Mold in Collections

THE CONSERV GUIDE

by Dr. Morena Ferreira

Conserv

Part I — Understanding Mold in Cultural Heritage Collections

1. Why is mold notable?

Mold appears in collections usually associated with the presence of excess moisture. It can appear discretely, affecting only a few items or surfaces, but it can also rapidly infest a large amount of items or entire collections or surfaces. Regardless of the extent of the growth detected, mold affects collections in multiple ways, making prevention and early action essential.

Mold is not only a threat to objects, it is also an environmental health hazard (classified by the World Health Organization) and is known to cause respiratory issues. Exposure to a moldy environment or contaminated objects can cause irritation of the nose and throat, allergic reactions and skin issues. In the case of extended exposure, it can increase the risk of developing asthma and can also trigger asthma symptoms in those who already have the condition.

Fig. 1 — Mold growth on the back of wooden furniture. Photo: Morena Ferreira.

Beyond health risks, mold causes damage to materials. As it develops, for example, on paper or fabric, this microorganism forms colonies (typically round if left for too long) that cover and disfigure surfaces. But more importantly, degradation is caused by metabolic compounds such as enzymes that are released onto the substrate to digest it.. A combination of this digestion process and mold physically pushing through substrates to find nutrients results in the weakening of materials. This process can lead to brittleness and loss of coherence.

Another common consequence is staining. Pigmented compounds used to digest materials, as well as fragments of mold structures that can be very difficult to remove, leave affected areas discolored.

Another concern is how mold impacts access to collections. As members of staff and visitors need to be protected, affected items cannot be accessed (handled or displayed) until they are considered safe. Also, depending on the extension of the growth, mold affects institutional planning and operations. Because treating moldy items is often given priority over ongoing projects, teams need to reorganize scheduled work and redirect resources.

The presence of mold is a universal problem. Its spores are always present in the air and exist in all climates with adapted species that vary in concentration throughout seasons. Although the amount of spores indoors is reduced compared with outside, it is very challenging to exclude them from indoor spaces with collections.

2. What is mold?

Molds are microorganisms belonging to the biology kingdom Fungi that includes molds and yeasts. Fungi were once considered plants (included in the kingdom Plantae) for being immobile and growing in similar ways. However, fungi do not have chlorophyll and their structures do not include leaves and roots, and so were classified separately in their own kingdom.

Fungi were incredibly important in shaping the Earth into what we know today: these microorganisms helped form the first soil by breaking down rock and enabled plants to live outside water (many millions of years ago!). Today, fungi are responsible for decomposing organic matter such as dead leaves and trees, playing a huge role in the management of the surface of the Earth. They also play an essential role in plants' absorption of water and nutrients from the soil. At the same time, some fungi are plant pathogens and are therefore of great concern for food production and storage. In the food industry, molds are used to produce fermented foods and cheese, and yeasts are used to produce beer and bread.

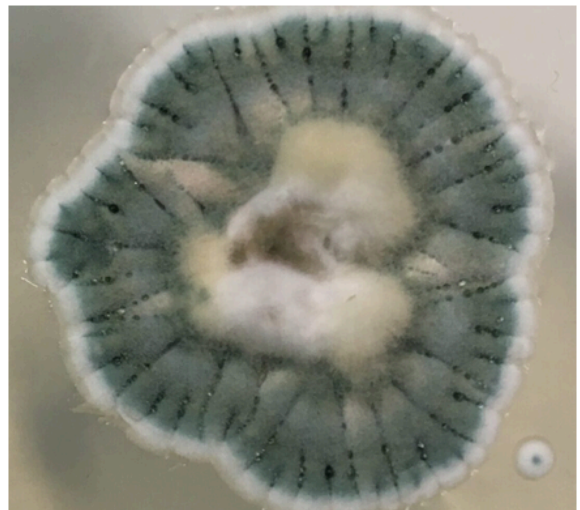

Fig. 2 — Aspergillus versicolor colony grown on agar media in laboratory conditions. Photo: Morena Ferreira.

Within the large kingdom of Fungi, molds are filamentous fungi. The name comes from their growth structures called hyphae (singular: hypha), which are very thin tubes or filaments. As hyphae grow and branch out, they form a macroscopic network called mycelium and grow into a mold colony – the familiar, powdery, circular patches visible with a naked eye.

3. Why does mold grow?

Mold propagates and reproduces with spores: microscopic propagules produced by the mycelium. Once these structures land on a surface, and conditions permit, they germinate and grow hyphae, making them vital to spread to new grounds. Mold growth – from a spore – depends on the presence of an acceptable amount of moisture, suitable temperature and nutrients on the surface where it lands. Oxygen levels and substrate pH are also important but to a lesser degree.

The moisture responsible for this process is moisture at the surface of a substrate, also known as water activity (aw). This is essentially the relative humidity in equilibrium with a surface and refers to the water that is available for metabolic growth of mold. For this reason it can be different from the relative humidity measured in the same space but far from the surface in question.

4. Basic mitigation strategies

Prevention is the most important approach to deal with mold development in collections and buildings, and it can involve several measures. Equally essential is early action once the presence of mold is detected to stop its spread on materials and the environment.

