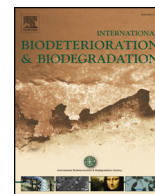




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## Assessment of indoor air environment of a Nigerian museum library and its biodeteriorated books using culture-dependent and -independent techniques

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## ABSTRACT

The surface-associated microflora on four deteriorated historical books kept in the library of a Nigerian museum were studied to identify microbial communities present, determine potential biodeteriogens and evaluate microbial aeroflora as a putative source of contamination. The application of culture-independent and -dependent techniques identified members of Actinobacteria, Bacteroidetes, Firmicutes and Proteobacteria as bacterial colonizers of the volumes, with *Bacillus*, *Stenotrophomonas* and *Variovorax* as the dominant genera. The fungal community belonged to Ascomycota with *Aspergillus* and *Penicillium* as the prevalent taxa. The retrieved microorganisms included some species that had never been detected on documentary heritage, though they have been found in association with soil particles and insects. Cellulolytic screening assay ascertained thirteen bacterial and six fungal isolates as potential biodeteriogens of the said documents. The higher microbial build-up on the discoloured areas compared to the control areas of the books highlighted microorganisms as a cause of the deterioration. The airborne microbial population, determined with passive sampling, revealed the microbial cell density to be higher in the rainy season than the dry. This is the first report on the use of both genetic fingerprinting and traditional methods in a biodeterioration study of books in Nigeria. The findings of the study should be taken into account to ensure the proper preservation of written heritage.

### 1. Introduction

Books in museum archives and libraries are repositories of human ideas, achievements, development and ways of life, and the significance of the information there in implies the need to preserve them for future generations (Polo et al., 2017). However, books are susceptible to deterioration by microorganisms under favourable environmental conditions, thus preservation becomes a serious challenge when such books are of cultural or historical importance. Microbial colonization and the deterioration of books is usually manifested as aesthetic or structural damage (Michaelsen et al., 2009), which can be irreversible and ultimately lead to total destruction. Aesthetic damage, observed as chromatic alterations or stains, is caused by the secretion of pigments of varying colour (Michaelsen et al., 2010) while structural damage results from the breakdown of the paper's components, e.g. cellulose, glue and plastifiers (Pasquariello et al., 2008).

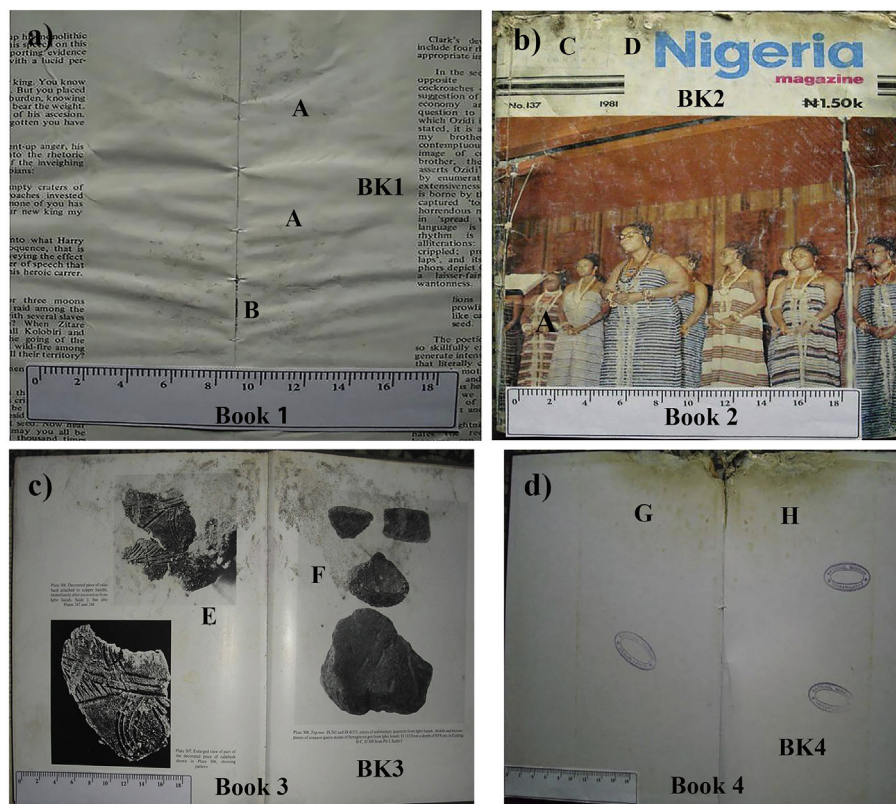
The process of biodeterioration is determined by various factors, mainly the relative humidity and temperature of the environment

