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HISTORICAL HERITAGE IN ANTARCTICA, THE CASA MONETA MUSEUM: A FIRST APPROACH TO THE CHARACTERIZATION OF XYLOPHAGOUS FUNGI AND THEIR POTENTIAL ROLE IN WOOD DAMAGE

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Abstract

The Casa Moneta Museum is located at the base located at an isthmus located on Laurie Island in the South Orkney Islands archipelago. Currently, the museum shows signs of deterioration of the wood (discoloration, fibrous appearance and presence of mycelium) and it is necessary to characterize this mycobiota to analyze the potential role in the biodegradation process. An assessment of the potential risk associated with fungal communities could provide valuable information for taking conservation action at the Casa Moneta Museum. The aim of this work was to evaluate the extracellular oxidase production of fungi recovered from deteriorated wood at the museum and to analyze the biodegradation risk index of three sampled sites in the building. The enzymatic profile showed the potential degradation of Cadophora spp. and Tulasnella albida strains. The analysis performed integrated data on several parameters like occurrences, species diversity, dominant species, wind direction, relative humidity, growth temperature, type of dispersion propagules and substrate, indicating Site 2 has a major biodegradation risk index which suggests that this site should be the immediate target for conservation efforts.

Keywords: *Cadophora; Tulasnella; Wood decay; Historical heritage; Extracellular oxidases; Biodegradation risk index*

Introduction

The Casa Moneta Museum is in the Orkney Base, an isthmus located on the Laurie Island of the South Orkney Islands Archipelago (60° 44’ 25.6 S 44° 44’ 24.3 W) [1]. This museum is part of the Historic Site and Monument N 42 (HSM Nº 42) formally designated by the Antarctic Treaty [2]. The HSM Nº 42 is made up of 3 independent facilities: a cabin known by the name of Omond House, a cemetery with 12 tombs, and the Casa Moneta [3]. This latter building was composed of three bedrooms, a living room, and a kitchen.

At present Casa Moneta museum houses the archeological material of the Omond House, exhibiting, through different rooms, objects collected at different times, accounting for the history of humans on Orkney; native animal and plant species and minerals are also exhibited; there is a room displaying instruments from the first communications of Antarctica, and a sector destined

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to the furniture and utensils brought from Buenos Aires [3, 4] (Fig. 1). The outer walls of the building were composed of an inner plank and an outer plank, with cork and sawdust in between to insulate the low outdoor temperatures [4].

The extreme climate of Antarctica represents a hostile environment for the wooden constructions, which leads to a very marked deterioration and decay. The abiotic deterioration is caused by wind erosion, metal oxidation and salt defibration [5], while fungi are one of the principal agents of biodegradation [6-9].

Fig. 1. The Museum Casa Moneta:a) Outside; b) Biology room; c) Radio room; d) Omond House room. Images by Natalia Skronski in the 2016 summer campaign.

Fungi can grow and deteriorate cultural heritage both indoors and outdoors, causing damage to the wood with which the cultural heritage represented by wooden frames and artifacts exhibited in museums are built [10]. These organisms have enzymes that secrete to the surrounding environment and some of them can degrade wood components, reaching a state of rot that produces structural weakness and can cause problems in buildings. In the Antarctic region, previous reports have cited the presence of soft rot fungi, mainly caused by members of the genera *Phialophora* and *Cadophora* in buildings in New Harbor, a bay along the coast of Victoria Land in Antarctica [7]. *K.E. Ludley and C.H. Robinson* [11] recorded some species of white rot Basidiomycota; *Trametes versicolor*, collected from the bottom of the wood at the whaling station in Grytviken, South Georgia and *Dacrymyces stillatus*, which was isolated from a wooden walkway, also at the Grytviken whaling station. *B.W. Held and R.A. Blanchette* [12] reported that several species of Basidiomycota belonging to the genera *Hypochniciellum* and *Pholiota* were the cause of advanced stages of brown and white rot, respectively, in the wood of Deception Island, even though they were found in low proportion compared to Ascomycota.