Environmental control

Precisely because moisture and temperature are so essential to the development of these microorganisms, controlling these parameters is one of the most important strategies to prevent and control mold development.

Environmental control of moisture and temperature indoors can be done in different ways. To varying degrees, the building fabric provides some buffering against the outside weather. However, temperature might need to be increased during colder seasons or kept cooler in hotter periods, many times as a means to control the relative humidity indoors. Additional humidity control might also be necessary, using dehumidifiers, for example.

The building itself can also have an impact on the indoor environment. The presence of wet walls, condensation on cold surfaces, and leaks, all increase moisture levels, making spaces more prone to the risk of mold.

Mold Inspections

Monitoring collections and susceptible surfaces is also crucial to prevent mold growth. It is important to regularly inspect collections that are very susceptible to mold, either because they are composed mainly of organic materials (including fabric, paper, photographic materials, and leather) or because the environmental conditions are close to those that sustain mold (or both!). But mold inspections or surveys are also be triggered by events such as the smell of mold, an increase in relative humidity induced by a temperature decrease, or the discovery of a leak.

Cleaning

Nutrients are virtually impossible to remove from the equation of mold development in collections. In fact, objects are composed of the very nutrients mold thrives on. Other factors important for mold such as oxygen levels and substrate pH are equally hard to control in most cases.

However, one way to reduce the risk of mold is to keep surfaces free of dust. This is because dust has organic matter in its composition, contributing with nutrients, and tends to trap moisture, increasing the moisture levels close to the surface and supporting growth. This preventive measure is also very important because it removes spores that accumulate on surfaces, as they settle, waiting for suitable conditions to germinate and develop.

The amount of spores present indoors depends on factors such as the air exchange rate of the building (how fast the indoor air is renovated or replaced with new air), if there is an air filtration mechanism (for example, as part of a ventilation system) and the local airborne concentration of spores, which varies geographically, with seasons and weather conditions. The less sealed a space is, the more important cleaning tends to be, but there are constraints to an intense cleaning schedule such as time available and the conservation condition of materials.

Fig. 3 — Mold growth on a gilded frame.
Photo: Morena Ferreira.

Ultimately, the presence of mold affects collections and poses a risk for several reasons. Mold is a health hazard (contributing to respiratory and skin problems) and it causes biodeterioration of materials as it feeds on its components (staining and weakening materials). At the same time, it limits access to affected collections and requires special efforts from conservation teams and changes in scheduled work as addressing a mold issue is usually a priority.

Mold development indoors is usually linked to excess moisture, which can be a challenge to control in certain buildings or specific spaces. Because spores are always present in the air, prevention is essential. The main mitigation strategies are controlling environmental moisture and temperature, inspecting collections regularly, and keeping surfaces free of dust, which traps moisture and nutrients creating suitable conditions for fungal growth.

Part II — Growth and Biodeterioration

Part I introduced the fundamentals of mold in cultural heritage collections: what it is, why it grows, and why prevention matters. Part II goes deeper on the science behind two questions: what determines whether mold will grow in a given environment, and what is the impact on collections when it does?

Fig. 4 – Mold growing on leather sample. Photo: Morena Ferreira

First we will cover the biology of growth, and then discuss how mold causes damage. These concepts will help you understand the rationale behind the prevention and response strategies described in Part III.

1) What Enables Mold to Grow?

The two most important factors in enabling mold growth are the indoor environmental conditions and the presence of mold spores. Mold spores are pervasive. They will always enter buildings and land on surfaces; as a result, they cannot be eliminated from collection spaces. What we can influence is the environment that determines whether those spores remain dormant or germinate and grow. That is the focus of this section.

2) The Life Cycle of Mold

Despite their enormous variety, filamentous fungi share a common life cycle of four stages: hyphal growth, spore production, spore dispersal, and spore germination – from which new hyphal growth begins and the cycle repeats.

