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Recolonization of mortars by endolithic organisms on the walls of San Roque church in Campeche (Mexico): A case of tertiary bioreceptivity

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HIGHLIGHTS

- Biodeterioration of San Roque church, Campeche, Mexico, in a tropical climate.
- Restoration works increased tertiary bioreceptivity of mortars.
- Early colonization by endolithic phototrophic microorganisms was promoted on the restored church façades.

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ABSTRACT

San Roque church (Campeche, Mexico) was built at the end of the 17th century with a micritic limestone and lime mortar in baroque style. In 2005 the church exhibited heavy biodeterioration associated with the development of extensive dark green phototrophic-based biofilms. Several cyanobacteria belonging to the order Chroococcales and lichenized fungi (*Toninia nordlandica*, *Lobaria quercizans*, *Lecanora subcarnea*, *Cystocoleus ebeneus*) were predominant in the dark biofilm samples, as revealed by DNA-based molecular techniques. In 2009, a cleaning and restoration intervention was adopted; however, after few months, microbial recolonization started to be noticeable on the painted church walls, representing an early phototrophic-based recolonization. According to molecular analysis, scanning electron microscopy observations and digital image analysis of cross sections, new phototrophic-based colonization, composed of cyanobacteria and bryophytes, developed mainly beneath the restored mortars. The intrinsic properties of the mortars, the tropical climate of Campeche and the absence of a biocide treatment in the restoration protocol influenced the recolonization of the church façades and enhanced the overall rate of deterioration in a short-term period.

1. Introduction

The historical center of Campeche, in Yucatan peninsula, Mexico (Fig. 1A), is enshrined in the UNESCO World Heritage List. This coastal city is a model of Baroque colonial urbanism, where the defensive walls reflect the influence of the Spanish architecture in the Caribbean. The fortification system of Campeche, an eminent example of the military architecture of the 17th and 18th centuries, is part of an overall defensive system set up to protect the Caribbean ports from pirate attacks.

By the end of the 17th century, San Roque church (Fig. 1B) was built with hard limestone quarried in the region, like most buildings in the Campeche city. The stone is a micritic limestone with small calcite fragments, scarce particles of quartz and carbonate content higher than 96%. As mortars, a double solution was adopted: lime mortar and *sahcab* (a calcareous white earth abundant in the subsoil of Yucatan, which is mixed with lime, and traditionally used in the construction of ancient Maya buildings). The same materials were used for the flattening of the external and inner surfaces, which were finished with lime paint. The roofs, in flat shape, were built with limestone masonry, known in the region as *bahpek* system.

In 2005 the church exhibited heavy biodeterioration associated with the development of dark green biofilms (Figs. 2A and 3A), as some other limestone monuments in the area. The biodeterioration

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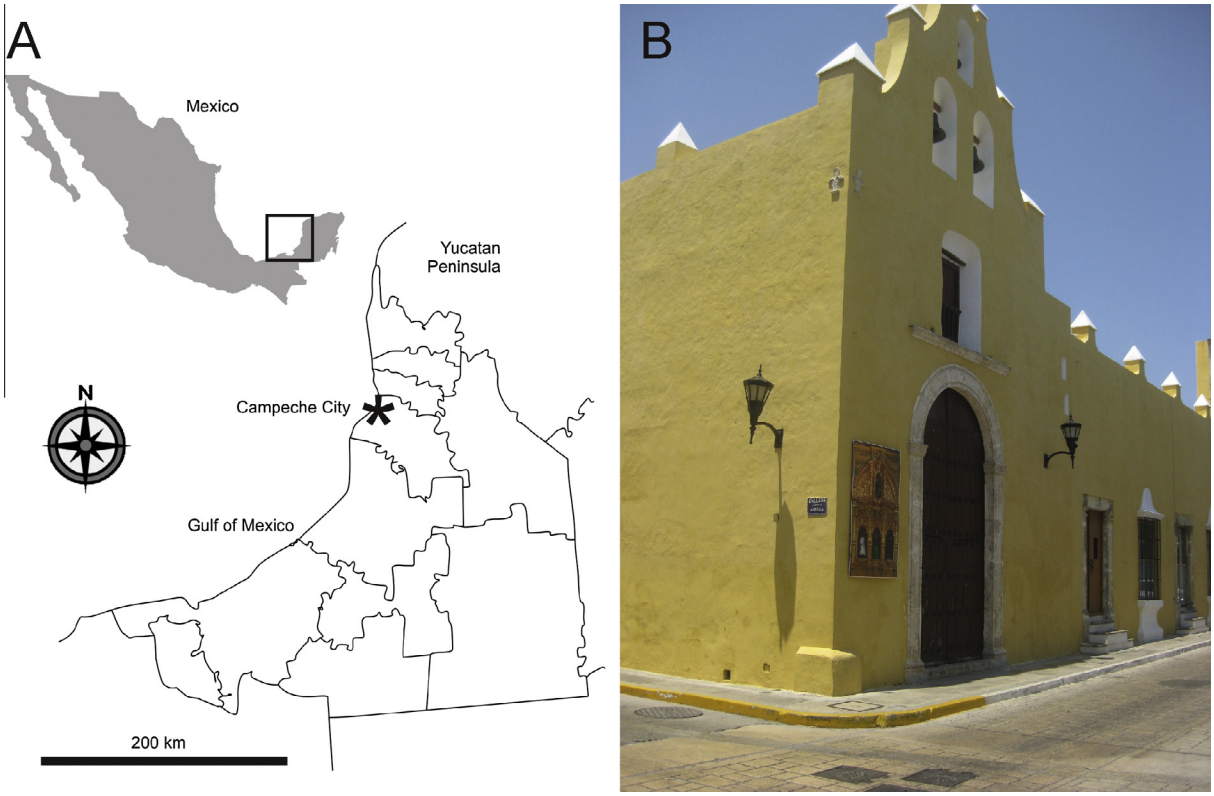