where the books are kept (Pinzari et al., 2006), the material composition of the book (Strzelczyk, 2004) and the presence of dust in the environment (Pasquarella et al., 2015). High relative humidity and temperature favour the growth of microorganisms, with the subsequent secretion of metabolites (Petushkova and Kandyba, 1999), such as pigments and organic acids that discolour paper (Sterflinger and Piñar, 2013). The warm and humid climate of tropical countries like Nigeria increases the risk of biodeterioration, thereby aggravating deterioration processes (Bankole, 2010). Cellulose, a major component of books made from paper (Sahin and Arslan, 2008; Pasquariello et al., 2008), can be attacked by bacteria and fungi through secreted cellulolytic enzymes (Lynd et al., 2002) that lead to depolymerisation and the paper becoming brittle (Dunca et al., 2014). Cellulolytic enzymes, viz. endoglucanase, exoglucanase and  $\beta$ -glucosidase, act synergistically, dissolving cellulose fibres (Zhang and Lynd, 2004) into simpler molecules that then serve as carbon and energy source for microorganisms on books. Dust is also an important factor in the risk of deterioration in library collections, especially in tropical areas (Plumbe, 1987), as it

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**Fig. 1. Sampled areas from Books.** (a) A–B: Discoloured area on Book 1; BK1: Control area on Book 1. (b) C–D: Discoloured area on Book 2; BK2: Control area on Book 2. (c) E–F: Discoloured area on Book 3; BK3: Control area on Book 3. (d) G–H: Discoloured area on Book 4; BK4: Control area on Book 4.

contains high numbers of fungal spores that settle on books and proliferate when humidity and temperature are high (Kaarakainen et al., 2009).

The determination of the Index of Microbial Air Contamination (IMA) is a key factor in the study of book biodeterioration; it is an evaluation of the airborne microbial population that falls on book surfaces (Pasquarella et al., 2000). Furthermore, in a library environment, a heavy microbial load of fungi and their spores poses health risks to library personnel and users as their inhalation has the potential to cause respiratory disorders in humans (Maggi et al., 2000; Ponsoni and Raddi, 2010). Thus it is very important to determine and monitor the air quality of libraries to ascertain the presence of biological pollutants (Górny, 2004; Šimonvičová et al., 2015).

The identification of microorganisms on the surfaces of deteriorated heritage objects is useful to formulate appropriate conservation strategies (Otlewska et al., 2014). Moreover, it allows an assessment of potential microbial and health risks to both the library books themselves and to the users (Cappitelli et al., 2010). Although traditional diagnostic methods are used to isolate and characterize microflora inhabiting paper heritage (Zotti et al., 2008; Borrego et al., 2010; Guimet et al., 2011), molecular techniques have recently come to the fore and are now widely adopted to determine the microbial consortia of historic objects (Michaelsen et al. 2009, 2010; Jurado et al., 2010). However, conventional cultivation methods are still useful in biodeterioration studies because of their ability to detect the potential capability of colonizing microorganisms to cause deterioration in cultural heritage (Laiz et al., 2003; El-Bergadi et al., 2014; Okpalanzie et al., 2016). Despite the current use of culture-independent techniques to determine microbial communities on deteriorated books, the approach has not yet been adopted in book conservation in Nigeria. Although there are many studies on the biodeterioration of paper heritage in developed countries (Pinzari et al., 2006; Zotti et al., 2008; Michaelsen et al., 2009; Mesquita et al., 2009; Lavin et al., 2014), few reports exist

in Nigeria (Bankole, 2010).

Therefore, the present study investigates microbial communities on the surfaces of four twentieth century books and magazines kept in a Nigerian library using, for the first time in Nigeria, both genetic fingerprinting and conventional methods.

The techniques, which are non-invasive, were applied to assess the microbial risk to the books and determine the presence of potential biodeteriogens. Also evaluated was the influence of environmental parameters on the deterioration of documentary heritage, and this in turn led to the provision of an index of the microbial surface contamination of the books.

## 2. Materials and methods

### 2.1. Documentary heritage description

The volumes used in the study were two magazines [Books 1 and 2] and two books [Books 3 and 4], printed in the years 1970–1984, and in the custody of the library of a Lagos museum, Nigeria. All the books were made from wood fibre, and had undergone surface sizing to prevent the ink from penetrating the paper, and to enhance its printability and surface strength; the glue binding the volumes was a polyvinyl acetate.

Books 1, 3 and 4 were characterized by brownish–black, powdery patches along the upper part of the pages, while Book 2 showed a light brown discolouration with felted edges of the upper part of the page.

### 2.2. Sampling

Samples were collected from the discoloured areas and the non-discoloured areas (from here on in called the control) of the books. A and B are discoloured areas on Book 1; C and D are discoloured areas on Book 2; E and F are discoloured areas on Book 3; G and H are

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