MOLD GROWTH: Life Cycle

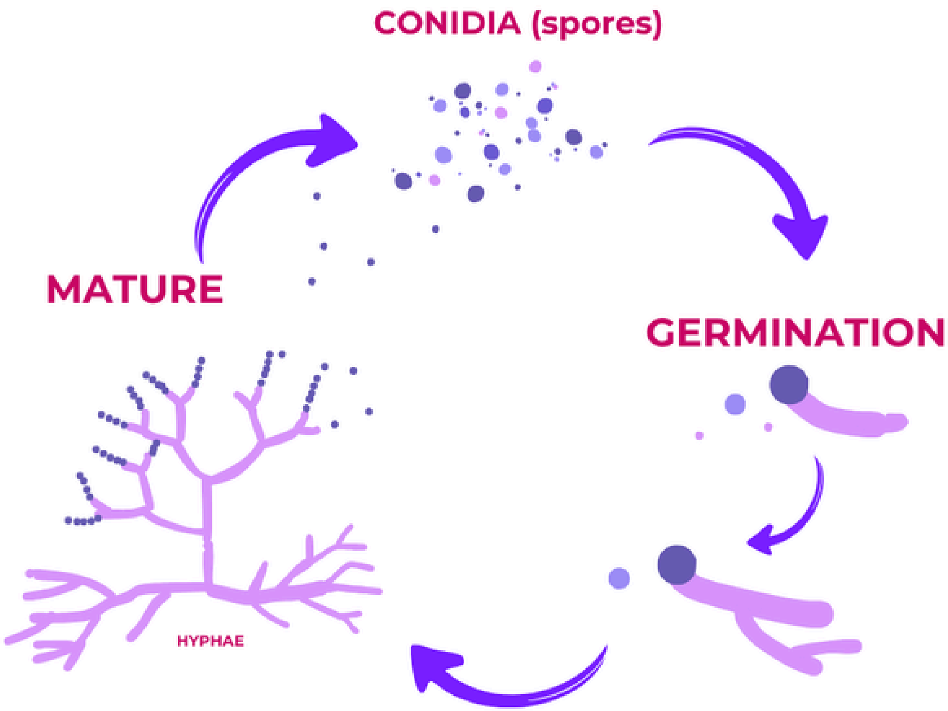

Fig. 5 – Life cycle showing the stages of mold growth

Hyphal growth is also referred to as vegetative growth, which starts with germination and occurs on and into the structure of materials. Spore production occurs with aerial growth, when hyphae grow away from the surface to produce reproductive propagules (spores) that eventually become airborne to colonise new materials.

Spores are produced with the aim of reaching other substrates with better survival conditions. Once a spore germinates, a hyphae emerges and continues to grow, branching along the way, to form a new colony whenever conditions are suitable. Hyphae grow only at their tips; this is called apical growth. As a colony expands, its center ages and no longer grows actively. In these central areas, spores are produced as a survival technique, to ensure new colonies will be produced.

Fig. 5 – Aspergillus versicolor hyphae growing after 20h (at ideal conditions: 27 °C and 98% RH). The average hyphal length is 0.06 mm. Magnification 100X. Photo: Morena Ferreira.

3) How Mold Grows

Mold greatly depends on the presence of water to survive and thrive, specifically water available at the surface of a material and in the air immediately adjacent to it, which is referred to as water activity (aw) or equilibrium relative humidity (ERH). This is water that has weak bonds to molecules in materials and that changes with temperature and RH. Each mold has ideal water activity and temperature at which germination and growth occurs at their highest rate. But mold does not depend on ideal water activity and temperature simultaneously to develop. When temperatures are close to optimal, these microorganisms can tolerate water activities that are either higher or lower than ideal. The reverse is also true: suboptimal temperatures can sustain growth if water activity is close to optimal level for that species. In such circumstances development will be slower compared to ideal conditions. The relationship between germination and growth rate, water activity, and temperature, is graphically described by isopleths – lines of equal germination or growth rate specific to each species. (1) For example, Aspergillus versicolor, a very common mold species, has an ideal growth temperature of 27 °C but can grow between 9 °C and 39 °C depending on the water activity. For collections care, this means that controlling temperature is often insufficient to guard against mold, as the mold can adapt as long as moisture is present. Given that heritage materials provide significant nutrients, this ability to grow at suboptimal environmental conditions increases the risk of mold growth indoors and is a big challenge for prevention.

Water plays additional roles beyond enabling germination. Together with nutrients, mold absorbs water through its cell walls to maintain the high level of water content (approximately 85%) its living cells require. Mold also uses water in the processes of external digestion and absorption of nutrients.

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(1) An example of isopleths for the growth rate for different molds can be found in fig.5 of "Prediction of mould fungus formation on the surface of and inside building components" by Klaus Sedlbauer (2001), available here.

Notably, mold is able to retain water not only inside its cells but also around its hyphae, creating a microclimate that supports continued growth even when the broader conditions become too dry. This self-sustaining quality makes mold more resilient to changes in its environment.

When conditions become unfavorable for mold, it becomes dormant, but it does not die. Germination, hyphal growth, reproduction, and production of spores all come to a halt (or close to it), but the organism remains viable and will resume metabolic activity and growth once conditions become suitable. From a practical standpoint, this means that addressing a mold outbreak without also correcting the underlying environmental conditions is unlikely to be a lasting solution.

Conserv Cloud Pro includes a Mold Risk Score indicator. The software reviews the data and automatically evaluates mold risk based on research completed at the Image Permanence Institute. Read more here.

4) Types of Mold

Mold species are incredibly varied – it is estimated that 2.2 to 3.8 million species exist, of which approximately 8% have been identified. In the UK and the US, some of the most common species present in historic houses and museums belong to the genera (2) Aspergillus, Penicillium, Alternaria and Cladosporium. These are the same groups of fungi generally found indoors in these countries. However, the distribution of species varies with geography and climate, as well as across seasons and weather conditions.

Another factor that will dictate the microorganisms found growing on a surface is the type of materials present. In archives, we will mostly find mold that is able to digest cellulose substrates. In other collections, species capable of breaking down protein-based materials, such as animal glues or gelatin on photographs, may be more prevalent.

5) How Mold Causes Damage

As discussed in Part I, mold is a health hazard, in addition to being a threat to collections. The first signs of biodeterioration caused by mold are often visual and can be accompanied by a moldy or musty smell.

