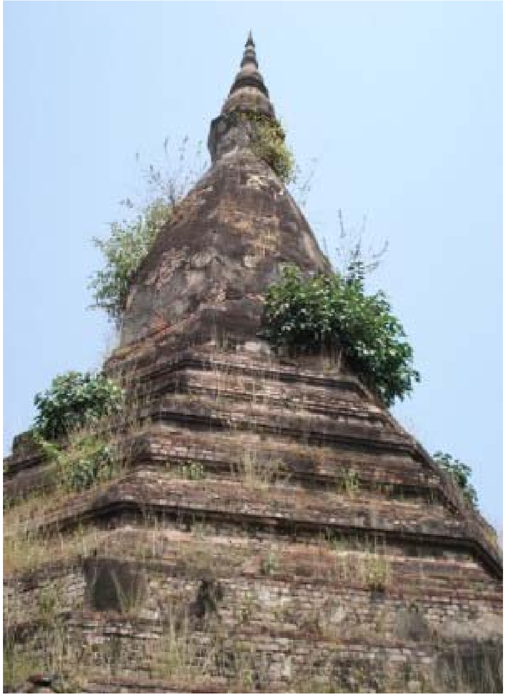
Museum Collections and Biodeterioration in Laos



Outdoor collection, Vientiane. Photo by Author

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Chapter 1 Introduction

1.1 Background

Biodeterioration, defined as damage caused by living organisms such as fungi and termites, endangers cultural property all around the world. The destruction results in “enormous economic loss” (Khadelwal 2003:76) and the irreversible cultural and artistic loss of the information of the objects affected.

The loss is greatest among materials derived from plants and animals, since the food value of the cellulose or protein that comprise these materials makes them particularly vulnerable to biological attack (Allsopp, Seal & Gaylarde 2004:1). As a result, wooden objects and structures, bamboo artefacts, manuscripts, books, textiles, leather, paper, basketry, and various types of paintings are most at risk. Stone and masonry are also vulnerable, however, and stone monuments and outdoor sculptures may become severely damaged. Cultural property is even more endangered while kept under adverse environmental conditions that invite biodeterioration, typically hot and humid surroundings.

In Laos, situated on Southeast Asia mainland, temperatures range from 23˚C to 40˚C and humidity is high throughout the year, even during the dry season (Lao PDR Forum: Lao PDR Climate 2007; Climate Information for Lao Climate: Lao Climate Zone 2004). These environmental conditions encourage microorganisms and insect pests to thrive and reproduce, and therefore make biodeterioration an especially urgent problem. The author’s experience in Laos has been involved with this situation and with questions about what can be done in museums to deal with such conditions and protect Laos’s cultural heritage.

1.2 Key Issues

Museums in Laos preserve cultural materials of the past for future generations. However, the fertility and the high temperature and humidity of the tropical climate bring on biodeterioration. These conditions combined with urban pollution, bad building maintenance and low budgets make long-term preservation of collections very difficult for museum professionals. Mould and insect pests are a major problem for museums, even with repeated treatments for insect infestation. Because appropriate and safe environments are not provided for collection storage and display, the mould and insect problems reoccur. Therefore, plans for prevention and control of biodeterioration that are appropriate for the conditions in Laos are critically important for museum personnel (Daniel 2003:76).

1.3 Aims

The aim of this thesis is to compile comprehensive information about biodeterioration and solutions to biodeterioration, to explore the current situation regarding museum collections and biodeterioration in Laos, and to develop an action plan for Lao museums to help them control and prevent biodeterioration.

1.4 Objectives

The objectives of this thesis are:

1. To define biodeterioration and to investigate the main causal agents, especially those in Laos
2. To identify how environmental conditions affect biodeterioration
3. To identify the materials in Lao collections affected by biodeterioration
4. To review the literature relating to the prevention of biodeterioration

5. To evaluate biodeterioration in Lao museums by studying biodeterioration and environmental conditions in a sample of museums and identifying key problems and possible solutions to them
6. To formulate an action plan for museums in Laos regarding biodeterioration.

Objectives 1, 2 and 3 will be treated within an introduction to the biodeterioration framework developed using literature on theory as a starting point.

Note: Museums in this thesis refers to museums, galleries, monuments and temples

1.5 Methodology

First of all, this thesis states clearly the aim and objectives of what the research is trying to achieve, what it is all about, and the reason for doing the research; otherwise there would be no point to spending time, money and effort undertaking the investigation. These statements of purpose indicate the focus and direction of the research, and provide criteria for the evaluation of the outcomes of the research. The research relates the existing knowledge to the needs, makes a contribution to the development of existing knowledge, and addresses specific practical needs. The research also recognizes the availability of resources and times the investigation to opportunities for access to relevant data (Denscombe 2002:25, 43, 64). Data collection is critically important, is the “soul” of a study, and this thesis follows the principles that the validity of research depends on accurate data, and the accuracy of the data depends on the validity of the data collection method (Fink 2005:106).

In accordance with these foundations of research, this thesis combines information from the literature on biodeterioration and heritage preservation, from communications with museum professionals in these fields to fulfill objectives 1 through 4. These sources provide the research related to biodeterioration in tropical environments and in museums. The research is concentrated on tropical biodeteriogens and biodeterioration, since the focus of this thesis is on the types of biodeteriogens found in Lao museums, ranging from microorganisms to higher plants, insects and animals. Therefore the emphasis in the research has been on selecting sources that reflect the conditions and preservation needs of tropical regions and, whenever possible, those of Southeast Asia in general or Laos in particular. The research was done to answer two thesis questions of, firstly, what are the life cycles, habits, and food sources of these biodeteriogens and their effect on Lao cultural property; and, secondly, what are the means of controlling and preventing biodeterioration that are applicable to Lao museums.

To fulfill objective 5, questionnaire interviews and observations at Lao museums, whose methodology will be discussed in Chapter 4, have also been used to get information about biodeterioration at nine representative institutions. The observations utilise the author's research and experience in Laos as collections manager of the Luang Prabang National Museum.

All this information has been brought together to create the action plan for Lao museums (objective 6). This action plan and the research that precedes it fulfills the overall purpose for this research, which is to find as much information as possible for the staffs of Lao museums to study, so that they can take action to solve the problem of preserving their collections for long term preservation.

Information on biodeterioration problems and solutions has been tabled in the text to provide easy reference for museum professionals and other readers who will need the information for their work.

1.6 Organisation

This thesis begins in Chapter 2 with a discussion of the most common agents of biodeterioration, including microorganisms, higher plants, and animals, which are described by their habits and life cycles and by their effects on specific types of materials used in cultural artefacts. The chapter tables the information and also cross-references it by artefact materials in a table that lists the biodeterioration threats to each one.

Chapter 3 concerns the solutions to the problems described in Chapter 2. General preventive and remedial methods of preservation are explained, and techniques of controlling or eliminating each type of infestation are outlined. The information is summarised in a table

Chapter 4 describes a survey of biodeterioration at nine representative Lao museums and collections. The survey's objectives, methodology, and results are presented and discussed.

In Chapter 5, information given in Chapters 2 and 3 is applied to the results of the survey to create the action plan to help Lao museums protect their collections from biodeterioration.

Finally, Chapter 6 contains conclusions about biodeterioration in general and about its effect and the possibilities of managing it in Lao museums and collections.

Chapter 2 An Introduction to Biodeterioration

2.1 Biodeterioration and Its Causal Agents

Biodeterioration can be defined as “any undesirable change in the properties of a material caused by the vital activities of living organisms”, as distinguished from changes produced by “chemical, mechanical, and physical influences” (Kumar and kumar 1999: vii). Biological agents that produce deterioration are referred to as *biodeteriogens*, and these range from microorganisms like fungi to higher plants and to animals such as insects and rodents (see **Table 2.1**).

Biodeterioration of cultural property is a major problem in almost all parts of the world, for art works and artefacts are constantly being destroyed by biological agents. Since organic materials, which are most vulnerable to biological attack, are used for many traditional Lao artefacts, and since the high heat and humidity in Laos weaken organic materials and favour the growth and reproduction of biodeteriogens, Laos faces critical problems in protecting its cultural collections from biodeterioration. This chapter will discuss the major biodeteriogens, the effects of environmental conditions on biodeterioration, and the threats of biodeterioration to the materials most commonly found in the museum collections of Laos. The information is summarised briefly with an emphasis on biodeterioration of Lao artefacts.

2.1.1 Bacteria and Bacterial Biodeterioration

Bacteria

Bacteria are colonial organisms of various shapes. As biodeteriogens of cultural materials, they are most commonly found on outdoor stone objects and monuments, especially where the surface is wet. Because bacteria are microscopically small, their presence on stone is usually known by the chemical changes that they bring about in the stone (Kumar and Kumar 1999:12).

Bacterial Biodeterioration

In tropical environments, where there are many different kinds of bacteria, bacteria damage stone by producing acids that react with stone to create crusts on the stone surfaces, dissolve cations in the stone, and stain the surface (Kumar and Kumar 1999:14). The most common effects are colored microbial films, which cause aesthetic damage to stone monuments. Bacteria can also support the growth of other microorganisms by becoming a nutrient source for fungi or other bacteria that have a higher destructive potential (Kumar and Kumar 1999:15-16).

Wood is subject to attack by bacteria when it is waterlogged from standing in water or mud. These bacteria eat portions of the wood and weaken it so that it even more damaged by contact with water (Heritage Collection Council: Caring for Cultural Material 2 [“HCCCCM 2”] 1998:50).

2.1.2 Fungi and Fungal Biodeterioration

Fungi

Fungi, such as moulds, are “a group of chemoheterotrophic organism characterized by unicellular or multicultural filamentous hyphae” (Kumar and Kumar 1999:17). The air carries of all kinds of fungal structures, so any material exposed to the air can become contaminated with many different fungi, but the fungi will develop only if environmental conditions and the moisture and composition of the material of the objects meet the fungi’s growth requirements (Florian 2002:2). Most fungi that develop on the surface of cultural objects are a type called “conidial” fungi (Florian 2002:31).