In the context of a project of conservation of Antarctic historical heritage, the first step was to evaluate the fungi present in Casa Moneta Museum. *R.F. Gaiser et al*. [13] studied the mycobiota associated with deteriorated historic wood used in the construction, recovering and identifying 43 strains belonging to 17 genera. Twenty-eight strains were isolated from the exterior of the museum and the other 15 strains were isolated from the interior of the museum. *Cerinosterus luteoalbus* and *Cadophora* sp.4 were the only two species found both inside and outside the museum. The occurrences reported indicate that both the interior and exterior sectors of Casa Moneta present an important species richness, but the fungal communities appear to be specific to each sector. However, no additional analysis has been carried out to find out if any of the registered organisms represent a risk to the museum's integrity. An evaluation of the potential risk associated with the presence of the fungal communities could provide valuable information to take conservation actions at Casa Moneta Museum.

The characterization of enzymatic profiles of fungi allow us to hypothesize about the type of rot that the fungi can develop, thus improving our ability to estimate the potential degradation capacity, and this could be a good indicator of the risk that these organisms represent in terms of biodegradation. The incorporation of a biodegradation risk index in the management of cultural heritage is an approach already explored by several authors [14-16]. *S. Bhattacharyya et al.* [17] developed a risk scale using several parameters such as viable spore load, species diversity, species dominance, relative humidity, among others, as a tool to determine the biodegradation status of museum pieces. Despite its usefulness, to our knowledge, this tool has not yet been used in polar cultural heritage.

At present, the Casa Moneta Museum shows signs of wood deterioration (discoloration, a stringy or fibrous appearance, and the presence of mycelium). Although the mycobiota associated with the wood of the museum has been identified [13], it is necessary to characterize this mycobiota to analyze its potential role in the biodegradation process. In this context the aims of this work were to a) evaluate the production of extracellular oxidases by fungi recuperated from wood of the museum to detect their potential to cause wood rot and b) calculate the biodegradation risk index of each sampled site according to a modification applied to the biodegradation index developed by *S. Bhattacharyya et al.* [17].

Experimental part

Materials

The Casa Moneta Museum is built on a concrete base; its walls, openings, columns, and beams are made of wood. The walls and ceilings are thick and made of different materials to insulate the interior from extreme cold, wind, rain, and snow; finding, from the outside to the inside: a layer of asphalt cardboard painted with asphalt paint, tongue and groove boards, wood

(in the form of sawdust) and then again tongue and groove boards painted with synthetic paint. The building has a rectangular shape, northeast-southeast oriented and its orientation determines that the south face withstands the strongest winds (Fig. 1a).

The Orcadas station is in the climate zone of Coastal Antarctica. The wind reaches a mean annual speed of 24km/h, and the dominant wind direction is from the south. The snow free period is in January and February. The precipitation type is snow and rain, and total annual precipitation is 1180mm. The mean annual temperature is -3.6ºC [1].

Sampling was done during January and February 2016. The mean temperature and relative humidity at the Orkney Base was 0.4°C and 82.4%, respectively, for January 2016 and 0.8°C and 92.6% for February 2016 (http://www.TuTiempo.net). Temperature inside the Museum was always 2°C higher than outside the building.

Methods

Studied material and fungal strains

A total of 36 strains were considered in the analyses. These strains were previously isolated from samples, extracted from wood from outside and wood from inside the Casa Moneta museum [13]. The samples analyzed here belonged to 3 sites, which were named as: Site 1, 2, and 3. Sites 1 and 2 were located in the exterior of the museum, while Site 3 was inside the museum (Fig. 2). The museum walls have a double layer of gymnosperm wood (Fig. 3a) with sawdust filling in the middle.