Mold growth results in both chemical and physical damage to materials. The secretion of metabolic enzymes and acids causes pigmentation and a weakening of materials as they are broken down, ingested, and lose structure. Physical damage is also caused by growing hyphae: they grow not only along a surface, but also enter materials, developing under the surface.

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(2) Genera are categories of organisms with shared characteristics. Each genera contains several species.

6) How Mold Feels

As mold expands its hyphae and colonies, it feeds on the compounds that form the substrate. Its method of acquiring nutrients is distinct from other organisms: while plants and animals ingest food and digest it internally, mold digests materials externally. Digestive enzymes are produced along the length of the hyphae, in greatest concentration at the growing tips. This external system exists because many compounds, such as cellulose, lignin, and proteins, are unavailable to mold because they are either insoluble or too big to enter the walls of fungal cells. They must first be broken into smaller, simpler molecules that can be easily absorbed.

7) Mold's Effects on Different Types of Materials

Mold grows on most materials, and feeds mostly on organic compounds. Different mold species specialize in deteriorating and digesting certain compounds, dictated by the type of digestive enzymes they produce. For example, species that produce cellulase are able to break down cellulose (present in paper, textiles, wood), such as many Aspergillus and Penicillium species which are commonly found indoors. But these microorganisms produce a range of enzymes enabling them to grow on materials with complex compositions and to not depend on very specific molecules. One species might simultaneously produce enzymes to digest cellulose, starches, and proteins, for example. Acids produced by mold to aid digestion can also deteriorate inorganic materials. Molds can survive on the surfaces of inorganic material, where organic matter – such as the dust that settles on most surfaces – provides a food source. This reinforces the importance of regular surface cleaning as discussed in Part I: removing dust minimizes this organic food source. Deteriorated or aged materials may also be more vulnerable to mold growth, as aged materials are more fragile and can therefore be easier to decompose.

Fig. 6 – Mold white spots on black and white photograph. The mold growth is particularly visible on the hair area. Photo: Argentina, Instituto Nacional de Estudios de Teatro, Sección Documentos Visuales. Ana Masiello.

Part III — Dealing with Mold

The biology of mold discussed in Part II provides the foundation for effective prevention and response that we will discuss in Part III. This Part translates our understanding into practice: which specific events raise the risk of mold, how to manage and mitigate it, and some of the common challenges that institutions encounter.

Specific events that increase risk of mold

Humidity Changes

Because mold depends greatly on moisture and temperature, changes in these parameters are usually the cause of an increase in the risk of mold growth. The risk of biodeterioration rises when relative humidity increases water activity to levels suitable for the mold life cycle, which can occur in the event of condensation, rainy seasons, leaks, or floods. The longer the higher moisture conditions persist, the greater the risk of growth.

Temperature changes

Temperature also matters for fungal development but is not as crucial as the presence of moisture. On one hand, an increase in temperature might bring conditions into the suitable range for mold to germinate and grow. On the other hand, a decrease in temperature will cause the relative humidity to rise, which in turn will increase the water activity of certain materials. This can occur in localised pockets such as the surface of a cold wall where condensation forms, elevating the risk of growth. As mentioned in Part II, mold can germinate and grow under a combination of ideal and suboptimal conditions, which means temperature changes are also important.

Dew Point changes

Unlike relative humidity, which fluctuates with changes in air temperature, dew point temperature reflects the absolute amount of moisture present in the air and remains stable unless the moisture content itself changes. This makes it a more reliable baseline for assessing ambient conditions, as a rising dew point indicates that moisture is genuinely accumulating rather than simply redistributing due to temperature shifts. When dew point approaches the temperature of surrounding surfaces, condensation becomes likely, creating the localized high-moisture conditions most associated with mold growth. Dew point is also widely used by HVAC engineers as a standard measure of moisture load, meaning it provides a useful common reference when coordinating with building services teams on ventilation and climate control. Monitoring dew point alongside temperature and relative humidity therefore gives a more complete picture of the conditions driving mold risk.

Fig. 6 A screenshot of Conserv analytics showing the dew point temperature (teal), relative humidity (blue), and temperature (red). If you only viewed the relative humidity data it would be hard to know if the temperature or the amount of moisture in the air (absolute moisture) were causing the humidity spikes, but looking directly at the dew point temperature shows more correlation between absolute moisture and relative humidity than temperature and relative humidity (these spikes were caused by a humidifier in the space).

Climate changes

We are witnessing changes in the climate in all parts of the globe. In some areas, wetter and warmer seasons can encourage mold growth, and extend the periods when growth is expected. These periods can also cause more intense growth and infestations. Many buildings were not designed to handle these shifting conditions, which has an impact on the indoor environment and potentially raises the risk of mold.

Contamination

The introduction of a contaminated object in a collection means that the environment in its proximity will have a higher concentration of spores – especially if the mold is very active or if it encounters the conditions to start sporulating. This is why incoming objects should be carefully inspected and cleaned before being integrated into the collection.