Fungal Biodeterioration

Fungi contribute to the decay of limestone, marble, and other stones, which can become discolored and powdery on the surface (Kumar and Kumar

1999:17-18). Among artefacts, fungi most often attack paper, and manufactured paper is more susceptible than handmade paper because it contains starch, glue, vegetable proteins, dyestuffs, pigments, dispersing agents, and other additives that provide nutrients. Dirty paper is especially susceptible, and acidic paper is also highly susceptible because fungi prefer a slightly acidic environment. Textiles are also affected, though less frequently; cotton cloth is more susceptible than silk, and dirty textiles are more susceptible than clean ones (Aranyanak 1995:85-86). Fungi breed most successfully on damp walls and can move from there to infest artefacts (Florian 2002:25). Moulds attract insects such as silverfish, which feed on moulds, and therefore also expose cultural materials to infestations by other biodeteriogens (Pinniger 1989).

2.1.3 Algae and Algal Biodeterioration

Algae

Algae are non-flowering stem-less water plants representing a diverse group of organisms of various shapes that contain pigments. Algae are most commonly found as patinas or sheets of organisms, varying in extent, thickness, consistency, and color, growing on outdoor stone or masonry. The most important conditions for establishing algae on these surfaces are dampness, warmth, lights, and inorganic nutrients, particularly the calcium and magnesium minerals of certain stones and in cement, mortar, and stucco (Kumar and Kumar 1999:18). Algae usually appear in green-black layers on the surface of stone, especially on horizontal surfaces that stay damp for most of the time (Aranyanark 2003:12).

Algal Biodeterioration

The most obvious damage caused by algae is a loss of aesthetic value when algae cover over the surface of stone or masonry, and removal of algae may leave light-green to black-coloured stains which may entirely mask a surface (Aranyanark 2003:12). Algae may also cause biochemical deterioration, since they produce a variety of organic acids which dissolve stone and lead to a powdering of stone or masonry surfaces. Algae also secrete proteins, which dissolve stone by removing minerals from it, and sugars which promote the growth of bacteria (Kumar and Kumar 1999:19-20). Algae therefore stain and disfigure stone and masonry surfaces and weaken these materials.

2.1.4 Lichens and Lichenic Biodeterioration

Lichens

Lichens are a large group of composite organisms formed by the association of bacteria or algae with fungi. They grow on rocks and outdoor stone monuments and artefacts, especially those of sandstone (Kumar and Kumar 1999:20). Some lichens prefer surfaces with low humidity and a shady location. Some lichens prefer external surfaces which are protected from rain and drainage, and some prefer horizontal surfaces close to the soil level and in contact with vegetation that keeps the surface damp (Aranyanark 2003:12).

Biodeterioration by Lichens

Lichens grow primarily in preexisting cracks and fissures in the stone. As the hyphae that attach lichen to stone grow longer and wider, the cracks and fissures become larger, and other biodeteriogens may come to live in them. Because they are especially strong and grow aggressively, lichens are extremely harmful biodetergens (Kumar and Kumar 1999:22). Some lichens form a hard crust on the stone surface that acts as a protective coating, shielding the stone from the action of wind and rain, but the lichens are still active underneath the crust and continue to damage the stone (Aranyanark 2003:13).

2.1.5 Higher Plants and Biodeterioration by Higher Plants

Higher Plants

Higher plants are photoautotrophic organisms with specialised tissues and organs that permit a subdivision of activities. They have a differentiated structure composed of roots, stems, leaves, and other elements. Higher plants can be on the basis of the absence or presence of seeds (Kumar and Kumar 1999:22).

Biodeterioration by Higher Plants

Higher plants take root in preexisting cracks in outdoor stone and masonry and cause physical and chemical damage. The biophysical damage occurs as plant roots lengthen and thicken into the cracks, which leads to breakage and crumbling around the roots (Kumar and Kumar 1999:25). When this happens in plaster or the mortar between stones, the stones gradually loosen and become more unstable (Gill and Bolt; Winkler; Mishra, Jain, and Garg quoted in Kumar 1999:25). The presence of plants also influences the microclimate of the stone surface by increasing relative humidity and water retention, which favour the growth of microorganisms and additional higher plants (Kumar and Kumar 1999:27).

2.1.6 Silverfish and Biodeterioration by Silverfish

Silverfish

Silverfish are small (less than 10mm) insects named for their silver-grey colour and fish-like shape. They have long antennae at the front and a three-pronged forked tail; adults have wings, but nymphs (immature silverfish) do not. Silverfish are common insect pests in homes, museums, and heritage buildings. They prefer warm, humid environments (70%-80% RH), they like darkness, and they live in tight, dusty cracks (Florian 1997:57).

Biodeterioration by Silverfish

Silverfish are a threat to heritage collections. They eat the glue and the starch and protein sizing of books, documents, stored paper, wallpaper, and works of art on paper (Florian 1997:57). They also feed on textiles, especially starched or stained cotton or linen, and on photographs. They create holes and surface erosion in all these materials (Heritage Collections Council: Damage and Decay [“HCCDD”] 1998:51). Because they like their bodies to make tight contact with surfaces, they are likely to move through tiny openings that museums are unaware of or thought were sealed and silverfish-proof. Any sighting of silverfish means that silverfish are also elsewhere in a museum and its collection (Florian 1997:57).

2.1.7 Termites and Biodeterioration by Termites

Termites

Termites are social insects that resemble ants and generally live in groups or colonies. Their members are differentiated by division of labour, i.e., queens lay eggs and control population, workers provide the colony with a food supply, and soldiers carry out defense (Verkerk 1990:7).

Termites are of many different species. Some termites develop their colonies and maintain their headquarters in the ground. They build their tunnels through earth and around obstructions to reach food sources, especially wood. They also must have a constant source of moisture, whether from the wood on which they feed or the soil where they nest. They travel underground from the nest to a food source, creating mud tunnels across surfaces exposed to air (Highley 1999:11). Termites are most commonly found in tropical and sub-tropical areas where the high humidity increases the moisture content of wood (HCCDD 1998:50).

Biodeterioration by Termites

Termites eat anything containing cellulose, e.g., plant materials such as those in wooden architecture, wooden furniture and artefacts, bamboo, cellulosic textiles (cotton, linen), paper, and ethnographic artefacts of grasses or fibres. Termite damage can be extensive if left undisturbed (Kingsolver 1988:81, Verkerk 1990:8). Termite infestations occur when cellulosic materials are wet from rain or dampness or when moisture content is high from high humidity. For this reason, all cellulosic materials in tropical regions are at risk, from the timber supports of buildings to collection objects.

Certain species of termite eat not only cellulosic materials, but also plastic, leather, and almost any other soft material (Verkerk 1990:110).

2.1.8 Borers and Biodeterioration by Borers

Borers

Borers are insects that, in their worm-like larval stage, bore their way through timber. Most borer larvae feed on the sugars and starch found in the sapwood portion of wood, creating tunnels and producing a powder, called “frass”, that consists of excrement and undigested particles of wood. Larvae may live in wood for as many as five years, until the larval stage of their life cycle is complete and they transform into adults, lay their eggs in the wood, and emerge into the air though tiny “exit holes” which they eat in the remaining surface shell of the wood. Their eggs hatch and become larvae, thus amplifying the infestation and its damage. The two most common borers are the powderpost beetle and furniture beetle (HCCDD 1998:48), but deathwatch beetles, longhorn beetles, and bostrychid beetles are also found in heritage collections worldwide. Adult powderpost beetles are dark red to black in colour, and the larvae are white with a brown head (Kingsolver 1988:57). Furniture beetles have the same colouring as powderpost beetles, but are slightly larger in size (HCCDD 1998:48).

Biodeterioration by Borers

Powderpost beetles eat hardwoods and also bamboo and basketry, and their borings typically turn wood into a powder underneath the outside shell of wood, which is marked only by the exit holes of adults. Frass may emerge from exit holes or from cracks or gaps in the shell (Kingsolver 1988:57, HCCDD 1998:48).

Furniture beetles attack softwood rather than hardwood, but will infest some hardwoods as well (HCCDD 1998:48). Additional targets are plywood and books. The larvae eat tunnels in the wood for two to three years before transforming into adults, laying their eggs, and emerging through small round exit holes, leaving gritty frass in the tunnels they have bored. They require an environment where the relative humidity exceeds 50% (Museums and Galleries Commission [“MGC”] 1998:15; Blyth 2001:44).

Deathwatch beetles attack historic building timbers, producing severe damage. Longhorn beetles produce extensive damage because the larvae bore tunnels for three to five years and the adults lay extremely high numbers of eggs (Pinniger 1989; Pinniger 2001).

2.1.9 Cockroaches and Biodeterioration by Cockroaches

Cockroaches

Most cockroach species are tropical, and would not survive in cold climates (Bell 1988:83). They prefer to live near sources of food and water and in warm, dark or dim areas, which they leave only to satisfy their hunger and thirst. In the dark they run quickly and tend to cluster in the middle of a room. They like to crawl into tight cracks where their backs and undersides are in contact with other surfaces (Bell 1988:86-87; Florian 1997:58-59).

Biodeterioration by Cockroaches

Both adult and nymph (immature) cockroaches cause damage. They eat plant (cellulosic) and animal (proteinaceous) materials, including starchy materials, sugary or fermented foods, leather, parchment, books, wallpaper, and natural history specimens (Kingsolver 1988:74; Florian 1997:59). Damage commonly occurs in drawers and closets, in bookshelves where cockroaches feed on binding paste, and inside furniture (Bell 1988:85). Cockroaches also leave a trail of excreta, which stains materials and can attract other biodeteriogens, and they are thought by some to carry diseases, which might affect humans (Florian 1997:58).

2.1.10 Carpet Beetles and Biodeterioration by Carpet Beetles

Carpet Beetles

Carpet beetles are small (less than 4mm), oval insects. The colour of adults is dark brown or black with white patches and an irregular orange band in the middle of wing covers. Adult carpet beetles are commonly found indoors at windows. The larvae are dark brown with tufts of black hairs, usually about the same size as or smaller than the adults. The larvae often wander about the infested location (Kingsolver 1988:65; The Textile Museum: Pest Busters ["TTMPB"] 1998; Virginia 1996). Because the larvae are extremely small (less than 1mm) they can find tiny cracks in display and storage cases through which to enter and eat artefacts (Florian 1997:42).

