Creating of a xylarium and herbarium with a preventive conservation profile: review of procedures and materials

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Abstract

The significance of plant material sample deposits extends beyond the scientific community, with various industries, historians, and law enforcement agencies increasingly relying on them. Preserving global xylariums and herbariums is essential for accessing centuries of data, species, and samples that may no longer exist in their original locations or may be extinct. While maintaining these archives is crucial, it is equally important to ensure proper collection, structure, organization, and classification of new xylariums and herbariums. In that order, a preventive conservation approach is essential to ensure future research by defining actions, materials, and uses to prevent degradative factors and potential harm to the collection This guarantees future accessibility to valuable samples and the knowledge they offer. The paper explores key factors in xylarium and herbarium construction and preservation, including sample drying, pest control, preventive measures, archival materials, facilities, and handling procedures.

Keywords: conservation; degradation; herbarium; preservation; wood; xylarium.

Introduction

The notion of wood collections initially emerged in central Europe during the late 18th century. This practice involved the creation of wooden libraries, which frequently consisted of boxes crafted from the wood of relevant tree species. These containers also held other components of the selected species, such as dried flowers and leaves (Feuchter-Schawelka & Freitag, 2001). Wood collections, intended for anatomical studies, may have been originated in the mid-19th century, as for example, the Royal Botanic Gardens, Kew, which began collecting wood specimens with a scientific methodology since 1847. Subsequently, numerous xylaria (plural of xylarium) were established around the world, with their peak of development occurring during the 1940s and 1950s (Wiedenhoeft, 2014).

In countless instances, these collections were little more than an accumulation of wood and herbarium samples. Due to the absence of preventive measures, they soon displayed a subpar state of conservation, leading to vigorous and, in certain cases, irreversible measures that restricted their scientific utility and usage.

Nowadays, preventive conservation is no longer optional, but a mandatory approach. Although curative conservation and restoration, and their before and after conditions, capture the public's attention, it is the invisible preventive approach that yields the most satisfactory long-term outcomes for cultural heritage. Preventive conservation aims to prevent damage from occurring by conducting research, planning, and conserving. To maintain, instead of restoring, is the pivotal statement here and is being implemented across various sectors including society, economy, environment, and cultural heritage, as previously mentioned.

Cultural heritage cannot be viewed as a distinct and self-contained aspect of human knowledge. Nowadays, it is increasingly regarded as a dynamic platform for sharing knowledge and expertise. As such, it absorbs and disseminates valuable experience and knowledge.

This article aims to outline the necessary steps for creating a xylarium and herbarium in such a way that it avoids most, if not all, variants of degradation processes that could affect their stability and longevity. This proactive approach, which seeks to prevent these degradation processes before they begin, ensures that this invaluable scientific repository does not degrade unnecessarily, thus preventing the loss of information that, in specific cases, may not be represented in other specimens.

In this way, focusing on the environment and heritage sectors, we aim to summarise information that was previously scattered across various authors, by carrying out a bibliographical review of the available literature in order to obtain an overview of the information available in books, articles, lectures, and other sources, making the most relevant and necessary information available in a single article. We adopt a preventive conservation approach and establish foundations to incorporate future investigations, techniques, and methods, which includes guidance on the collection, preparation, cataloguing, recording, preservation, organisation, storage, and, if necessary, the technologies and curative methods for xylarium and herbarium samples. This approach ensures that stored samples remain available and useful in the future, enabling the preservation or enhancement of their physical and chemical characteristics and profiles over time.

As such, this review encompasses all publications on herbaria and xylaria (plural of herbarium) discovered through keyword searches on Google Scholar and academic databases. The keywords used included: "xylarium conservation," "xylarium preservation," "xylarium development," "collecting xylarium samples," and "xylarium preservation methodologies." The same search was conducted using the keyword "herbarium." There were no date restrictions for the publications analysed, and papers that did not specifically address herbarium, xylarium, development, or preservation were excluded.

1. A vouchered xylarium for the 21st century

A collection of wood samples offers a consistent and manageable resource for analysing, comparing, and studying wood that enables researchers to explore more research areas besides wood identification.

The standout feature of a xylarium created in the 21st century is its potential to be an invaluable resource for future investigations, resources, and technologies that are yet to be discovered. For any future xylarium to be scientifically confirmed and retested at any time, it is paramount that vouchered samples are associated with a herbarium for the scientific verifiability of the preserved sample. This statement extends beyond mere scientific accreditation but guarantees the potential for future confirmation and re-examination of the current samples, facilitating continuous adaptation to future identity checks, taxonomic changes, and discoveries (Barker & Flinders, 2005; Ross, 1973 cited in Greve et al., 2016).