Health and safety

Because mold is a health hazard it is necessary to protect those handling contaminated objects. The level of protection depends on the extension of the mold growth. In the case of small scale growth, it is important to use personal protection equipment (PPE) such as disposable gloves (e.g. nitrile), a correctly fitting FFP3 mask or a respirator with HEPA filters for more complete protection, and to protect the eyes with safety goggles. For larger outbreaks it is advisable to use a full disposable body suit with adequate air filtration. A risk assessment should be undertaken to determine the appropriate PPE for the personnel involved.

To protect people and collections, the use of fume cupboards or suction tables to clean contaminated items is important. All equipment used during a mold outbreak (such as brushes and vacuum cleaner nozzles) should be disinfected after use to avoid further contamination.

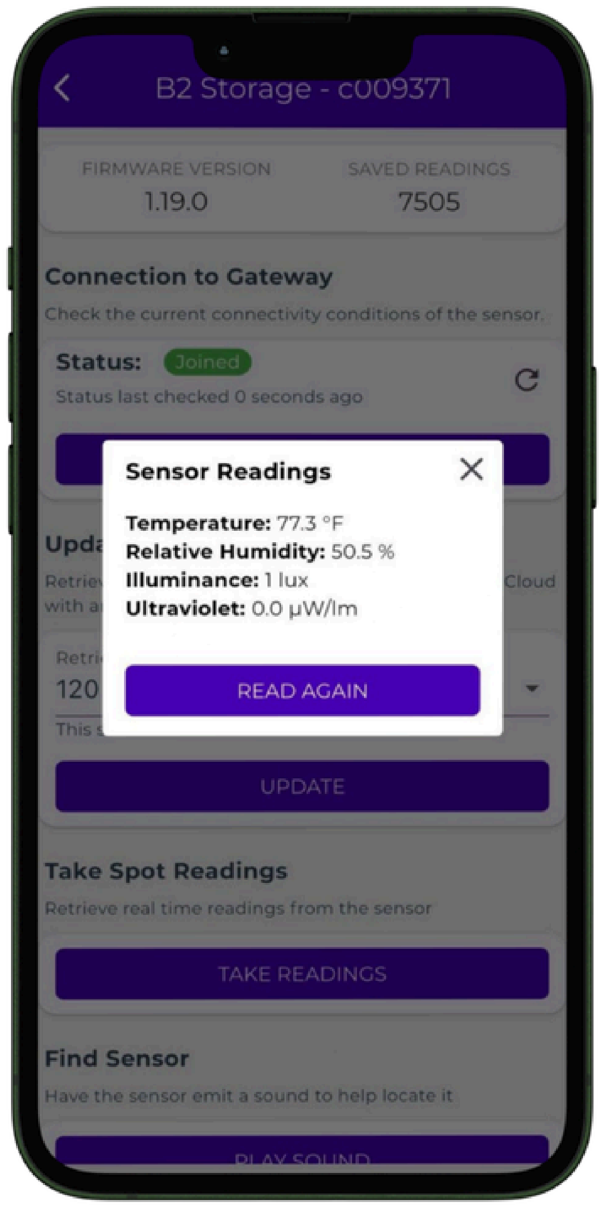
Mitigation and management

Managing the risk of mold involves both prevention and response: keeping conditions unfavorable for growth while also being prepared to address mold quickly when it appears.

Preventive measures

As mentioned in Part I, environmental control is a crucial measure to manage moisture and temperature, and usually includes monitoring relative humidity and temperature. It is also insightful to monitor the dew point and absolute humidity because these parameters inform us of the risk of condensation on colder surfaces and help better understand sources of moisture (whether internal or external).

Conserv Cloud Pro includes a Mold Risk Score indicator. The software reviews the data and automatically evaluates mold risk based on research completed at the Image Permanence Institute.



In some cases, however, it is a challenge to maintain uniform environmental conditions. Large rooms, rooms with external cold walls or cold floors, and enclosed areas such as deep shelves or drawers require special attention because microclimates can form. These are areas where relative humidity and temperature can differ from the intended conditions and create conditions favorable to mold. One way of eliminating such microclimates is to use air movement: fans or supplementary ventilation that mixes the air and reduces the variation in relative humidity and temperature across the space.

Surveys help identify mold and objects that need cleaning (dust or mold removal). Collections or areas that have previously been affected by mold growth are usually surveyed more frequently because the risk of future growth is potentially higher in these areas. Rather than conducting comprehensive surveys, which can be very time-consuming, spot checking can be an efficient approach. It can also be advisable to conduct surveys more frequently in areas where the control of temperature and humidity is more challenging, as the risk of mold is higher.

Responding to mold growth

Once mold is detected, preventive strategies should be continued when possible to keep the environment as adverse to growth as possible and stop ongoing biodeterioration. The response will depend on the extent of growth found and if the mold is active or dormant.

Fig. 8 – Temporary air movement used to dissipate areas with high relative humidity in the sound library. Photo: Argentina, Instituto Nacional de Musicología Carlos Vega. Ana Masiello.

There is an important distinction between active and dormant mold. Active mold must be treated urgently because it is actively deteriorating the substrate and it will spread spores that are ready to produce more colonies. When dormant mold is found, it can be isolated until treatment is possible, as long as environmental conditions remain adverse to growth.