Biodeterioration by Carpet Beetles

The larvae of the carpet beetles can cause extensive damage to a variety of proteinaceous materials, as its feeds without preference on wool, fur, horn, skins, hides, feathers, insect specimens, hair and silk. The larvae also feed on dead insects and cellulosic textiles, such as linen, cotton and rayon. Carpet beetle larvae leave clean neat holes in textiles and leave behind a fine powdery frass the same colour as the object they have eaten (TTMPB 1998; Blyth 2001:46; Virginia 1996).

2.1.11 Fur Beetles and Biodeterioration by Fur Beetles

Fur Beetles

Fur beetles are similar to carpet beetles, but they are slightly larger at 5mm. The adults are black with patches of white hair on either side near their middle. They are often found in foodstuffs and occasionally in grain (Bennett 2000).

Biodeterioration by Fur Beetles

As with carpet beetles, the tiny larvae can move through extremely small openings and do damage by feeding on the protein of wool, fur, feathers, leather, silk and dead insects. Fur beetle larvae produce irregular holes and leave long banded cast skins (Blyth 2001; MGC 1998).

2.1.12 Hide Beetles and Biodeterioration by Hide Beetles

Hide Beetles

Hide beetle adults are black with a band of white hairs and a white abdomen with lateral black spots. They are less than 10mm in length (Kingsolver 1988:63). The larvae are initially white but soon become dark. They are very active in the dark but become immobile and feign death in the light (Florian 1997:42).

Biodeterioration by Hide Beetles

It is the hide beetle larvae that produce damage. They eat mainly the protein in dried animal materials, e.g. woolens, feathers, hides, dried meat, dead insects, bone, and cast skin of insects, and they may also attack wood. Most adults eat only pollen (Kingsolver 1988:63; Florian 1997: 41).

2.1.13 Biscuit Beetles and Biodeterioration by Biscuit Beetles

Biscuit Beetles

Adult biscuit beetles are 3mm long and require temperatures above 22˚C to fly, so they are common in the tropics. The larvae are nearly white, usually hidden in the food source, and attack a wide variety of cellulose-containing items but prefer starchy and dried materials (Kingsley and Pinniger 2001:52).

Biodeterioration by Biscuit Beetles

Biscuit beetle larvae are attracted by dried food and spices, starchy plant specimens, seed heads and freeze-dried animal specimens. They produce round exit holes and gritty frass (Blyth 2001:46; MGC 1998:15).

2.1.14 Clothes Moths and Biodeterioration by Clothes Moths

Clothes Moths

Clothes moths are commonly of two types, case-making clothes moths and webbing clothes moths. Adult case-making clothes moths are less than 10mm long and brownish in colour, usually with three dark spots on each front wings; larvae are white with brownish head, less than 10mm in size for adults. Adult webbing clothes moths are golden-yellow with a tuft of bronze-coloured hairs on their head; larvae are whitish in colour. The larvae of clothes moths live in flat, oval cocoons of silk that the insects excrete and mix with bits of hair, frass, and fibres of the textiles they eat. The larvae drag the cocoons with them. After about a year, the larvae crawl into stronger cocoons and metamorphose into pupae, which later transform into adults (TTMPB 1998; Florian 1997:38-39; Kingsolver 1988:72-73).

Biodeterioration by Clothes Moths

Damage is done by the clothes moth larvae, which feed on the protein of wool, fur, and silk. Infestations may be hard to see because the cocoons under which the larvae feed include bits of fiber from the object so that it is often effectively camouflaged. Larvae produce large irregular holes and leave large quantities of silk webbing tubes, gritty frass, and thin areas in a textile. Moth infestation can develop rapidly and cause severe damage (TTMPB 1998; Blyth 2001:46).

2.1.15 Booklice and Biodeterioration by Booklice

Booklice

Booklice are small hard-bodied winged insects, less than 2mm long and grayish white in colour. The nymphs (immature lice) are smaller than the adults, move fast, have soft bodies, and are wingless. Booklice need a warm temperature of 30˚C to lay their eggs, so they are commonly found in warm environments, including the tropics (Kingsolver 1988:77; Florian 1997:58).

Biodeterioration by Booklice

Damage is done by both nymphs and adults. Booklice are attracted to the moulds growing on starch paste, paper, and wallpaper, and they scratch and erode the surface of these materials when they eat the fungi (Blyth 2001:46). For this reason, damp or mouldy books and paper are frequently infested (Kingsolver 1988:77; Florian 1997:58).

2.1.16 Geckos and Biodeterioration by Geckos

Geckos

Geckos, a type of lizard, are common in all buildings in the tropics and can be seen running along ceilings, walls, doors and windows. Big geckos like to hide in the dark, especially on beams or pillars or, in museums, in the space between the walls and hanging works of art. Geckos leave droppings; they may also lay their eggs in the recesses of artefacts.

Biodeterioration by Geckos

Although the geckos do not eat museum collections, they can cause damage from their acidic feces and urine; the urine leaves a white acidic residue consisting of uric acid. The droppings can also attract insects and feed microorganisms, encouraging infestations. Geckos are insectivores; therefore it is reasonable to assume that where there is a healthy gecko population there is also a healthy insect population (Egunnike 2001:30).

2.1.17 Rodents and Biodeterioration by Rodents

Rodents

Rodents, particularly rats and mice, are frequently found in museums and historic buildings. They can move through openings the diameter of a thumb and gnaw through wood and even light metal wire, so it may difficult to prevent their entrance into galleries and storage rooms. Rats grow to more than 12 cm long, so they are larger than mice; they also have longer teeth and leave larger droppings. Both mice and rats tend to live in groups and construct their nests with grass, fibres, shredded material or anything that they could find, which they place in dark undisturbed places like drawers and boxes, when the nests are indoors. Mice and rats are more active at night (MGC 1998:11).

Biodeterioration by Rodents

Rodents cause serious damage by eating wood, leather, and other soft organic materials and by shredding paper and textiles to make nest bedding. Mice and rats spread diseases through their parasites and feces, so these present a health hazard in museums, as well as produce staining of museum objects and attract infestations by other biodeteriogens. Their nests can also attract insect infestations (MGC 1998:11).

Typical signs of a rodent problem include gnaw marks near the base or side of the doors and cabinets to reach food; droppings and urine stains. Rat access burrows are dug in soft earth around building foundations (MGC 1998:13).

2.1.18 Bats and Biodeterioration by Bats

Bats

There are two suborders of bats, microbats that eat insects, blood, small mammals and fish and mega bats, which live only in tropical Asia, Africa and Oceania that eat fruit, nectar or pollen. Mega bats, or fruit bats, may be hosts of the Marburg virus, which is excreted in their droppings and is highly dangerous to humans. Most bats are active at night, when colonies leave their roosts to find food (Wikipedia 2008). Bat colonies may develop in attics and roof areas of older and historic buildings (Pinniger 2001).

Biodeterioration by Bats

Although the bats do not eat museum collections, their droppings and urine can cause collection damage and attract insects and microorganisms, encouraging infestations. Dying bats may slip into small spaces among or inside artefacts where the corpses decay, encouraging infestation and sometimes damaging artefacts. Bat droppings dry to a powder that enters the air, releasing microbes, and is dangerous to museum staff (Author's personal experience).

Table 2.1 The most common biodeteriogens and damage in tropics

Biodeteriogens	**Type of damage**	**Materials damaged**
Bacteria	Staining and chemical damage	Limestone, sandstone
Fungi	Weakened stone surfaces and permanent staining of heritage materials	Stone, brick, and soft organic materials such as paper, leather, textiles, wood, as well as plaster and stucco.
Algae	Covering of surfaces, causing a loss of aesthetic value, and powdering of surfaces	Limestone, sandstone, marble
Lichens	Cracking and breakage around pores, preexisting cracks, and fissures where lichens live	Limestone, sandstone
Higher plants	Fissures and cracks, loosening and detachment of bricks or stones in a built structure	Stone, bricks, masonry
Silverfish	Holes and surface erosion	Paper, cotton, linen, photographs, books
Termites	Severe structural damage	Wood, bamboo, basketry, textiles, and other materials containing cellulose
Borers *Powderpost beetle*	Disintegration of wood and holes in the shell of wood around disintegrated areas	Hardwood, basketry
Borers *Furniture beetle*	Disintegration of wood and holes in the shell of wood around disintegrated areas	Softwoods and some hardwoods
Cockroaches	Scratched and eroded surfaces, stains from feces, disease	Books, leather, parchment, wallpaper, natural history specimens, and more
Carpet beetles	Holes and large losses	Wool, fur, horn, skins, hides, feathers, insect specimens, hair, silk, linen, cotton, rayon

Fur beetles	Holes and large losses	Wool textiles, fur and feather
Hide beetles	Holes and large losses	Woolens, feathers, hides, dried meat, dead insects and cast skin of insects
Biscuit beetles	Holes and large losses	Dried food and spices, starchy plant specimens, seed heads and dried animal specimens
Clothes moths	Holes and large losses	Wool and silk textiles, and fur
Booklice	Scratched and eroded (eaten) surfaces	Damp or mouldy books and paper
Geckos	Staining from droppings and urine	Paper, textiles, paintings, any object displayed or stored outside a case.
Rodents *Rats and mice*	Holes, gnawing, shredding, stains from droppings and urine, disease	Wide range of materials, such as paper, textiles, timber, basketry, leather, bone.
Bats	Dropping and urine, disease	timber

2.2 Environmental Conditions and Their Effect on Biodeterioration

A number of environmental factors, including heat, humidity, light, dust, and airborne pollutants, affect the preservation of museum collections. Extremes or rapid fluctuations of temperature or relative humidity (RH) will make materials expand and contract, leading to a range of problems like warping, cracking, and splitting, while high RH also promotes chemical decay (HCCDD 1998:23). Consequently, there are ranges of temperature 18˚C - 22˚C and RH 45% - 55% that are internationally recommended for the preservation of materials (see **Table 2.2**). Nonetheless, stable environments are more important to preservation than the actual level of temperature and RH, for it

has been found that greater damage occurs when these fluctuate than when stable conditions lie moderately outside the recommended parameters (Corr 2000:20). So good environmental conditions help prevent physical damages in objects and slow down the irreversible chemical deterioration that will happen naturally over time as materials age (Staniforth 1984:192).
Light is also damaging. The energy in light waves, whether from sunlight or from high-UV artificial lights like halogen and fluorescent bulbs, can fade pigments and dyes, weaken fibres, dry wood, degrade fragile organics like paper and ivory, and contribute to metal corrosion. Light damage is irreversible. For inorganics like stone, glass, and ceramics, high levels of light are normally not a problem, but organics require lower light levels and survive best in dark storage.