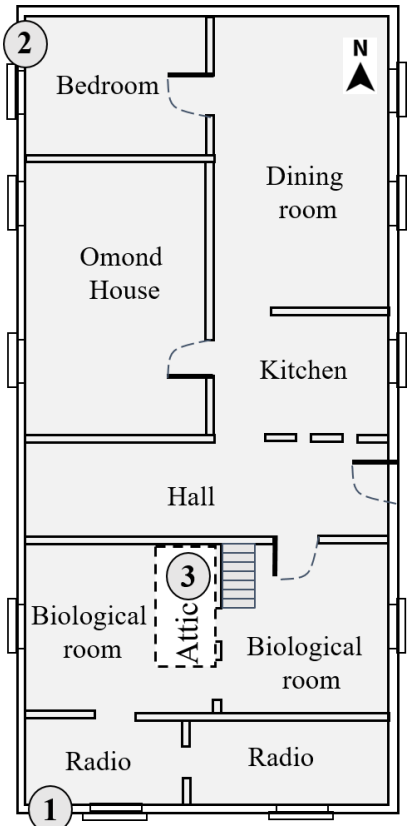

Fig. 2. Plan of Casa Moneta Museum. The numbers represent the sampled Sites.
Site 1: samples taken from outside the radio room, Site 2: samples taken from outside the bedroom,
Site 3: samples taken from the interior in the attic above the biological room on the first floor
(represented as a rectangle of dotted lines)

The layer of the wall facing the outside is lined with 2 or 3 layers of Ruberoid (asphalt thermal insulator), while the paint used to paint the interior is synthetic. Some of these walls show a presence of mycelium, fibrous appearance or discoloration (Fig. 3b, c and d).

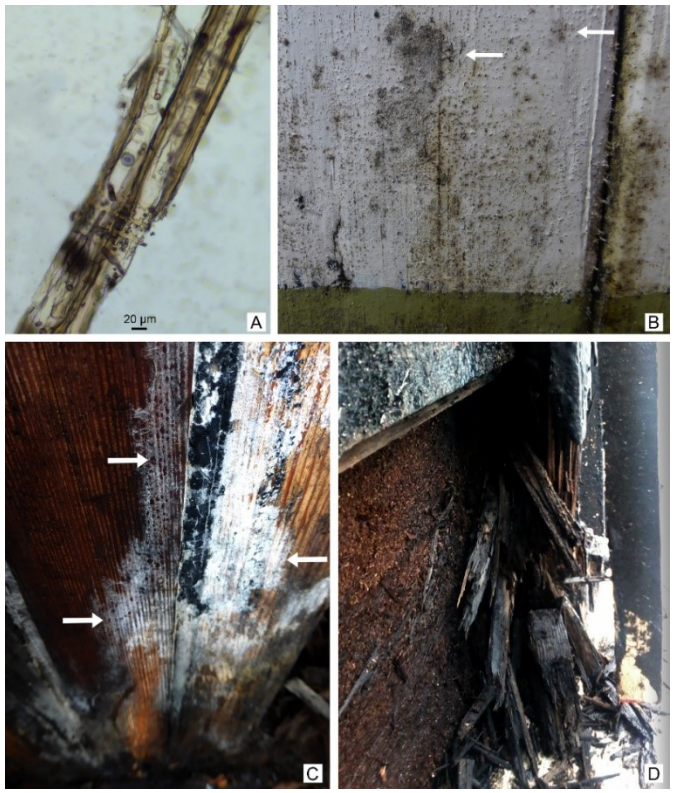

Fig. 3. State of the wood outside and inside the Museum Casa Moneta:
a) gymnosperm wood with tracheids; b) wood with white mycelium outside the museum;
c) fibrous appearance; d) painted wood with dark mycelium inside the museum.
Arrows indicate grown mycelium. Images by Natalia Skronski in the 2016 summer campaign.

All strains analyzed during this study were characterized and identified by *R.F. Gaiser et al*. [13] (Table 1). The taxa names used in this study correspond to names currently accepted in the online database Mycobank (http://www.mycobank.org/).

Evaluation of the presence of extracellular oxidases

In order to detect fungal strains with potential to cause wood rot, the production of extracellular oxidases was studied. The analyses were performed using the most abundant species registered and all Basidiomycota's strains recuperated. Medium with gallic acid and tannic acid [18], and with 0.2% tyrosine [19] were used. These special media are used to detect rot-causing fungi [20, 21]. The evaluation was carried out by recording the presence of a diffusion zone around the inoculum and its relative intensity after a week of incubation in 9 cm diameter Petri dishes at 23 °C, in the dark. Each test was replicated twice. The absence of halo was taken as an indicator of a negative reaction (-), corresponding to the absence of extracellular oxidases, while the presence of halo was taken as an indicator of a positive reaction, with different intensities evaluated qualitatively (+ to +++++).