Distinguishing between active and dormant mold can be challenging. Unless we know if the mold growth is recent, assessing if it is actively growing based only on visual examination can be difficult: active mold might look flat and inactive and dormant might look fluffy. However, a powdery aspect usually indicates a dormant state, and musty smell is present in active infestations.

Still, there are ways to test mold's current state and ability to develop. An indication of the viability of mold and mold spores is the presence of adenosine triphosphate (ATP). This is the main energy-carrying molecule in cells and is commonly used as an indicator of metabolic activity. There is a higher generation of ATP when the metabolic activity is higher and lower for lower activity (dormant state). This test is relatively simple, it requires swabbing a surface and introducing the swab in a portable ATP meter, which gives the result in a short period of time.

Another way to test if mold is active is to collect and culture a mold sample on growth media such as agar in lab conditions. This standard test assesses growth and sporulation over time to determine whether the microorganisms are viable. This test requires lab faculties and should be done by a qualified biologist or microbiologist.

After the extent of growth is assessed, it is important to decide where treatment on affected objects will be done and whether they can be safely moved. If transport is not an option, cleaning has to be done in situ. Where only a few items are affected, a more contained response is usually preferable. A larger infestation – for example, one following a water leak that went undetected for a few days, will involve a more complex approach. The latter will often include more people, more space to quarantine and work on affected items, potentially closing an area to visitors, and a longer treatment period. In such cases, there is a high risk of contamination while handling and treating objects because more active mold means more mold spores are being released. Extreme events, such as floods, require swift action. Mold will not grow on drenched materials, but as drying starts, it can start developing quickly. As a result, it is important to dry materials as fast as possible.

Cleaning mold residues is a specialist task and is associated with hazards to the operators and those in their vicinity. There are also considerations to make in terms of the treatment approach and how that might impact the collection object. Many of the following treatments may be best contracted to external specialized companies with the relevant safety training, conservation knowledge, equipment and liability insurance.

Cleaning

It is important to consult with a conservator before attempting any cleaning to get a fuller understanding of the damage risks to the objects from the cleaning approach. Depending on the amount of mold growth, cleaning affected objects might be possible in situ (in storage or in a gallery). Spaces might have to be closed to the public during this time. Cleaning can be done with dry or wet techniques using brushes and swabs, or vacuuming (equipped with high efficiency particulate air (HEPA) filters) while brushing. Surrounding surfaces, such as drawers and shelves, also need to be cleaned to avoid further contamination. A challenge found when cleaning mold is that it is difficult to assess the effectiveness of mold removal. It is not always clear how much mold has been removed, especially because hyphae grow within the structure of materials. Changes in color can be an indicator of progress, but are not conclusive, and observations under magnification are helpful.

For larger infestations, objects should be placed in quarantine to avoid further contamination of other items, when treatment is not possible immediately, or if it's not clear if the cleaning was fully effective. Quarantine should be done at low temperatures and low humidity to slow down mold development.

Despite prevention being the best option, in some cases chemical treatments can be an option for affected materials. Antifungal chemicals can be toxic, from causing eyes and skin irritation (e.g. formaldehyde) to being carcinogenic (e.g. ethylene oxide and formaldehyde). They can also damage materials, such as by leaving marks or accelerating deterioration of certain components such as metals and pigments. As a result, many of these treatments have been discontinued in conservation practice.

Some less toxic treatments have been developed recently, such as the use of ethanol solutions, which has shown to have antifungal properties. Despite the lower toxicity, all chemical treatments should be done by or under the supervision of a conservator because there is always a risk of damaging objects, as well as the health risks associated with such chemicals. Physical antifungal methods for contaminated collections can also be used. Some examples include freezing, low-oxygen environments, and ultraviolet radiation. Not all are feasible in every situation and again a conservation professional should be consulted for guidance. Before undertaking any mold remediation actions make sure that you identify and comply with all relevant safety precautions for the institution and country in which you are working.

Challenges in dealing with mold

Identifying mold

Is it mold? This is a common question when spots or stains are found on materials. The answer is not always straightforward. Sometimes it is difficult to distinguish mold from salt efflorescence or corrosion products. To rule out the presence of salts, a sample can be mixed with water: salts will dissolve but mold will not. Otherwise, observation under magnification, when possible, is a good step in identification.

Identification of fungal species is complex and not always necessary for response and treatment. If one is interested in identification you can utilize DNA analyses for accurate lab results. Observation under magnification using a microscope, a more widely accessible technique, can be used to identify some fungal genera (but not specific species).

Fig. 9 – Magnified image of fungal hyphae. Aspergillus versicolor after 20 hours of growth under ideal conditions, 200X magnification. Photo: Morena Ferreira.

In Aspergillus, strings of round spores radiate from a “head” attached from a thin “stalk”. Penicillium spores are also organized in strings but are attached to a broom-like structure, which in turn is attached to a “stalk” that is divided by septa (cellular divisions perpendicular to the length of the stalk).

Species identification can be useful because the optimal growth temperature and humidity vary between species, and that information can help design more targeted preventive measures and treatments. For example, a new species of mold resistant to drier conditions was recently identified in a museum in Denmark. Identification led the team to adjust humidity and temperature targets, ultimately preventing further growth. Species identification can shed light on cases where mold is growing despite the environmental conditions that would typically prevent growth.