Dust and other airborne pollutants can adhere to collection objects and, because they are acidic, damage them chemically. Fine dust can become so deeply embedded in pores and cracks that it cannot be removed, making museum objects look dull and neglected. Embedded dust is an even more serious problem because dust tends to attract water vapour, which expands the volume of the dust and places pressure on the sides of the pore or crack, sometimes causing damage (Author's personal experience).

Altogether, environmental factors contribute critically to the degradation of museum collections. The examination of all environmental factors is outside the purpose of this thesis. So this discussion will focus on heat and humidity, since they provide an environment that encourages biological pests to thrive and reproduce.

2.2.1 Heat

Heat is measured in temperature on the centigrade or Fahrenheit scales. In museums, the heat they measure comes from the infrared radiation of the sun or artificial lighting. When heat increases, the movement of molecules also increases, so chemical reactions happen faster, solids become softer, and liquids evaporate. For museum objects, increased heat makes materials age faster and dry out (Florian 1997:6). A cool temperature, on the other hand, slows down ageing and makes materials absorb moisture. Cold has no direct adverse effect on objects, which tend to survive better in colder environments (Corr 2000:23), so lower temperatures for museum objects are preferred (Staniforth 1984:194).

Higher temperatures are especially damaging to museum collection materials such as acidic paper, acetate and nitrate films, celluloid, rubber, and objects which contain waxes or resins, such as ethnographic collections. Yet probably most significant influence of temperature is its relationship with RH, for temperature determines the amount of moisture or humidity that the air can hold, and this amount is used to calculate RH (Heritage Collections Council, Guidelines for Environmental Control in Cultural Institutions [“HCCGECCI”] 2001:10), which will be discussed in the following section.

2.2.2 Relative Humidity (RH)

All materials that contain water react to the amount of water that is present in the air surrounding them. In dry air they release water into the air, and in the damp air they absorb water from the air. Warm air can hold more water than cool air, and RH is measured as the percent of water vapour in a given volume of air relative to its maximum holding capacity (Staniforth 1984:195). Air temperature influences the water-holding capacity of the air, because increased temperature makes air molecules more energetic and active and more capable of attracting molecules of water vapour and mixing with them. Therefore air at higher temperatures can hold more water (Florian 1997:6). As temperatures rise, the same amount of water, in grams, represents a smaller and smaller percent of the total amount of water vapour that the air can hold. For example, for a cubic metre of air with 8.5g of water:

- At 15˚C, the RH is 68%;
- At 20˚C, the RH is 50%;

- At 25˚C, the RH is 37%.

Florian 1997:7

When temperature goes up and RH goes down, the air is "drier" and will have to equalize its RH with that contained in objects. Water will be released from objects into the air, so that the RH of the air and the water eventually become the same (Florian 1997:7). Different materials require different RH levels for preservation. Metals normally survive best in a drier environment, so that the chemical conditions for corrosion are limited. Organics, however, contained a great deal of water when they were living materials, so it is not surprising that organic artefacts require greater moisture, a higher RH, to ensure that they are less likely to dry out, crack or break.

2.2.3 Effects of Temperature and Relative Humidity on Biodeterioration

High temperature can increase biological activity, for most insects and moulds thrive and reproduce more readily in warmer conditions. The general rule for fungi and insects is that growth occurs from about 5˚ or 10˚C to about 37˚C, with slow growth between 15˚ and 20˚ and rapid breeding at 25˚-30˚C. Above 40˚C insects become distressed, and above 55˚C, most insects will die within an hour (HCCGECCI 2001:14, Pinniger 1989). In other words, temperatures over 25˚C best promote the breeding of insects and moulds and therefore promote biodeterioration.

RH is also a key environmental factor in biodeterioration because the more moisture in the environment and in materials, the greater the potential of insect or fungal attack. Environmental RH affects of the growth of microorganisms; for example, "some pupal cocoons can adsorb moisture from the air which will initiate adult emergence and the conidia of fungi may need fluctuations of temperature and moisture before they can germinate" (Florian 1997:7). Moreover, damp conditions promote not only the growth of moulds and other fungi, but also the breeding and activity of insects, such as silverfish, which are most active when RH exceeds 70%, but would not be a problem at low humidity (Thomson 1999:66, 86). Moisture in artefact materials affects biodeterioration because damp objects provide the habitat that microorganisms and insects need to survive, and moisture can also break down some materials and make them more digestible and attractive to biodeteriogens, which is why wet wood encourages infestation by termites and borers such as powderpost beetles.

In conclusion, it is clear that a high-temperature, high-RH environment is the most damaging one for museum collections. Yet this is the environment of the tropics and the environment in Laos during nine to ten months of the year. Laos has a daily average temperature of 23˚C - 34˚C, and its RH remains over 65% throughout most of the year and rises to over 80% in the wettest month (Sully, Liu and Lee 2001:63; Thomson 1999:89). While the ideal environmental conditions in Table 2 may be achievable in temperate climates, they are almost impossible to attain in Laos.

Table 2.2 Ideal environmental conditions for storage and display

Environmental Conditions	**Storage**	**Display**
Temperature	18˚C - 22˚C	18˚C - 22˚C
Relative humidity	45% - 55%	45% - 55%

2.3 Museum Materials Affected by Biodeterioration

The materials used in museum objects can be divided into two major groups: organic materials (obtained from plants and animals) and inorganic materials (obtained from minerals like metal and stone). Each category requires more or less similar environmental conditions, though RH is preferably lower for metals and light must be controlled for organics (Horie 1984:280). However, the two categories differ greatly in their vulnerability to biodeterioration because the protein and cellulose in organic materials are good food sources for biodeteriogens. Some biodeteriogens attack only cellulosic materials, others attack only proteinaceous materials, and a few can eat both. The result is that all organic materials are at risk. Most inorganics supply no nutrients, so only a few, like stone and masonry, attract biodeteriogens.

Lao museums contain numerous artefacts made from organic materials, including wood, grasses, paper, and cotton and bone, leather, wool, and silk. This section examines the materials vulnerable to biodeterioration (see **Table 2.3**), and discusses the type of biodeterioration they undergo and their representation in Lao collections.

2.3.1 Organic Materials

Paper

Paper is used to make a wide range of objects found in Lao collections, including prints, maps, letters, documents, watercolours, art drawings, technical drawings, posters, books, photographs, architectural plans, magazines, newspapers, and bank notes.

The most common biodeterioration happens to paper that contains cellulose sizes and animal glues that are good food sources for mould and some insects, like silverfish. The insects eat holes in paper, and moulds stain and weaken the paper; “foxing” is the name given to the small, brown spots of a mould that commonly appears in patches or over an entire sheet of paper when paper, especially acidic paper, is exposed to a combination of high humidity and high temperature (HCCCCM 1 1998:5). Rodents also shred paper for their nests.

Books

Lao collections include books with cloth, leather and paper covers, sometimes bound with animal glue. Many books cloths are susceptible to damage from mould and insect attack of the paper, cardboard covers, leather covers, and animal glue. Certain biodeteriogens may also eat inks (HCCCCM 1 1998:38-39). In addition, rodents may shred books for nesting material, gnaw on them, and eat the animal glue (Author’s personal experience).

Photographs

Photographs include daguerreotypes, tintypes, glass plate negatives, albumen and collodion and silver-gelatin prints, color prints, film negatives, and modern color and black-and-white prints on fiber-based and resin-coated paper (HCCCCM 1 1998:69). The photographs found in Lao museums are primarily old photographs on fiber-based paper, including some silver-gelatin and albumen prints.

While the paper itself attracts certain biodeteriogens, especially if the paper is moist from humidity, the proteinaceous gelatin and albumen used to make photographic emulsions are also a good food source for others. Mice and rats will eat the paper base of photographs and do severe damage to them, as well as eat storage boxes (HCCCCM 1 1998:70).

Painting

Lao museums have a good number of Western-style oil paintings on canvas framed in wood, and the larger paintings have stretcher bars for support. These paintings are susceptible to attack by mould, insects, and rodents.

For example, wooden stretchers and frames become infested by borers, termites attack wooden elements and canvas, mould grows on canvas (especially in high-RH conditions), and silverfish may attack canvas and cardboard backings. Rodents may eat canvas and wood and gnaw on frames and stretchers (HCCCCM 1 1998:115).

Textiles

Textiles are found in many collections in Lao museums. These include silk and cotton shawls and other clothing, ceremonial uniforms, ethnographic textiles like healing cloths, upholstery, carpets, curtains, embroidery, appliqué work, netting, dance costumes, and paintings on cotton. Textiles are a principal art form in Laos, and textile collections, especially of silks displaying secondary wefts and *mutmee* designs, are large and varied. There are also many fine examples of gold-woven textiles, made with threads wound with filaments of gold.

The most common damage is caused by moulds and insects. Mould, which is especially prevalent because of the high RH, causes staining, which may become permanent, and eventually fibre loss (Glover 1984: 337; TTMPB 1998). Silverfish, both adults and nymphs, eat irregular holes in fine fabrics such as silk, cotton and linen. Carpet beetles feed on wool and silk carpets, leaving holes, and are attracted by dead insects that may be embedded in carpet pile or backing (Blyth 2001; Florian 1997; Glover 1984; Kingsolver 1988; MGC 1998; TTMPB 1998). Rodents may eat textiles, shred them for their nests, or make their nests in textiles, which they stain with urine and feces.

Leather

Leather, made from animal skin that has been dried into rawhide or tanned to preserve it from rotting, has been used since ancient times for clothing, saddles, boats, thongs, shields, aprons, shoes, upholstery straps and belts, book covers, and an enormous range of other items (HCCCCM 2 1998:31). In Lao museums, leather is most often found on ethnographic drums, which include tanned skins and rawhide, and on shoes and the interior supports for dance headdresses. There are also a few documents on parchment and skins with attached fur.

