International Biodeterioration & Biodegradation 88 (2014) 91–96

Contents lists available at ScienceDirect

International Biodeterioration & Biodegradation

journal homepage: www.elsevier.com/locate/ibiod

A prevention strategy against fungal attack for the conservation of cultural assets using a fungal index

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ARTICLE INFO

Article history:
Received 8 October 2013
Received in revised form
18 December 2013
Accepted 19 December 2013
Available online 11 January 2014

Keywords:
Preventive conservation
Cultural assets
Fungal index
Fungal contamination
Microclimate
IPM (Integrated Pest Management)

ABSTRACT

The present study aimed to establish a prevention strategy to protect cultural assets from fungal attack. A fungal index that assesses conditions critical for fungal growth was determined using a fungal detector in the storerooms of historical buildings in Higashiomi area, Japan. The index measurements were repeated after 4 weeks' exposure of the detectors during the seasons when relative humidity outdoors and/or indoors was high. The index values obtained were from below the measurable lower limit to above the upper limit. The prevention strategy proposed was as follows. Each microclimate was categorized into three levels, A, B, or C, depending on the index values, <1.8, 1.8–18 or >18, respectively. If all microclimates in a room maintain level A continuously, the room is considered free of contamination. If some microclimates maintain level B, fungal contamination might occur. If microclimates maintain level C, fungal contamination is unavoidable, and countermeasures should be taken promptly. Finally, fungal indices are measured for evaluation of the countermeasures and for level-A confirmation. The systematic use of fungal indices will provide practically useful information for conservation and must be applicable to IPM (Integrated Pest Management) in museums and libraries.

1. Introduction

The conservation of cultural assets in the storerooms of historical buildings is not an easy task to accomplish on a limited budget and without specialized conservators, especially in local districts. Growth of fungi causes the deterioration of cultural assets. Mycelia penetrate the spaces between fibers of paper or cloth and weaken their structure. Namely, fungi use them as substrates and destroy them using enzymes (i.e. proteolytic, cellulolytic activities, etc.). Moreover, fungal growth discolors materials: Spores usually have their own colors, and mycelia produce pigments. Foxing (Meynell and Newsam, 1978; Arai, 2000), the formation of brown spots on surfaces colonized by xerophilic fungi, occurs even at the growth stage when spores or pigments are not visible to the naked eye. Fungal contamination of artifacts has detrimental effects on both the cultural and historical legacy.

A fungal index together with a fungal detector, which quantifies the potential for fungal growth in the microclimate at an examination point, has been established by one of the present authors (Abe, 1993a). For measuring the index, a fungal detector encapsulating the spores of sensor fungi is exposed at each survey point. The spores show a growth response in a given microclimate if the microclimate has enough potential for fungal growth. The index is assessed based on the growth response of the sensor fungi in a given exposure period.

Dependence of the index on microclimatic factors, temperature and relative humidity (RH) was mentioned previously (Abe, 1993a). The index increased approximately twofold with a 5 °C elevation of temperature in the range between 10 and 20 °C, and approximately twofold with 5% elevation of the RH in the range between 80 and 90%. The fungal index varied depending on the temperature and RH.

We know that spores of fungi are always floating in the air, infiltrating storerooms and attaching to items stored in the rooms. If there are microclimates in a storeroom that have enough potential for fungal growth, fungal spores will germinate, extend hyphae, produce new spores, and finally scatter the spores, resulting in inescapable fungal contamination. Under such conditions, not only contamination of items stored in the room, but also negative effects on health, such as fungi-induced allergy, might develop in people who enter the storeroom. It was also noted that children in all homes with fungal index >18 in their living rooms (10 out of 100 investigated homes) in summer were found to have allergies (Abe, 2012). To avoid fungal contamination of items and

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http://dx.doi.org/10.1016/j.ibiod.2013.12.012

negative effects on health, we need to detect the microclimates that facilitate the growth of fungi and take suitable countermeasures before detrimental damage occurs. By using the fungal index, it is possible to detect such conditions.

Here it should be noted that, in this report, the aerial environment around a survey point during exposure of a fungal detector is referred to as a microclimate and that the group of microclimates in a given room is referred to as the indoor environment.

In this study, the fungal index was introduced for systematic monitoring of microclimates in selected rooms where artifacts were stored. The primary aim was to establish a prevention strategy against fungal attack for the conservation of cultural assets, providing a method to detect points with high potential for fungal growth using fungal detectors and to take countermeasures before fungal contamination occurs. Also, the application of the fungal index to IPM, namely Integrated Pest Management (Strang and Kigawa, 2009; Winsor et al., 2011) was mentioned.