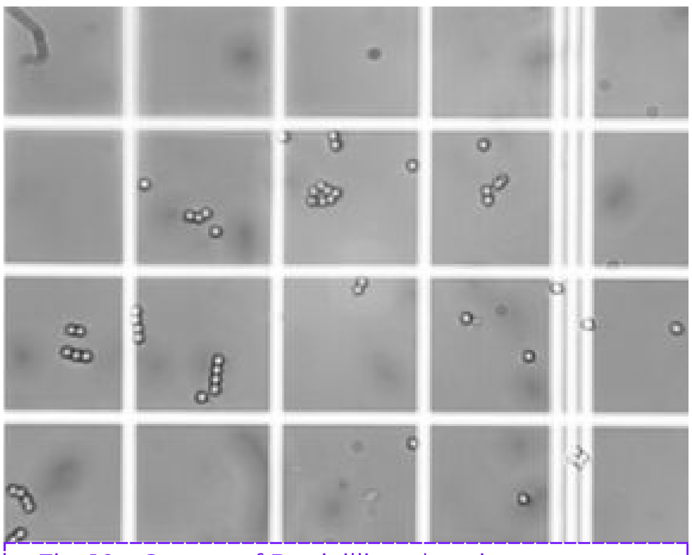


Fig. 10 – Spores of Penicillium brevicompactum. Average diameter: 0.0035 mm. Photo: Morena Ferreira.

The indoor environment

Controlling humidity and temperature is a challenge in most buildings, and as discussed in Part II, the conditions that support fungal development overlap with the conditions that are comfortable for humans and for most collections. This presents a fundamental tension with no simple solution.

Although moisture and temperature are the main triggers of mold outbreaks, identifying the root cause of a specific outbreak is not always obvious. For example, monitoring data from a single sensor might show an overall stable environment, while a nearby microclimate may be sustaining conditions that are favorable to growth. Identifying possible microclimates and placing sensors to capture the conditions there can provide a more complete picture. When you identify a potential outbreak you may need to increase the number of sensors operating in your space as you search out the pockets of mold-supporting conditions. As noted above, a sensor monitoring room conditions may not identify the danger zones. Wireless systems like Conserv allow for easy installation of additional sensors as necessary. If possible, one can set up fans to create air movement as that will help reduce the high relative humidity and cold temperatures in microclimates by mixing the stagnant air with the conditioned air of the room.

Dormancy of spores is a real challenge because changes in environmental conditions can trigger unexpected germination and growth. Mold also grows on surfaces that are not always visible or easily accessible, such as the interior of books, on the back of furniture, or behind bookshelves.

Controlling indoor moisture and temperature also raises questions related to energy use, cost, and its associated carbon footprint. Sufficient good quality monitoring data can help target the response to where it is needed.

In summary: Mold is disruptive because it is time consuming and because it is resource intensive, and immediate response comes at the expense of other planned work. Tthe challenges encountered when dealing with mold are numerous and complex. For that reason, they need to be assessed in the context of every specific case.

Conclusion

The biology of mold is complex, and the challenges of managing it in a collection environment are significant. However, the fundamental techniques to reduce mold risk are clear: control moisture, monitor consistently, inspect regularly, and act early. Understanding the science of mold makes those actions more targeted and more effective.

Mold mainly depends on moisture and suitable temperatures to develop, making environmental control the most important preventive strategy, but there are limitations that can make it hard to achieve our objectives through control alone. Identifying and eliminating moisture sources, anticipating problem areas before growth occurs, and recognizing mold when it appears (particularly in hidden spaces, inside books, and behind objects) are all very important. Flexible and continuous environmental monitoring systems are now accessible to institutions of all shapes and sizes and can help provide the data necessary to identify areas of risk, monitor them, and take action quickly when necessary.

Preventing biodeterioration by mold is an evolving subject. New species have been found that defy current knowledge and preventive measures, and changes in the climate bring new challenges to some areas, in the shape of floods and warmer and wetter seasons. In many cases, historic buildings were not designed for these new conditions.

Each collection, building, and climate is different, and the strategy for managing mold must reflect those specific circumstances, as well as the resources available. The most robust protection for any collection is a combination of informed expertise, the right policies and controls, and a data-informed understanding of the risks present for the collection and its environment.

About the Author

Dr. Morena Ferreira is a conservator specializing in preventive conservation, with particular expertise in the prevention of mold development in heritage materials and environmental control in museum contexts. She teaches risk management in cultural heritage at the Escola Superior de Conservació i Restauració de Béns Culturals de Catalunya in Barcelona, Spain. Prior to completing her PhD in Heritage Science at UCL (London) in 2023, Morena worked in the conservation of wall paintings, stone, and easel paintings in Portugal, Brazil, and the UK.

Dr. Morena Ferreira

Bibliography

Ayerst, G. 1969. 'The Effects of Moisture and Temperature on Growth and Spore Germination in Some Fungi'. Journal of Stored Products Research 5 (2): 127–41. https://doi.org/10.1016/0022-474X(69)90055-1.