Mould usually attacks leather when RH rises about 65% and almost always when RH exceeds 70%. Bacteria, rodents, and termites and other insects attack leather and lubricants that may be incorporated in it (HCCCCM 2 1998:32). Insect attacks are often extremely serious and cause irreversible damage (Priestman 1984:303).

Wood

Wood is represented in Lao collections in furniture, sculpture, ethnographic implements, thrones, altars, and manuscript cases, as well as architectural supports, building sidings, and storage cabinets that hold artifacts.

Wood is very susceptible to biological damage from bacteria, fungi, and insects, especially if the water content of wood is high due to rainfall or the high RH levels of the surrounding environment. Bacterial attack, which is most likely to happen when wood is in constant contact with water or mud, causes slow deterioration of wood and eventual weakening of the wood after long periods of exposure. Fungi cause rotting and staining of damp wood. Insect damage to wood is most severe in hot, humid environments that encourage the growth of fungi and produce a high moisture-level in wood. Insects are the most serious pests affecting wooden objects, and powderpost beetles, furniture beetles and especially termites are the major insect enemies of wood (HCCCCM 2 1998:50; Horie 1984; Florian 1997; Highley 1999; Highley et al 1994). Gnawing and boring by rodents also is common.

2.3.2 Inorganic materials

Stone

It is commonly thought that stone is extremely durable and resistant to decay. In fact, stone is vulnerable to damage from a number of environmental factors, including water and salts, as well as biodeteriogens (Priestman 1984:304). High RH contributes to the growth of microorganisms, such as the bacteria, algae, and fungi, along with lichens, mosses, and higher plants that develop on outdoor sculpture, monuments, and architectural features like staircases. Sandstone, limestone, and marble are most affected, but these biodeteriogens also grow on concrete, bricks, mortar, stucco, and plaster (Kumar and Kumar 1999).

Sandstone and limestone are especially vulnerable because they are often porous and weak. Their pores and cracks collect and retain rainwater, so they are frequently colonised in these damp areas by algae, lichens and higher plants, whose growth is enhanced by high humidity (Aranyanark 2003:11). Algae and lichens are perhaps the most damaging, for they enlarge cracks and crevices that allow higher plants to take root and retain water and, when they die, to provide food that helps higher plants grow (Aranyanark 2003:12-13). The mechanical and structural damage caused by the roots of higher plants, as well as the discoloration produced by microorganisms, cause significant damage (Kumar and Kumar 1999:10).

In Laos, building materials such as stucco and concrete are affected by biodeterioration, and the marble steps at one museum have been colonised by moss and algae.

Table 2.3 Materials affected by biodeterioration

Types of Materials	Types of Biodeteriogens
Organic Materials	
Paper	Fungi, insects, and rodents
Books	Fungi, insects, and rodents
Photographs	Fungi, insects, and rodents
Paintings	Fungi, insects, and rodents
Textiles	Fungi, insects, and rodents
Leather	Fungi, insects, and rodents
Wood	Bacteria, fungi, insects, and rodents
Inorganic Materials	
Stone, masonry	Bacteria, fungi, algae, lichens, mosses, and higher plants

2.4 Summary

The problem of biodeterioration of museum collections is significantly increased in tropical regions like Laos because of the great variety of biodeteriogens that thrive there, the environmental conditions that favour biological growth and make materials more susceptible to attack, and the frequent use in traditional Lao artefacts of organic materials, which are especially susceptible to biological attack. The result is that Lao collections are at great risk of irreversible loss. Therefore it is extremely important to prevent biodeterioration to these endangered Lao collections through the preventive and remedial methods which are discussed in the next chapter.

Chapter 3 The Prevention and Control of Biodeterioration

3.1 Fundamentals of Prevention and Control

There are several reasons why the work of preventing and controlling biodeterioration is complicated. Biodeteriogens require a variety of different treatments. Treatments must be chosen so that they are effective against the biodeteriogens, but not damaging to museum objects. Museum environments may be so favourable to biodeterioration that control is extremely difficult. Museum staff may lack the time or training needed to carry out the monitoring and treatments involved, and the costs or technical demands of some treatments may make them impossible to use at some museums, so that alternative treatments must be found.

To clarify the issues and evaluate current treatments, this chapter will first give an overview of preventive and remedial methods and then examine specific methods appropriate for each group of biodeteriogens discussed in Chapter 2, especially methods most appropriate for Laos.

3.1.1 Preventive Methods

Preventive methods, also called “indirect” methods, are activities aimed at controlling and preventing biodeterioration by improving the environmental conditions where museum collections are stored and exhibited. Since warm and moist environments favour the growth of biodeteriogens, preventive methods that make environments cooler, dryer, or both can be extremely effective against biodeteriogens. Reducing the materials that biodeteriogens can use for food, such as the dead skin and insect matter in dust will also reduce biodeterioration. Placing cultural materials in storage containers and well-sealed display cases can reduce their exposure to dust, spores, insects, and rodents can also control biodeterioration. Inventorying, registering and cataloguing objects will record their condition so that changes can be recognized and museums will achieve documentary control of their collections.

Routine Maintenance of Buildings

The fabric of a building is the primary barrier or skin against the exterior climate. It can absorb moisture to a greater or lesser extent, depending on the materials used in its construction. Keeping it an effective barrier between the exterior and interior requires regular and proper maintenance and inspection for damage and weathering. Regular building maintenance will add many years to the life of a building and help maintain a healthy environment for the content (Corr 2000:15).

Routine preventive measures that reduce dampness in buildings will help to control or even prevent the growth of biodeteriogens. Keeping buildings dry means repairing roofs from broken or missing tiles and slates, repairing leaking windows and doors, and repairing and clearing roof gutters, rainspouts and drainage lines on the ground that move water off and away from buildings (Kumar and Kumar 1999:29; Corr 2000:16).

Buildings will also be inaccessible or unattractive to biodeteriogens if timbers, windows and doors are regularly painted to prevent fungal infestations, particularly along the base where water might lodge, and windows and doors should be well sealed against insects (Corr 2000:16). Overhanging trees should be trimmed, and foliage should be cut back so that there is a clear space around the walls of the building. Holes and cracks that rodents can enter through should be blocked, and the flaps and screens on doors and windows that block the entry of spores, insects, and rodents must be maintained (Author's personal experience). Building exteriors may need periodic cleaning, such as the removal of moss with brushes and knives or the use of steam cleaning to kill mould and algae, though the large quantities of water involved could also dampen buildings and their foundations and do more harm than good (Kumar and Kumar 1999:31-32).

Termites present especially serious problems in tropical countries. It is important to create physical barriers to termites by sealing gaps at wall joints and around electrical fittings and sewerage lines. Soil around the museum building and ground must be treated with an insecticide effective against termites, and water must be prevented from flowing into the walls and floors (Monowar Jahan & Noor Munshi 1995).

Routine maintenance and cleaning, as well as routine use of insecticides, such as injection into the ground of insecticides against termites, must be done on schedule to make sure these measures are effective (Author's personal experience).

Housekeeping

Regular cleaning of dirt, dust, spores, and seeds as preventive conservation is the primary way to prevent and control biological attack, for cleaning minimizes the development of mould and removes materials that biodeteriogens can use for food (Kumar and Kumar 1999:29-30). Cleaning work ranges from regular dusting of objects and sweeping or damp-mopping of floors (Gilroy and Godfrey 1998:8) to removing dirt and stains on collection items that could be food sources, though care must be taken to retain dirt that is part of the history of an object, such as soot on an ancient cooking pot (Pye 1984:212; Wheatley 1984:319). It is especially important to keep storage areas clean, for infestations there may not be immediately found and can spread throughout the storage area (Corr 2000:48). Stored textiles need particular care: they are best stored in protective fabric coverings and should be periodically vacuumed to remove dead insects, human hair, and dust (TTMGCT 1998).

Flowers and plants need to be avoided inside museums because they may be infested with insects when they enter the museum and they will attract insects while they are there. If flowers and plants must be brought into museums, they must be removed as soon as possible, and the areas where they were displayed should be thoroughly cleaned so that no droppings from the plants remain in the building (TTMPB 1998).

Environmental Control

Cool, moderate-RH environments are advisable for displaying and storing museum collections. Storage areas should be well ventilated and maintain a temperature below 25˚C and RH below 65%, so that mould will not occur and insects will not grow and reproduce (TTMPB 1998). But good air circulation and a RH of 65% are acceptable in the humid tropics, regardless of temperature (Thomson 1999:88). The stability of RH is just as important as the RH level itself, and perhaps more important, so that contraction and expansion of the materials in response to changes in RH are minimized. Fans have been shown to inhibit fungal growth, and air circulation combined with climate-control machinery such as dehumidifiers and air conditioners can be used to keep RH stable and will prevent fungal growth entirely (TTMGCT 1998; Canadian Heritage: CCI Notes 1996, 13/15; Sakamoto et al. 1995). Another technique for protecting objects from high or fluctuating RH is to place them in acid-free cardboard boxes, which will absorb moisture and help safeguard the objects against rapid changes and extremes in humidity (HCCCCM 1 1998:26).

Monitoring and Integrated Pest Management (IPM)

The most effective way of reducing the risk of pest damage is by developing an appropriate Integrated Pest Management (IPM) program (Xavier-Rowe and Pinniger 2001:37). An IPM program includes physical control, cultural control and chemical control. Physical control involves the use of screens and seals on doors, windows and display and storage cases, and the use of sticky traps, which should be monitored weekly, to catch insects that may be active during the night or in corners or low areas that are hard to see. Cultural control involves regular inspection of all items in collections in storage and exhibition spaces along with good regular housekeeping. Chemical control involves the use of insecticides or non-chemical alternatives to destroy infestations (Coote 1998:83).

Other types of monitoring are reminders to staff not to eat of keep food in collection areas and the use of hygrothermographs or dataloggers to measure and record the levels of heat and moisture in the air. These instruments provide detailed picture of the climate within a building and indicate where problems may exist (Corr 2000:47).