Estimation of the biodegradation risk index

The methodology used was outlined by *S. Bhattacharyya et al.* [17]. In the current study we present a modification of Bhattacharyya´s equation (see below) to include: the data from

culture studies (presence of enzymes), the temperature ranges for fungal growth, the effect of the wind and factors of dispersion of fungi. Here we evaluated the risk for each site, in terms of biodegradation, applying the linear equation proposed by *S. Bhattacharyya et al.* [17], as function for the multiple risk factors, including: occurrences (S), species diversity (D), species dominance (SD), wind direction (V), relative humidity (RH), growth temperature (GT), type of dispersion of propagules (P) and substrate (SU) of the sampling site. Thus, the biodegradation risk index (R) was calculated as follows:

$$R = 0.25\sum S + 0.12\sum D + 0.08\sum SD + 0.05\sum V + 0.17\sum RH + 0.08\sum GT + 0.1\sum P + 0.15\sum SU \quad (1)$$

Table 1. Taxa and relative frequencies represented by sampled sites. *The sum gives 102 due to the roundings used

Site	Taxon	Relative frequency
1	*Hypochniciellum molle* (Fr.) Hjortstam	3
	Tulasnella albida (Quél.) Bourdot & Galzin	19
	Cerinosterus luteoalbus (de Hoog) R. T. Moore	11
	Cadophora sp. 1	8
	Cadophora sp. 2	3
	Cadophora sp. 3	3
	Cadophora sp. 4	6
	Geomyces fujianensis W. H. Chen, G. P. Zeng, Y. Luo, Z. Q. Liang & Y. F. Han	8
2	*Penicillium* sp. 1	3
	Penicillium sp. 2	3
	Penicillium sp. 3	3
	Acremonium sp. 1	3
	Antarctomyces sp.	3
	Gliocladium sp.	3
	Sarocladium strictum (W. Gams) Summerbell	3
	Periconiella mucunae M.B. Ellis	3
	Phoma sp.	3
	Cadophora sp. 4	3
3	*Cerinosterus luteoalbus* (de Hoog) R. T. Moore	3
	Coniochaeta sp.	8
Total	36	100*

Table 2 summarizes the risk factors evaluated and the risk scale assigned to each risk factor (0 to 2 for wind speed; 1 to 4 for occurrences, species dominance, species diversity and type of propagation; 1 to 5 for relative humidity; temperature and substrate). To assess the biodegradation risk index of each site in the Casa Moneta museum the following risk factors were considered:

Table 2. Risk scale of risk factors (modified from *S. Bhattacharyya et al.* [17]).

Risk factor (RF)	Risk weightage percentage (%)	Class description	Risk scale
Occurrences (S)	25	>9	4
		6-9	3
		3-5	2
		0-2	1
Species diversity (D)	12	>6	4
		4-6	3
		2-4	2
		<2	1
Species dominance (SD)	8	SD4	4
		SD3	3
		SD2	2
		SD1	1

Risk factor (RF)	Risk weightage percentage (%)	Class description	Risk scale
Wind speed (V)	5	V2	2
		V1	1
		V0	0
Relative humidity (RH, %)	17	70-80	5
		60-70	4
		50-60	3
		40-50	2
		30-40	1
Temperature (GT, °C)	8	T5	5
		T4	4
		T3	3
		T2	2
		T1	1
Type of dispersion propagules (P)	10	P4	4
		P3	3
		P2	2
		P1	1
Substrate (SU)	15	Paper/old manuscript/newsprints	5
		Oil paintings/photograph	4
		Leather/bone	3
		Metal/ stone	2
		Glass/porceline	1
Total score	100		

- Occurrences (S): number of strains at each sampled site; this value is equivalent to the viable spore load by *S. Bhattacharyya et al.* [17], since both try to estimate the viable fungal sources for colonization. Following this consideration, four class descriptions were defined and the risk scale was assigned in Table 2.

- Species diversity (D): numbers of species registered at each site. This value is used as described by *S. Bhattacharyya et al*. [17]. Four class descriptions were defined, and the risk scale was assigned in Table 2.