Bastholm, Camilla J., Anne M. Madsen, Birgitte Andersen, Jens C. Frisvad, and Jane Richter. 2022. 'The Mysterious Mould Outbreak – A Comprehensive Fungal Colonisation in a Climate-Controlled Museum Repository Challenges the Environmental Guidelines for Heritage Collections'. Journal of Cultural Heritage 55 (May): 78–87. https://doi.org/10.1016/j.culher.2022.02.009.

Ferreira, Morena, Josep Grau-Bove, Hector Altamirano, and Nigel Blades. 2022. The Causes of Air Movement in Hidden Indoor Micro-Environments: Measurements in Historic Bookshelves. December 2. https://doi.org/10.14324/111.444/000134.v2.

Florian, Mary-Lou. 2003. 'Water, Heritage Photographic Materials and Fungi'. Topics in Photographic Preservation 10: 60–73.

Guild, Sherry, and Maureen MacDonald. 2020. Mould Prevention and Collection Recovery: Guidelines for Heritage Collections – Technical Bulletin 26. Canadian Conservation Institute. https://www.canada.ca/en/conservation-institute/services/conservation-preservation-publications/technical-bulletins/mould-prevention-collection-recovery.html#a3ae.

Pinheiro, Ana C., Sílvia O. Sequeira, and Maria F. Macedo. 2019. 'Fungi in Archives, Libraries, and Museums: A Review on Paper Conservation and Human Health'. Critical Reviews in Microbiology 45 (5–6): 686–700. https://doi.org/10.1080/1040841X.2019.1690420.

Scott, Graeme. 1994. 'Moisture, Ventilation and Mould Growth'. Studies in Conservation 39 (sup2): 149–53. https://doi.org/10.1179/sic.1994.39.Supplement-2.149.

Sedlbauer, Klaus. 2002. 'Prediction of Mould Growth by Hygrothermal Calculation'. Journal of Thermal Envelope and Building Science 25 (4): 321–36. https://doi.org/10.1177/0075424202025004093.

Sequeira, Silvia O., Alan J. L. Phillips, Eurico J. Cabrita, and Maria F. Macedo. 2017. 'Ethanol as an Antifungal Treatment for Paper: Short-Term and Long-Term Effects'. Studies in Conservation 62 (1): 33–42. https://doi.org/10.1080/00393630.2015.1137428.

Sterflinger, Katja. 2010. 'Fungi: Their Role in Deterioration of Cultural Heritage'. Fungal Biology Reviews 24 (47–55): 47–55. https://doi.org/10.1016/j.fbr.2010.03.003.

Mold Risk Quick Reference

For cultural heritage collections

STEPS FOR MOLD PREVENTION

Environmental Management

- ☐ Set up continuous monitoring of temperature and RH, focusing on areas most at risk of mold
- ☐ Add dew point tracking alongside RH — it shows true moisture accumulation, not temperature shifts
- ☐ Set RH thresholds for your collection type: below 65% for most collections, below 55% for high-risk organics
- ☐ Survey for microclimates: cold walls, deep shelves, enclosed drawers, spaces behind furniture
- ☐ Install fans or supplementary ventilation where air is stagnant
- ☐ Repair leaks, condensation and wet surfaces on discovery

Regular Inspections

- ☐ Build an inspection schedule prioritising organic materials and previously affected areas
- ☐ Add trigger inspections after humidity spikes or water events
- ☐ Add hidden areas to the inspection route: inside books, behind shelving
- ☐ Set up an inspection step for all incoming objects

Cleaning

- ☐ Assign responsibility for keeping surfaces free of dust
- ☐ Put high-risk and high-traffic areas on a fixed cleaning schedule

Conserv-Specific Monitoring Tools

- ☐ Configure threshold alerts for RH and temperature
- ☐ Schedule a regular Mold Risk Score review in Conserv Cloud Pro
- ☐ Map potential microclimates using the app's spot reading feature

Mold Risk Quick Reference

For cultural heritage collections

MOLD FIRST RESPONSE CHECKLIST

Before Touching Anything

- ☐ Do not handle affected items without PPE
- ☐ Document the area and affected objects with photos
- ☐ Note any musty smell — this usually indicates active mold growth

Put on PPE

- ☐ Nitrile disposable gloves
- ☐ FFP3 mask or respirator with HEPA filters
- ☐ Safety goggles
- ☐ Full disposable body suit for large outbreaks

Assess the Situation

- ☐ Determine scale: isolated items or widespread growth?
- ☐ Active or dormant? Active mold has a musty smell; dormant is often powdery
- ☐ Consult a conservator before any cleaning begins

Contain and Stabilize

- ☐ Isolate affected items; quarantine at low temperature and low humidity if available
- ☐ Identify and correct the moisture source
- ☐ Restrict access — close the area to staff and visitors if needed
- ☐ Avoid disturbing mold unnecessarily; handling releases spores

After Treatment

- ☐ Clean surrounding surfaces: shelves, drawers, nearby objects
- ☐ Disinfect all equipment used (brushes, vacuum nozzles, etc.)
- ☐ Monitor the area closely for signs of recurrence