If insects are found in traps or if insect or fungal damage is found, the artefacts infested or located near the traps should be sealed in plastic so that the infestations will not spread and then de-infested by one of the methods described below (Author’s personal experience).

Documentation of Collections

Collection objects should be documented in written and photographic records so that their condition is recorded and biodeterioration over time will be evident through comparison. Documentation is a continuing program, and so documentation systems, such as digital databases, must afford an opportunity for collection managers to go back to objects and add information to the records (American Association of Museums: Caring for Collections 2004). Documentation requires a long-term commitment from a museum and professional competence that must be enhanced by continuing education and training programs (Author’s personal experience).

3.1.2 Remedial Methods

Remedial methods are aimed at controlling infestations of buildings and collections. These methods include the use of heat and cold, low-oxygen environments, and chemical treatments to destroy pests. Most of these treatments have no residual effects, so biodeteriogens will develop again if environmental conditions, monitoring, and preventive maintenance are poor.

Heat Treatments

The successful use of heat to kill fungi on seeds and to disinfect granaries and mills suggested that it might also be effective in destroying infestations of museum collections. In museums that want to replace chemical treatments with non-toxic treatments or have a limited budget or lack electricity, or have a large number of objects to disinfect in a short period of time, heat has been used to kill insects in cultural collections (Strang 2001:127).

Objects are heated to temperatures of about 52°-60°C, which kill adult insects, larvae, pupae, and eggs in about an hour once the heat penetrates through the thickness of the material. Heat treatments must overcome the problem that materials lose moisture as they are heated, and they will crack if they cannot reabsorb this moisture as they cool (Strang 2001:121).

For these reasons, several European organisations use metal or wooden heating chambers that heat objects in a precisely measured way. English Heritage, for example, lines its chambers with wood, which absorbs and later releases the moisture from the objects, and uses electric heaters, fans, and sensors that heat the chamber and distribute and monitor the heat throughout it (Kingsley et al. in Strang 2001:127).

Heat treatments may use solar heat, in a process called “solarisation”. Objects are covered with cotton cloth, such as towels, that will absorb the moisture lost from artefacts during heating, and then sealed in black plastic or in black cloth covered by clear plastic. They are then placed on a surface like a hammock that lets air circulate and enclosed in a clear plastic tent that protects them from breezes that would lower the heat. A solar-operated fan inside the tent circulates the air for uniform heat, and a thermometer inside the tent, with a probe placed inside one of the sealed bags, measures the temperature. After heating, objects are kept sealed for 24 hours so that they can reabsorb the lost moisture (Author's personal experience, described in Strang 2001:124).

One restriction in heat treatments is that materials with a melting point below 75˚C can become damaged (Brokerhof 2003:96). Therefore, solarisation treatment is not suitable for all materials, such as items containing wax or resin elements, items that are deteriorated, or items made with "improperly tanned collagens or leather" (Pearce 2003: 31-34; Strang 2001:114). An added restriction in solarisation is that objects must be small enough to be sealed completely and placed inside a solar tent (Brokerhof 2003).

Freezing Treatments

Freezing is another non-toxic method of destroying insect infestations. It has been successful with paper, books, textiles, and leather, for example, but cannot be used with oil paintings, acrylic paintings, lacquer ware, and other objects that have layers of different materials that will contract differently when exposed to a fast drop in temperature (Ishizaki 2003:62).

As with heating, objects must be wrapped in cotton and sealed in plastic so that moisture will not escape. Objects are placed in a freezer chest for a minimum of 48 hours at -20˚C, and ideally kept there for a full week. The temperature must be kept constant, so the freezer cannot be opened at any time during this process. After leaving the freezer, objects should remain sealed for 24 hours. Textiles that are frozen should be carefully inspected afterwards and vacuumed to remove frass and insect debris. If it is not certain that all insects have been killed, the object should be refrozen (TTMPB 1998; Pinniger 2001).

The drawbacks to freezing are that object size is limited by freezer size, and the process normally takes a week. It requires a sub-zero freezer, which can be expensive for some museums, and uninterrupted electricity, which may not be available in some developing countries and in some rural areas of developed countries.

Low-oxygen Treatments

Low-oxygen environments kill infestations by cutting off the oxygen that adult insects, larvae, pupae, and eggs need to survive. Most of the time, infested objects are placed in a sealed bubble containing nitrogen or argon and no more that 0.3% oxygen, with water vapour added to achieve 55% RH. Also, objects can be sealed in a bag with Ageless oxygen “scavengers”, which bond chemically with oxygen and thus remove it from the environment. After two weeks--or three to four weeks, if the temperature is low—in a low-oxygen environment, all stages of the insects will be dead (Sugiyama, Sato and Daniel 2003:50). Low-oxygen environments are effective for eradicating infestations, as well as for preserving fragile or valuable organic materials by keeping them in environments in which they cannot oxidize and age. They are difficult and expensive to create and operate, however, and treatments require 14-28 days, while freezing and heating take much less time.

Biocidal Treatments

Biocides to control microorganisms and higher plants include bactericides, fungicides, algicides, and herbicides, which are frequently used to eliminate these biodeteriogens and inhibit their future growth (Kumar and Kumar 1999:32). The use of biocides, which are toxic, raises concerns about their effect on cultural objects and their risk to humans, and so biocides should be well understood before they are used. For mould, though, there are also effective non-toxic treatments. These involve brushing and vacuuming away surface spores (making sure the spores are not re-deposited on the infested object or surrounding objects) and then applying a solution of 70% ethanol and 30% deionized water, which must first be tested to be sure that will not harm the objects. Hydrogen peroxide (3%) can be used on buildings. Mould is dangerous for humans, so people destroying mould must wear masks and plastic gloves for their own protection and wash their hands and face afterwards (Baskin, pers. comm. 2008).

Biocides to control insects are toxic sprays and powders formulated to destroy particular insects. Most of these insecticides evaporate soon after use, but “residual” insecticides, which can be sprayed onto material or in cracks and crevices, remain effective over longer periods. The toxicity of insecticides on humans and their effects on cultural materials, which may become stained, faded, or dissolved by insecticides, must be understood before insecticides are used. Insecticides must be correct for the specific type of insect being targeted, and applying more than the required amount is unnecessary and increases the potential risks to both objects and people (Child 2003:36-37; Blyth 2001).

These are also less toxic insecticides. The silica gel granules in Drione, for example, tear the bodies of silverfish that crawl over them, so that the silverfish eventually die of dehydration. (Similarly, the metal filings in used motor oil, spread over the wooden beams of buildings, tear the bodies of termites and cause their death.) In addition, the borate salts in products like Tim-Bor kill insect eggs deposited in the wood and therefore stop infestations. Traps can also be used to against crawling insects (Author’s personal experience).

3.2 Prevention and Control of Biodeteriogens in Laos

A number of these remedial methods, as well as all of the preventive methods discussed above, can be used against the biodeteriogens found in Laos. The following describes, for each of these biodeteriogens, the prevention and control measures most appropriate for the artefacts and museum conditions in Laos.

Table 3.1 Prevention and control of biodeteriogens in Laos (Baskin, pers. comm. 2008; Pinniger 2001; Kumar and Kumar 1999; Florian 1997; 2002)

Biodeteriogens	**Preventive methods**	**Remedial methods**
Fungi	Control environment by lowered RH and ventilation to prevent growth	Kill with ethanol and water, hydrogen peroxide, fungicides
Algae	Regular cleaning to stop growth, lower RH for indoor collections	Use algicides to kill, algistats to inhibit growth
Lichens	Control environment by lowering the RH to stop growth (for indoors)	For outdoor collections use biocide
Plants	Regular cleaning to remove dusts and seeds from collection surface	Remove by the root, use herbicides when necessary
Termites	Regular monitoring, keep buildings, objects and storerooms dry, avoid wood contact with soil	Use insecticides to eliminate, use solarisation for infested artefacts
Cockroaches	Keep storerooms dry and clean, avoid food sources, protect stored artefacts in containers	Use traps, insecticide if necessary
Silverfish	Lower the RH to stop them from thriving and reproducing	Use traps and silica gel
Borers, lice, beetles	Keep materials dry and clean	Solarisation, freezing if practical
Geckos	Keep objects covered or enclosed in storage and on display	Use traps if necessary

Rodents	Keep objects and storerooms clean, avoid food sources, close larger holes with heavy wire mesh, plug smaller holes with steel wool	Use traps; some museums use cats
Bats	Keep roof openings sealed, remove food sources in roof area	Seal or screen all roof openings so bats can leave but not return after feeding

3.3 Summary

A wide variety of biodeteriogens exists in Laos due to the particularly favourable environmental conditions, such as high temperatures, high RH, and heavy rainfall. Fungi, algae, lichens, higher plants, and especially insects and rodents are the enemy of Lao cultural property and must be controlled and prevented as much as possible to prolong the life of our cultural heritage for posterity.

In the recent past, only chemicals were used to fumigate cultural property, but some have been found to damage materials and pose health hazards to the people using them. It is therefore extremely important to develop alternatives, such as heat and freezing. The most important part of controlling biodeterioration is prevention, however, and so an Integrated Pest Management program that includes inspections, good housekeeping, building maintenance, and environmental control are essential activities of museum and collection management.

It is only through knowledge about biodeterioration, an understanding of the threats to the materials used in cultural property, constant monitoring, development of preventive measures, and prompt use of appropriate remedial methods that infestations can be controlled and prevented and cultural property can be saved.

The next chapter investigates the biodeterioration problems in Lao museums and collections, the extent of knowledge in these institutions about the causes and prevention of biodeterioration, and the ability of these institutions to take action to preserve their collections.

Chapter 4 A Survey of Biodeterioration in Lao Museums and Collections

4.1 Rationale

A survey was carried out from 9 March to 30 March 2008 to learn about the biodeterioration problems and the methods used to control biodeterioration at nine museums and collections in Laos. The survey had two aims. First, it would describe the effect of biodeterioration on Lao collections by indicating which of the materials susceptible to biodeterioration are most common in Lao collections, the types of biodeteriogens found, the methods chosen to deal with biodeterioration, and the ideas of officials at these collections about the kinds of help they needed to protect their artefacts. Second, it would provide a practical application of the research done for this thesis by showing how this research information, applied to the survey findings, can create an action plan for managing the problems of biodeterioration in Laos (see Chapter 5).