- Dominant species (SD): the risk scale was assigned considering the results of the presence of extracellular oxidases. This value was considered as equivalent to the species dominance in *S. Bhattacharyya et al.* [17]. In this risk scale, the production of extracellular oxidases by the most abundant morphotypes and the Basidiomycota, was included. Following this consideration, strains were assigned to four class descriptions as follows: **SD1**: no enzymes were detected; **SD2**: only degrade tyrosine/only degrade gallic acid/only degrade tannic acid; **SD3**: degrade gallic acid and tannic acid but not tyrosine and **SD4**: degrade gallic acid, tannic acid, and tyrosine (Tables 2 and 3).

- Wind direction (V): the risk assignment was performed according to the wind at Orkney Base. This value is equivalent to the wind in *S. Bhattacharyya et al*. [17], and it was modified taking into account that inside the museum there is no wind and that the south wind is the strongest outdoors. Three class descriptions were defined as follows: **V0**: without wind, **V1**: wind that does not come from the south and **V2**: south wind (Table 2).

- Relative Humidity (RH): considering that the average relative humidity of Orcadas Base is 82.4% (http://www.TuTiempo.net), we assigned a risk scale and class descriptions for all sites following *S. Bhattacharyya et al.* [17], see Table 2.

- Growth Temperature (GT): five class descriptions were recognized regarding the fungal growth estimated as the colony radius at 6°C, 12°C and 23°C at 3 weeks. Data were taken from *R.F. Gaiser et al.* [13]. The class descriptions were defined as follows: **T1**: 0-10mm, **T2**: 10-20mm, **T3**: 20-30mm, **T4**: 30-4 mm and **T5**: growth radius greater than 40mm (Tables 2 and 4). This factor was considered analogous to parameter T in *S. Bhattacharyya et al*. [17]. This author includes the max temperature as a risk factor considering its impact on the rate of fungal growth.

For the present analyses specific data about the fungal growth were available. The biodegradation risk index was calculated for three different growth temperatures, because the effect of temperature on the growth of strains was evaluated: 6 °C, 12 °C and 23 °C, and the average of the risk scales of each tested strain was considered.

- Type of dispersion propagules (P): the assignment was performed taking into account the propagules for dispersion observed for each species. This parameter was incorporated instead of P (presence of SOx) used by *S. Bhattacharyya et al.* [17], taking into account the features of the museum and that the types of propagules represent different risk of dispersion. Therefore, in our study, the type of propagules presented by each species was considered. Among them, we recognized chlamydospores and conidia. Following this consideration, four class descriptions were obtained as follows: **P1**: without propagation structures, **P2**: chlamydospores, **P3**: production of conidia in small quantities and **P4**: production of conidia in large quantities (Table 2).

- Substrate (SU): considering that the material involved in this study was wood, we assigned a risk scale and class descriptions for all sites following *S. Bhattacharyya et al*. [17], see Table 2. Figure 2 shows the plan of the Casa Moneta Museum indicating sites from which the samples were collected, the numbers boxed in black represent the numbers assigned to the sampling sites, the arrow painted black indicates the original entrance and the arrow painted light grey, the current museum entrance.

The *S. Bhattacharyya et al.* [17] color scale was used: very high risk (R above 4), high risk (R 3.9-3), moderate risk (R 2.9-2), partially moderate risk (R 1.9-1) and low risk (R below 1).

Table 3. Assays in special culture media for extracellular oxidase production. Each of the strains seeded in duplicate in Petri dishes with the respective means to qualitatively evaluate the negative reaction (-) or the positive reaction range: (+) to (+++++). DP = white precipitate from the medium with tyrosine degraded. MG = mycelial growth.

Strain	Tannic acid medium		Gallic acid medium		Tyrosine medium		Dominant species (SD)
Ascomycota							
Cadophora sp. 1 (BAFCcult 4703)	+++ MG	+++ MG	+++++	+++++	- MG	- MG	SD3
Cadophora sp. 1 (BAFCcult 4704)	+++++	+++++	+++++	++++++	- MG PD	- MG PD	SD3
Cadophora sp. 2 (BAFCcult 4714)	+++ MG	+++ MG	+++++	+++++	- MG PD	- MG PD	SD3
Cadophora sp. 3 (BAFCcult 4702)	+++++	+++++	+++++ MG	+++++ MG	- MG PD	- MG PD	SD3
Cadophora sp. 4 (BAFCcult 4700)	+++++ MG	+++++ MG	++ MG	++ MG	- MG	- MG	SD3
Cadophora sp. 4 (BAFCcult 4701)	- MG	- MG	-	-	- MG PD	- MG PD	SD1
Coniochaeta sp. (BAFCcult 4707)	+++ MG	+++ MG	- MG	- MG	-	-	SD2
Geomyces fujianensis (BAFCcult 4708)	-	-	-	-	-	-	SD1