2. Methods

2.1. Investigation rooms and the survey points

The storerooms of several historical shrines and temples in the district of Higashiomi, and Storeroom I and II of the Archaeological Center of Higasiomi City, Japan, were selected as the rooms for this investigation. Buddha statues, silk books, traditional paper books etc. were placed in the storerooms of the temples, and Noh costumes, hanging scrolls, mikoshi (portable shrines) and items for local festivals were placed in the storerooms of the shrines, some of which have been designated as national treasures or important cultural assets of Japan. In storeroom I of the Archaeological Center, unearthed articles, clay vessels, iron swords, etc. are stored, and storeroom II contains documents such as photos, books, and maps. Higashiomi is an area known for having historical temples and shrines. The area is located on the east side of Lake Biwa, which is the largest and most well-known lake in Japan. On the east side of Higashiomi are the Suzuka Mountains. Therefore, the area is full of greenery, and moisture could easily infiltrate the buildings from the surroundings.

The number of survey points in each room was three to ten. The survey points included (1) the lower parts of the room corners, which are the moistest in a room in general, (2) the middle of the room, which is generally relatively dry, and (3) other points where important items were placed in the room.

2.2. Survey period and seasons

Focusing on fungal growth, the investigations were conducted from June to October 2011 and 2012. The periods included the rainy season, summer, and autumn. The temperature and humidity in Japan are relatively high during these seasons, and therefore fungi are liable to grow at a higher rate. Fungal index measurements were repeated four times during the following periods: June 22 to July 20, July 20 to August 17, August 17 to September 14, and September 14 to October 12.

2.3. Fungal index

The fungal index was determined biologically using the fungal detector illustrated in Fig. 1, which was mentioned in the previous paper (Abe, 2012). The detector comprises a device encapsulating spores of sensor fungi. In the survey more than 10 years ago, spore-containing spots were sandwiched between a gas-permeable cover film and a support film in a fungal detector (Abe et al., 1996). The design of the detector was changed to completely sealed type,

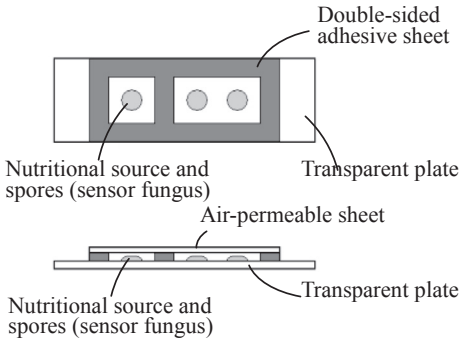

Fig. 1. A fungal detector. The upper and lower figures show the frontal and cross-sectional view of the detector, respectively, encapsulating three sensor fungi. (from Abe, 2012).

because there were incidents in which hyphae were eaten by mites, such as *Tyrophagus* spp., invading the detectors of the previous sandwiched type. After changing the design of the detector, that is, the cover and support films were sealed using a frame of a double-sided adhesive sheet, mites could no longer eat hyphae. The change of the design did not affect the fungi in the detector.

The measuring procedure of the index was described in detail previously (Abe, 2010). The procedure employed in this investigation was as follows: (1) A fungal detector was exposed for 4 weeks at each survey point; (2) after exposure, the detector was placed in a container with silica gel and the development of hyphae was terminated by desiccation; (3) the length of hyphae in each sensor fungus was measured under a microscope; (4) the number of response units, ru (Abe, 2012), was determined from the length of hyphae in each sensor fungus; and (5) the fungal index was calculated using the greatest growth response among the sensor fungi in the detector. The value of the index was defined as the growth response (ru) per exposure period (week).

Fig. 2 shows examples of the responses of a sensor fungus *Eurotium herbariorum* J-183; A is "below the measurable lower limit" with no germination, B is when hyphal length is ca. 500 μm, and C is "above the measurable upper limit" with hyphal length >2600 μm.

The responses shown in Fig. 2-A, -B, and -C, which are visible as hyphal lengths, correspond to the growth responses of <7, 24, and >72 ru, respectively, which are expressed as response units. When the exposure period of fungal detectors was 4 weeks, the values of the fungal index (response units divided by exposure weeks, 4) were calculated to be <1.8, 6.0, and >18.0, respectively. If the exposure periods were different, the values of the fungal index would differ. For example, if the exposure period was 8 weeks, the values of the index would be <0.9, 3.0, and >9.0, respectively.

Three fungi differing in sensitivity to RH were chosen as the sensors for measuring the index, which were described in the previous paper (Abe, 2012). The sensor fungi were moderately xerophilic *Eurotium herbariorum* J-183, strongly xerophilic *Aspergillus penicillioides* K-712, and hydrophilic *Alternaria alternata* S-78. The fungus *E. herbariorum* J-183 was the standard sensor fungus screened from candidates isolated from more than 10,000 colonies formed on agar plates for isolation of xerophilic fungi floating in the air. The fungal strain showed the greatest growth response in various test climates (Abe, 1993b), but its sensitivity was low at higher RH of >96% and lower RH of <72%. To compensate for the low sensitivity at higher and lower RH, hydrophilic *A. alternata* S-78 and strongly xerophilic *A. penicillioides* K-712 were added, respectively, to the fungal detector.

The strains *E. herbariorum* J-183 and *A. alternata* S-78 were deposited in the National Institute of Technology and Evaluation