4.2 Methodology

The museums and collections selected for this survey were chosen because they are the major museums and collections in Vientiane, the capital city, and in Luang Prabang, the second city of Laos. The museums and collections include four national museums, a city monument, a private ethnography centre, a large private collection, and two monasteries (*vats*), which house most of the Buddhist art in the country. Laos has one other national museum that contains artefacts, as well as a small museum of stone sculptures, a dinosaur museum, a series of very small one-room display centres with artefacts, and of course many more monasteries with large or small collections of artefacts. Therefore the museums and collections surveyed in this study provide a good representative sample of the types of artefacts in the Lao cultural heritage. A list of museums and collections, with the names of the officials interviewed, is shown in **Appendix A**.

A questionnaire (see **Appendix B**) was developed to guide discussions with officials at these museums and collections. It was known in advance that almost all museums and collection staff in Laos are untrained in collection preservation and would not be knowledgeable about biodeterioration. For this reason, the officials were asked very general questions about biodeterioration, and the interviewer also examined the displays, storage areas, and building herself, wherever possible, to observe biodeterioration causes and effects.

Because of the lack of information in Laos about biodeterioration, it was also expected that questions would often have to be explained to interviewees. These explanations would cause the officials to answer with information and understanding they did not have before. This presented a threat to the validity of the survey, so care was taken to separate as much as possible what the interviewees knew before and after the explanations. The threat to validity is not serious, however, because the main purpose of the survey was to collect as much information as possible, and ultimately explanations improved the quantity and quality of the information gathered.

The observation portion of the survey was done by examining objects on display and in storage rooms and studying the condition of the building and outdoor collections with the museums' officials. Collection surveys were aimed at looking for evidence of all types of biodeteriogens, but especially damage of organic materials from mould, insects, and rodents. Outdoors, the emphasis was on looking for evidence of mould, algae, lichens and higher plants in wood and stone. During the observation, the officials allowed photographs of the objects damaged by biodeteriogens (see **Figures 4.1, 4.2 and 4.3**).

4.3 Data Collection

Most visits to museums and collections were two to eight hours in duration. The visits lasted a long time because almost all the interviewees were not clear what biodeterioration is and needed descriptions and explanations. Then they tried to answer the interview questions and also wanted to talk more about some other museum problems like administration, lack of staff, facilities, budget and so on. Most museums were interested in biodeterioration and supportive, and they wanted to know and learn from the interviewer. All except one museum were very happy to show the researcher exhibits and storage. Except at two institutions, the staff clearly does not spend much time looking around in the galleries of their museum or examining the artefacts in their collection or monastery. For this reason also, the interviews required a lot of time because the officials were not familiar enough with the condition of the artefacts to answer questions without examining them alongside the interviewer.

4.4 Results

The survey results are summarised in **Table 4.1**. The interview questions are summarised in the heading for each row of the table.

Table 4.1 Survey of biodeterioration in nine Lao museums and collections

	Lao National Museum	**Luang Prabang National Museum**	**Traditional Art and Ethnology Centre**	**Vat Visoun Monastery**	**Vat Xiengthong Monastery**
Materials susceptible to biodeterioration	Baskets Photographs Natural history specimens Textiles Leather Stone (outdoors)	Baskets Photographs Wood Books, documents Paintings Works on paper Textiles Leather Stone (outdoors)	Textiles Paper Baskets Wood	Wood Masonry (outdoors)	Wood Masonry (outdoors)
Biodeterioration agents identified by staff	Mould* Termites* Rodents	Algae, lichen, mould*, silverfish*, termites*, borers*, geckos, rodents	Termites	Termites, borers	Termites, borers
Staff solutions tried	Insecticides for termites	Washing off algae Solarisation Insecticides for termites Alcohol-water for mould	Insecticides for termites	Insecticides for termites	Insecticides for termites
Staff training?	No	Yes (4 trained)	Yes (1 trained)	No	No
Staff's prevention techniques	(none)	Housekeeping Controlled RH, ventilation Building maintenance Rodent barriers Silica gel for silverfish Covered storage Documentation of collections	Housekeeping Covered storage Building maintenance	(none)	(none)
Staff's needs for controlling biodeterioration-ion	Insecticides	More dehumidifiers More insecticides for termites	(no suggestions)	(no suggestions)	(no suggestions)
Observations: agents of biodeterioration not identified by staff	Borers, lice, silverfish, geckos, clothes moths, lichen, algae, cockroaches	Clothes moths, lice, cockroaches	Mould, borers, geckos, rodents, clothes moths, silverfish, cockroaches	Geckos, rodents, algae, lichen, higher plants, mould	Geckos, rodents, algae, lichen, higher plants, mould
Observations: causes of biodeterioration not identified by staff	Dust and dirt Extreme fluctuation of RH and temperature	Dust and dirt Areas with high RH	High RH High temperature	High RH Dust and dirt Flowers	High RH Dust and dirt Flowers
Observations: changes needed not identified by staff	Housekeeping Environmental control Routine maintenance Monitoring Documentation of collections Staff training	Inspection/IPM More staff training	Environmental control More staff training Documentation of collections	Housekeeping Monitoring Environmental control Facilities for exhibition Documentation of collections Staff training	Housekeeping Monitoring Environmental control Facilities for exhibition Documentation of collections Staff training

* Indicates large numbers of objects made of this material or attacked by this biodeteriogen.

	Pra Thatluang Monument	**Vat Sisaket Monastery**	**Hoh Prakeo Museum**	**Keomontree Collection**
Materials susceptible to biodeterioration	Wood Masonry (outdoors)	Wood Masonry (outdoors)	Wood Masonry (outdoors)	Textiles Wood
Biodeterioration agents identified by staff	Termites	Termites Bats	Termites	Mould Silverfish Rodents
Staff solutions tried	Insecticides	Insecticides	Insecticides	Drying mouldy artefacts under sun
Staff training	No	No	No	No
Staff's prevention techniques	(none)	(none)	(none)	Provides food for rodents Covered storage Housekeeping
Staff's needs for controlling biodeterioration	Insecticides for termites	Insecticides for termites A way to control bats	Insecticides for termites	(no suggestions)
Observations: agents of biodeterioration not identified by staff	Borers, geckos, rodents, algae, lichen, mould and higher plants	Borers, geckos, rodents, algae, lichens, mould and higher plants	Borers, geckos, rodents, algae, lichens, mould and higher plants	Termites, borers, geckos, and clothes moths
Observations: causes of biodeterioration not identified by staff	High RH Dust and dirt Flowers	High RH Dust and dirt Flowers	High RH Dust and dirt Flowers	High RH High temperature Dust and dirt Food
Observations: changes needed not identified by staff	Housekeeping Monitoring Environmental control Routine maintenance Documentation of collections Staff training	Housekeeping Monitoring Environmental control Routine maintenance Documentation of collections Staff training	Housekeeping Monitoring Environmental control Routine maintenance Documentation of collections Staff training	Housekeeping Monitoring Environmental control Documentation of collections Staff training

Figure 4.1 Wooden Buddha sculpture affected by termites and woodborers

Figure 4.2 Outdoor collections affected by higher plants, bacteria, algae, fungi and lichens

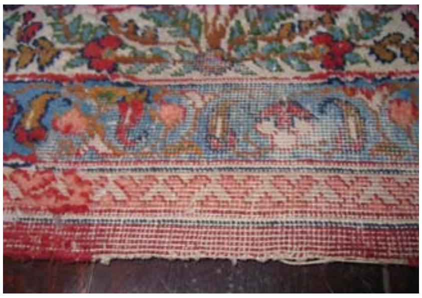
Figure 4.3 Book, paper, painting, photograph, leather and textiles affected by mould; insects included silverfish, booklice, termites, clothes moths, rats, and unknown insects.

Affected by silverfish and lice

uncertain

Affected by mould and silverfish

Affected by clothes moths

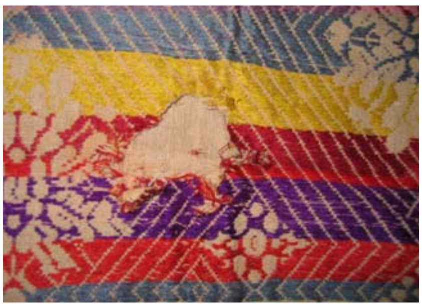


Affected by termites and mould

Affected by silverfish

Affected by mould and silverfish

Affected by rat



4.5 Discussion

4.5.1 Collections and biodeterioration

Lao collections include artefacts made from a full range of organic materials, and they are attacked by a full range of biodeteriogens. Particular problems are termites, mould, rodents, borers, and geckos, which are a problem at all nine museums and collections. More than half the museums and collections (five to eight) also have problems with algae, lichen, higher plants, and clothes moths. Four museums and collections have problems with book lice, cockroaches, and silverfish, and one has a problem with bats. Termites, mould, silverfish, and borers have caused especially great damage.

The museum and collection officials are most aware of termites, and a few are also aware of mould, borers, silverfish, and rodents as biodeteriogens. There is little or no awareness of algae, lichen, higher plants, clothes moths, geckos, book lice, and cockroaches as biodeteriogens, which one official or no officials mention.

4.5.2 Control and prevention techniques for biodeterioration

All museums and collections have used commercial insecticides, often to kill termites, and single collections have tried methods of drying mouldy artefacts in the sun, covering objects in storage, and putting out food for rodents so that they will be less likely to eat artefacts. Only one museum, which also has four staff members trained in biodeterioration, has used a variety of control and prevention techniques.

Except in two museums, there is almost a complete lack of prevention, not even housekeeping, the covering of rodent holes, building repair, and other prevention that people do in their own homes. Objects on display are often dusty, the floors and altars of the monasteries are dirty with decayed offerings, the smell of mould is usually ignored, and only large damage from termites or rodents is noticed by most officials. When the interviewer and officials observed serious biodeterioration together (see photographs), the officials were concerned and sad about the damage but not badly disturbed. Some had learned about housekeeping, ventilation, inspection, solarisation, and collection documentation from workshops with Lao and foreign specialists, but they had never been motivated to do more at their own institution than use the same insecticides they had used before. They were accepting of damage and they were not motivated to take good action to prevent it.