Strain	Tannic acid medium		Gallic acid medium		Tyrosine medium		Dominant species (SD)
Basidiomycota							
Cerinosterus luteoalbus (BAFCcult 4705)	-	-	-	-	- PD	- PD	SD1
Hypochniciellum molle (BAFCcult 4706)	- MG	- MG	-	-	++	+++	SD2
Tulasnella albida (BAFCcult 4709)	+++++	++++	+++++ MG	+++++ MG	- MG	- MG	SD3
Tulasnella albida (BAFCcult 4710)	-	-	++++	+++	-	-	SD2
Tulasnella albida (BAFCcult 4711)	-	-	-	-	-	-	SD1
Tulasnella albida (BAFCcult 4712)	-	-	-	-	-	-	SD1
Tulasnella albida (Gaiser 4A2)	++++	++++	+++++	+++++	- MG	- MG	SD3
Tulasnella albida (Gaiser 4A3)	-	-	-	-	+++	++	SD2

Table 4. The rank of temperature sensu *R.F. Gaiser et al.* [13]. The growth (mm) was taken on day 21 (final day of the test). Each growth range was assigned a value from 1 to 5: 1 = 1-10mm (low risk), 2 = 10-20mm (10-20 mm (partially moderate risk), 3 = 20-30mm (moderate risk), 4 = 30-40mm (high risk) and 5 = >40 mm (very high risk)

Strain	Temperature (°C)	Growth (mm)	Growth range	Class description
Hypochniciellum molle (BAFCcult 4706)	6	5,73	0-10	T1
	12	17,96	10-20	T2
	23	28,68	20-30	T3
Cerinosterus luteoalbus (BAFCcult 4705)	6	3,76	0-10	T1
	12	5,13	0-10	T1
	23	10,71	10-20	T2
Tulasnella albida (BAFCcult 4709)	6	22,04	20-30	T3
	12	63,96	>40	T5
	23	82,41	>40	T5
Geomyces fujianensis (BAFCcult 4708)	6	6,93	0-10	T1
	12	7,42	0-10	T1
	23	9,36	0-10	T1
Cadophora sp. 1 (BAFCcult 4704)	6	17,23	10-20	T2
	12	20,69	20-30	T3
	23	37,14	30-40	T4
Cadophora sp. 1 (BAFCcult 4703)	6	13,11	10-20	T2
	12	31,16	30-40	T4
	23	37,59	30-40	T4
Cadophora sp. 3 (BAFCcult 4702)	6	12,74	10-20	T2
	12	23,84	20-30	T3
	23	34,62	30-40	T4
	6	6,52	0-10	T1

Strain	Temperature (°C)	Growth (mm)	Growth range	Class description
Cadophora sp. 4 (BAFCcult 4701)	12	25,83	20-30	T3
	23	33,6	30-40	T4
Cadophora sp. 4 (BAFCcult 4700)	6	7,51	0-10	T1
	12	9,25	0-10	T1
	23	30,65	30-40	T4

Results and discussion

Historical heritage is the reflection of a past, a culture and a history worth preserving. In particular, the buildings in Antarctica were intended to serve as home and refuge for those first explorers and scientists who arrived in that inhospitable continent with such extreme climate, so the study of the biodegradation of this historical heritage is of vital importance. Casa Moneta Museum is a part of this history, their buildings erected with gymnosperm wood and today are affected by biodeterioration and biodegradation processes.

The fungi are one of the most important biodegradation agents in cultural heritage in Antarctica [10] and an important diversity of fungi is known to be associated with the historic wood of buildings in Antarctica with potential for degradation of wood, such as species of the genus *Cadophora* [7, 12, 22].