Fig. 1. A. Map of Campeche (Mexico). B. Front façade of San Roque church in 2010.

of stone buildings and monuments by phototrophic microorganisms is well known and has also been studied by several researchers [1–4]. Their development on stone cultural heritage produces aesthetic, physical and chemical damages, which can be noticeable through variously-colored surface patinas [5]. This deteriorative potential is related to the photoautotrophic nature of phototrophic microorganisms and the bioreceptivity of the stone material, i.e. the ability of a material to be colonized by living organisms [6,7]. According to Guillitte [6], several types of bioreceptivity can be differentiated: primary bioreceptivity, which is the intrinsic potential of a material for biological colonization; secondary bioreceptivity, the ability of an already changed over time material to be colonized; and tertiary bioreceptivity, the colonization potential of a material already altered by human hand (e.g. after a conservation treatment).

In 2009, due to its deterioration, unaesthetic and abandoned-like appearance, San Roque church was subjected to conservation-restoration intervention. The restoration works included cleaning and mechanical removal of biodeteriogens, replacement of decayed materials, reparation of wooden doors, iron works, and application of a mortar layer finished with yellow lime paint over the stone masonry (Fig. 2B). For this layer, slaked lime mixture with white and Portland cement (in proportion 20:1:1), rock powder, and Festegral®, a waterproofing for use in concrete and mortar composed of fatty acid salts, were used. The mixture was applied on the exterior walls for masonry wall flattening. In addition, the walls were painted with a mixture of mineral pigment, Festerbond® (liquid styrene-acrylic resin dispersion with characteristics of adhesiveness), vegetal oil and lime. No biocides were used in the restoration process and shortly after these works, occasional light green stains of small dimensions, representing epilithic phototrophic-based colonization, started to be noticeable on the paint layer (Fig. 3B).

To investigate the nature and associated deterioration processes of the dark green coatings covering the church façades, an exhaustive sampling campaign was carried out in 2005, before the restoration works. In addition, mineralogical, petrographic, petrophysical and microbiological studies were carried out in order to understand the origin and deterioration mechanisms of the exterior façades of San Roque church. To assess the biological recolonization of the church walls after restoration, a limited sampling survey was carried out in 2010. DNA-based molecular methods were applied for the identification and comparison of the microorganisms developing on the mortar before and after restoration works.

2. Materials and methods

2.1. Sampling

In 2005, mortars and biofilm samples (A3, A4, C1, C3, E1, R1A and R2C) were collected from dark green to black areas on the external surfaces of the main and lateral façades of San Roque church in Campeche, Mexico (Fig. 2A). Samples for molecular biology were scrapped with a sterile scalpel, placed into eppendorf tubes and stored at −80 °C until laboratory analyses. For materials characterization, mortar samples were collected by gently removing small fragments of the deteriorated mortar layer and gathering it into sterile vials.

In 2010, after the restoration works, a few samples of mortars (CC1, CC3, CC5 and CC9), were collected from the outdoor restored surfaces (Fig. 2B), in order to assess their tertiary bioreceptivity and characterize microbial recolonization. It must be mentioned that the sampling methodology was focused to optimize the sampling area dimension and the number of sampling sites minimizing any impact to the monument.

2.2. Climatic characterization

Weather conditions of the study area were analyzed by using the meteorological records from the Campeche station, which is located near the city airport (19°50′00″N, 90°33′00″W, 5 m a.s.l), approximately 4 km far from San Roque church (19°50′39.86″N, 90°32′15.03″W, 9 m a.s.l). This climatic information was provided