Only one institution has collection documentation. This is a serious problem not only for preservation, but for all functions of the museums, and it is bad for the security of objects in the monasteries, which have increasing problems of theft. It also means that no member of the staff is personally responsible for the welfare of the artefacts and personally committed to them because of long hours of working with them and recording them.

4.5.3 Environmental conditions and biodeterioration

Only one museum, which also has trained staff, uses environmental controls, including fans and climate control equipment, to manage and prevent biodeterioration. Other collections have fans, and one, the National Museum, has air conditioning in the upstairs galleries, but they use them to make the environment comfortable for people, not for their effect on biodeteriogens.

4.5.4 Staff training

Only two institutions have staff members trained to deal with biodeterioration, and only one of these, which has four trained staff, has a substantial number of activities for controlling and preventing biodeterioration.

4.5.5 Museums' needs for controlling biodeterioration

Most museums and collections (five) say their greatest need is to have better insecticides. One museum wants more climate-control units, one wants help with its bat problem, and four have no suggestions.

4.6 Summary and conclusions

In summary, the most common biodeteriogens in Lao museums and collections are termites, mould, silverfish, rodents, borers, and geckos, followed by algae, lichen, clothes moths, and higher plants. Most museums and collections use insecticides to deal with biodeteriogens, and a few have tried other methods. Only one museum uses a number of methods of control and prevention.

It is clear from these results that Lao museums and collections are unprepared to deal with biodeterioration. They need to learn how to identify biodeterioration and biodeteriogens and how to develop a range of solutions for protecting their collections (and buildings) against biodeterioration. They also need help in professionalising the way officials think about collection management and preservation, so that all staff members understand that biodeterioration is a critical problem and that part of their work is to take action to control and prevent biodeterioration.

It also seems that it is not enough to have only one staff member trained in biodeterioration, as more trained staff seem necessary to produce leadership and support for larger, ongoing programmes of control and prevention. Successful control and prevention involves all staff. Training must be appropriate and comprehensive to enable staff to identify problems and make decisions on appropriate action.

Prevention is always better than cure, but if biodeteriogens are found in objects or in the building, then some remedial action may be necessary. The options for the most appropriate course of action very much depend upon the biodeteriogens and whether they are in the building or the objects.

To prevent and control biodeterioration, the museum staff, especially staff in collection management, has to develop an action plan and then take action. An action plan based on the information in this thesis and the results of the survey will be presented in the next chapter.

Chapter 5 Biodeterioration Action Plan for Lao Museums and Collections

5.1 Programme objectives and overview

The following programme is aimed at training the staffs of Lao museums and collections in how to preserve their artefacts from biodeterioration. The programme focuses on providing information on the prevention and control of biodeterioration by presenting hands-on workshops and setting up a team of specialists who will teach the workshops and regularly visit all the participating institutions for follow-up. Written materials for the workshops will be Chapters 2 and 3 of this thesis, which will be translated into Lao and expanded with photographs and drawings. Grants will be requested to pay for translation and publication of the chapters, equipment and materials for the institutions, and travel of the specialists and some of the participants. The programme must receive the approval of the Lao Ministry of Information and Culture, so that the participants can attend.

5.2 Workshops

There will be two different workshops. The first will be for directors, because their position means that they must do hands-on activities and gain knowledge and insight separate from their staff. The second will be for all other staff and especially any collection managers and curatorial staff.

5.2.1 Directors' workshop

The directors' workshop will run for three days. The first day is for learning about biodeteriogens, preventive methods, and remedial methods, as described in Chapters 2 and 3. The second day is for demonstrations and hands-on practice in prevention and control techniques. On the third day, the directors and specialists will take field trips to different museums, so the directors get a wider and more varied view of the problems. The directors will make lists of the problems and required solutions at their own institutions, and these lists will represent the goals for that institution and be used to create a budget for the materials needed to achieve those goals. When the directors return to their own organizations, they will have new and better ideas for their staff on biodeterioration problems and solutions. The directors' workshops will take place in the capital, Vientiane, to make travel easier for participants.

5.2.2 Staff workshops

The staff workshops will take place at the National Museum in Vientiane and the Luang Prabang National Museum, Luang Prabang. The staff of regional and small museums can come to the location that is closer. Depending on the number of staff, the specialist team could go to some of these smaller museums also. The staff workshops will run for two days, one for information and one for demonstration and evaluation. As in the directors' workshop, teaching will focus on the biodeteriogens most common in Laos: termites, borers, mould, rodents, and gecko lizards, but the list will expand depending on the biodeterioration found at the museums visited during the directors workshop and the problems described by participants.

5.3 Follow-up

After the training, the specialist team will regularly visit the participating institutions to see the actual work that the staff has done to prevent and control biodeterioration. The specialists will evaluate the work, provide advice, and help with hands-on work. At the end of their visit, the entire staff will meet with them to present their work and summarise the results. The results will be documented and used as collection management records for each institution.

5.4 Specialists

The specialist team will include the author, trained staff from the Luang Prabang National Museum, and foreign specialists such as the UNESCO architect specializing in termites and a visiting conservator who has worked in Laos for 10 years.

5.5 Proposed outcomes

It is hoped that the workshops and follow-up support will encourage institutions to be more aware of biodeterioration and better prepared to deal with it. Through the programme, some building repairs will be done, and institutions will have new supplies, like ethanol and deionised water for killing mould. Laos museum staff care about the Lao cultural heritage, but they do not receive a living wage and do not feel valued. Until this situation change, it is difficult to ask them to do more work, and so training programmes can have small effects but not large ones.

It is also hoped that this programme will help to encourage more training efforts over time to professionise Lao museums so that they can develop digital databases, better systems and materials for display and storage, better security, didactic materials, publications, and educational activities. All of these are critically needed at museums in Laos and other developing countries, and so this ongoing programme about biodeterioration can help participants to start thinking about improving other aspects of their museums.

Chapter 6 Conclusions

Biodeterioration is a critical problem worldwide, and the world's material culture is damaged and diminished each year because of it. Biodeterioration is a greater problem in tropical regions than in temperate regions, since high temperature and humidity encourage the reproduction and growth of biodeteriogens. In Laos the threat is increased by the lack of specialists to offer expert advice and the economic constraints on acquiring pest control materials to deal with the wide range of biodeteriogens indigenous to the country and on obtaining the equipment required to manipulate the severe tropical environment. In addition, buildings and display and storage furniture made from traditional organic building materials are in themselves highly vulnerable to pest attack. Moreover, the staff of most of the main museums and collections lacks the motivation and information they need to prevent biodeterioration.

The research done for this thesis has fulfilled the aims of identifying the major agents of biodeterioration and the materials they damage, the standard techniques for controlling and preventing biodeterioration, and the ways that environmental factors contribute to biodeterioration. An additional aim of surveying conditions in a sample of Lao museums and collections has been fulfilled with research showing that the most common and, in most cases, most damaging biodeteriogens in Laos are termites, mold, rodents, borers, and geckos. There is also damage from algae, lichen, clothes moths, and higher plants, and a lower level of damage from silverfish, booklice, cockroaches, and bats. Because the list of important biodeteriogens is small, however, it is not difficult to take action to control or prevent the destruction they cause. A plan of action, which was a final aim of this thesis, appears in Chapter 5.

All museums and collections must understand that one of their main functions is preservation and that biodeterioration cannot be prevented without the involvement of all members of the museum staff. Good housekeeping, regular maintenance of the building, appropriate storage and exhibition environments, regular inspections, and reliable documentation are the necessities of museum work, and periodic activity to kill mold or borers, for example, will have a only a brief effect if these necessities are missing. This is proved by the discovery that most Lao museums and collections think their greatest preservation need is to have more insecticides, showing that their current insecticides, which are used in institutions that lack the necessary functions of museums, are not enough to solve the problems.

In conclusion, the best solution to biodeterioration in Lao museums and collections is education. The factual information required is in this thesis, and the materials needed to control and prevent biodeterioration are simple and affordable. But the attitude and the institutional capabilities needed to make these solutions effective are far more difficult to achieve.

To achieve the goal of preventing and controlling biodeterioration in Laos, the action plan presented in Chapter 5 therefore needs to be implemented to provide education about biodeteriogens and biodeterioration to museum staff at all levels. Training must be appropriate and comprehensive to enable staff to identify problems and make decisions on effective action.

The most valuable asset of a museum is its staff, and it follows that effective pest management makes the best use of available personnel. Successful biodeterioration prevention and control relies upon good communication between all those responsible for the collection, and optimal results can be achieved only through coordination with other relevant activities in and around the building and throughout the museum’s infrastructure.

7. Appendices

Appendix A: List of interviewees and name of organisations

1. Bounheuang Buosisengpaseth, Deputy Director, Lao National Museum, Vientiane.
2. Mr. Khojohn Keomanivong, team leader, Vat Sisaket, Hor Prakeo, and Pra Thatluang, Vientiane.
3. Mr. Sisavath Ngilathchay, Director, Luang Prabang National Museum, Luang Prabang.
4. Mr. Keomontree Duangboupha, Keomontree Collection, Luang Prabang.
5. Ms. Thongkhoun Southivilay, Director, traditional art and ethnography center, Luang Prabang.
6. Mr. Norseng Saivongdueane, team leader, Vat Visoun and Vat Xiengthong, Luang Prabang.

Appendix B: List of questions

I am writing my master's thesis on biodeterioration of cultural property, which means damage to artifacts from living things in the environment like mould, plants, rodents, termites and other insects.

1. Biodeterioration happens mainly to organic materials like wood, basketry, textiles, paper, and leather, because they are edible. Which of these materials are in your collection?

2. Are any of your collections currently affected by biodeterioration? If so, what has happened to them?

3. Have you been able to do anything to address the problems? What solutions have you tried? Have these solutions been successful or unsuccessful?

4. Is anyone on your staff trained to deal with biodeterioration problems?

5. Have you been able to do anything to prevent these problems from starting? If so, what have you done, and has it been effective?

6. What do you consider the biggest biodeterioration problems in your museum/collection? What do you need that you do not have now to help you try to solve these problems?

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