Evaluation of the presence of extracellular oxidases

For the extracellular oxidase assays, the strains of the Phylum Ascomycota (*Cadophora*, *Geomyces* and *Coniochaeta*) and strains of the Phylum Basidiomycota (*Cerinosterus luteoalbus*, *Hypochniciellum molle* and *Tulasnella albida*) were used. The results obtained to produce extracellular oxidases in the selected strains are shown below (Table 3). Members of *Cadophora* showed a positive reaction after one week of incubation in tannic acid medium and gallic acid medium, and a negative reaction in tyrosine medium, except for BAFCcult 4701, which was negative in all media. In contrast, for the Basidiomycota strains, positive reactions were obtained in tyrosine medium and negative for tannic acid or gallic acid media, except for strains of *Tulasnella albida* (BAFCcult 4709 and Gaiser 4A2) where the results were positive in tannic and gallic acid media and negative in tyrosine medium. *Coniochaeta* sp. only gave a small halo in the tannic acid medium. *Cerinosterus luteoalbus* and *Geomyces fujianensis* presented a negative reaction in all media. We did not obtain strains with positive results in the three tested media, and as a result SD4 was not added to the analysis.

The results of the present work show that strains associated with the wood of Casa Moneta Museum, detected by *R.F. Gaiser et al.* [13], have the potential to produce biodegradation of some components of the cell walls. In that study, soft rot was observed in wood samples. In particular, analyzed *Cadophora* strains can produce extracellular oxidases and would be associated with the observed deterioration. *R.F. Gaiser et al.* [13] indicated that the genus *Cadophora* was abundant and capable of growing at low temperatures. These results seem to support previous reports that described *Cadophora* species as causing soft wood rot. Soft wood degradation is the commonest rot in Antarctica. Several studies carried out in Antarctica discuss about historical heritage built in wood and biodegradation: in the Ross Sea region, the greatest decomposition caused by fungi that attacked the historic huts erected by the first explorers were several *Cadophora* species, such as *Cadophora malorum*, *Cadophora luteo-olivacea* and *Cadophora fastigiata* [7, 9]. In New Harbor, it was revealed that the predominant fungi were species of the genus *Cadophora* which would appear to be the main wood decomposers, causing a significant soft rot in it: *C. malorum*, *C. luteo-olivacea*, *C. fastigiata* and *Cadophora* sp. [23]. Other studies conducted in three cabins, built by expeditions to Antarctica in 1901, 1908 and 1911 in the Ross Sea region, identified species of the genus *Cadophora* as responsible for soft rot, without finding evidence of other types of rot, such as chestnut or white. This evidence suggests that these Ascomycota were endemic and had not been brought with the cabins [7]. The presence of *Cadophora* could be a good indicator of biodegradation risk.

The results obtained in the tests with tannic and gallic acid indicate that the strains of the Basidiomycota *Tulasnella albida* would be potential wood degraders, having an important role in the oxidative processes related to the degradation of lignin [24]. *Tulasnella albida* strains used for the extracellular oxidase assays showed differences in the production of the degradation halo. The results suggest that there would be several different strains acting in the wood and that the production of extracellular oxidases is strain specific. This specificity was reported by Käärik [21] for strains belonging to four fungal families.

B.W. Held and R.A. Blanchette [12] reported that *Hypochniciellum* spp. causes a brown rot type of decay, in the forest of Deception Island. These results are consistent with the data of the oxidase tests for *Hypochniciellum molle* (BAFCcult 4706) conducted during this research, its indicated that the evaluated strain would have degradation capacity since it showed positive results for tyrosinase production and support the assignation to SD 2 Class.

The oxidase tests carried out on strain *Cerinosterus luteoalbus* (BAFCcult 4705) indicate negative results in all the studied media. *Cerinosterus luteoalbus* was recorded in polar environments, such as driftwood in the Arctic [25] and deteriorated wood on Deception Islands in Antarctic [12]. However, *B.W. Held and R.A. Blanchette* [12] performed laboratory decay studies which did not show substrate weight losses with *C. luteoalbus*. These and our results suggest that it would not be a species with the potential to degrade wood.

For the *Coniochaeta* sp. strain, only a positive reaction was observed for the tannic acid medium, which would indicate a limited degradation capacity. Previous studies on *Coniochaeta ligniaria* indicated its ability to produce extracellular enzymes such as cellulase, xylanase and peroxidases [26]. Other reports registered *Coniochaeta pulveracea* [27] and *Lecythophora* (*Coniochaeta*) *hoffmannii* [28] as causes of soft rot and *R.A. Blanchette et al.* [29] recorded *Coniochaeta* spp. associated with soft rot in wood from polar environments.

In relation to *Geomyces fujianensis* (BAFCcult 4708) our results indicate that the strain does not produce extracellular oxidases. There are no previous records of oxidase tests with species of this genus. Currently, little is known about the ability of the genus *Geomyces* to cause decomposition of wood or other organic materials. However, its widespread presence in samples of wood, straw, fur, biscuits, flour, and construction paper in the Ross Sea region strongly suggests that it has a role in the decomposition and nutrient cycle in Antarctica [22].

The data analyzed from the degradation studies suggest that *Cadophora* and *Tulasnella* are the genera with the strains with the highest potential for degradation of wood in Casa Moneta museum in Antarctica.

Estimation of the biodegradation risk index in the museum wood

The biodegradation risk index (R) was carried out using a modified evaluation performed by *S. Bhattacharyya et al.* [17]. In Figure. 4 the R values obtained for each site (1, 2 and 3) are shown, and each temperature analyzed. Dark grey represents very high risk (R above 4) and light grey represents high risk (R 3.9-3).

SITE	BIODETERIORATION RISK INDEX		
	6 °C	12 °C	23 °C
1	4.7	4.8	4.9
2	9.5	9.6	9.6
3	3.5	3.5	3.7

VERY HIGH RISK (R ABOVE 4)
HIGH RISK (R 3-3.9)
MODERATE RISK (R 2-2.9)
PARTIALLY MODERATE RISK (R 1-1.9)
LOW RISK (R BELOW 1)

Fig. 4. R values in each site and temperature: Dark gray represents very high risk (R above 4), and light gray represents high risk (R 3.9-3)

In the present work a modified version of *S. Bhattacharyya et al.* [17] biodegradation risk index was calculated to determine biodegradation status of the three sites of the museum. Site 2 has a major biodegradation index risk of the three sites evaluated. Site 1 and Site 2 showed different characteristics. While Site 1 showed few records of fungal strains, is the target of the strongest winds and the fungal strains present were able to grow at low and high temperatures, Site 2 had more fungal strains and several of them have wood degradation potential. The high value of R associated with Site 2 responds to the high value obtained for P parameter (type of propagules), however, even in a hypothetical scenery with a P value of 9 (similar to Site 1 and Site 3), the R value remains as the highest (data not shown). Our results suggest that the high diversity and the potential of degradation pulls the R value, indicating that this Site is the most affected by biodegradation by fungal agents.

Our results suggest that the first intervention should focus on the external section of the bedroom to promote the conservation and restoration of the Casa Moneta Museum to minimize future deterioration or loss and preserve the wood with which the museum has been built.

A better understanding of the deterioration mechanisms that threaten the permanence of structures in Antarctica is a first step in deciding on management measures to conserve or rebuild these important historical sites. Environmental conditions, such as humidity [9], and the soils surrounding houses built in Antarctica are important factors to consider, since they favor the development of fungi and, the soil, particularly, serves as a reservoir to potentially wood degrading species [22]. The study of fungal organisms that degrade wood at the Casa Moneta Museum is vital to design a management and control plan that will limit biodegradation and preserve historical wood in the long term.

Conclusions

In conclusion, the results indicate the presence of several strains with degrading potential such as *Cadophora* and *Tulasnella*. For this potential, the strains that would cause greater damage to the wood of the Casa Moneta Museum belong mainly to the *Cadophora* and *Tulasnella* genres. *R.A. Blanchette et al.* [7] had already highlighted the importance of the *Cadophora* genus in wood degradation in Antarctica. This work highlights the presence of the Basidiomycota *Tulasnella albida* isolated from wood from the exterior of the museum at a high frequency and with the potential to degrade wood, since until now, there were few records of Basidiomycota and their contribution to the deterioration of wood in Antarctica [12]. This study is a first approximation to the application of biodegradation risk indices in environments with extreme cold and constitutes a good approximation for the study of the deterioration of the wood with which the historical heritage was built in Antarctica.

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