Recent research (Bebber et al., 2010; Schmitz et al., 2019) has identified previously unclassified specimens, utilizing innovative genetic technologies (Beck & Semple, 2015; Jiao et al., 2018; Yu et al., 2017), and mapping biodiversity changes over time in response to global alterations (IPCC, 2014). It is important to maintain objectivity, clarity, and precision of language, avoiding subjectivity and biased language. It is also essential to adhere to conventional academic writing standards, including regular formatting, clear structure, and precise word choice, free from grammatical errors and spelling mistakes.

The correlation of wood samples to other parts of the specimen, including leaves, flowers, fruits, and bark, holds significant importance. Therefore, the concurrent establishment of an herbarium is vital (D. Bridson & L. Forman, 2010; Schmitz et al., 2019). These herbaria form a vast and intricate source of information that can have applications beyond their original purpose (British Columbia Ministry of Forests, 1996; Drobnik, 2008; Greve et al., 2016; Pyke & Ehrlich, 2010). The scientific value attributed to herbarium records is increasingly significant as a source of information on global biodiversity, as highlighted by organizations like the IUCN Red List of Threatened Species (IUCN, 2022) and IPBES - Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES, n.d.) (Greve et al., 2016). As evidence of its increasing relevance, online access to herbarium is becoming more accessible through shared portals such as the Global Biodiversity Information Facility (GBIF, 2021).

Even if not affiliated with a xylarium, the range of research areas covered by an herbarium is extensive. These include confirming the identity of specimens or discovering new variants (taxonomy); providing material for morphological measurements (systematics); verifying scientific names (nomenclature); supplying material for DNA analysis (genetics) (Edinburgh, 2022); and for geographic information system studies (ecology) (Staudinger et al., 2012), or contemporary specimens for comparison with fossils in Palaeobotany. It can also provide access to pollen for taxonomic, systematic, and pollination studies, as well as for allergy research in insect ecology, pollination ecology, and medical studies. It also documents temporal changes in the phenological traits of species (Staudinger et al., 2012). It enables microscopic examination for anatomy and morphology, along with chemical analysis for lead-uptake, pollution documentation, bio-prospecting, and chemical concentration. Additionally, information on common names and local uses of plants was gathered for anthropology, linguistics, ethnobotany, and economic botany purposes, while the geographic distribution of species was determined according to Pyke and Ehrlich (2010). Temporal changes in the environment were monitored (Greve et al., 2016) and documentation on minor climate cycles (paleoecology) or providing carbon isotope ratios (for example, Lewis and Clark specimens from 200 years ago have increased C12) showed evidence of climate change. The institution serves as a repository for voucher specimens globally, for use in fields such as ecology, ethnobotany, and environmental impact studies (Funk, 2007).

Continuous support for xylarium and herbarium is of utmost importance to ensure a consistent supply of specimens that can be used for various scientific purposes (Greve et al., 2016). The inclusion of historical wood and herbarium samples, sourced from art objects, historical structures, and archaeological sites, can provide valuable information to a range of fields, including Dendrochronology, Palaeobotany, conservation & restoration, the history of commerce, environmental biology, and potential areas of research not yet identified. All these factors will facilitate the establishment of a xylarium, which can meet the increasingly frequent and specific requirements of the industry, judiciary, art history, archaeology, and others (Beeckman, 2003; Carlquist, 1982; Cartwright, 2015; Collins & Cruickshank, 2012; Schmitz et al., 2019).

2. Xylarium reference collections

Constructing a well-grounded xylarium and collecting its samples is a complex undertaking. This process requires considerable time, physical effort, and financial investment and should not be expected to be flawless, but rather aimed at achieving the highest attainable standards (Schmitz et al., 2019). When striving for a scientifically rigorous xylarium, Table 1 provides relevant factors to consider.

Table 1 – Protocol for the construction of a xylarium. (British Columbia Ministry of Forests, 1996; D. Bridson & L. Forman, 2010; Esteban et al., 2012; Perkins, 2022; RHS - Royal Horticultural Society, 2013; Schmitz et al., 2019, 2020; Wiedenhoeft, 2014).

I.	It is advisable to take note of the field trip season, particularly when collecting deciduous species, as this may impede the collection of leaves, flowers, and fruits intended for the herbarium.
II.	Ideally, a botanist ought to be present to identify the specimen before collection.
III.	It is recommended to choose adult, healthy specimens without particular characteristics or defects that are representative of the surrounding specimens.
IV.	Use a GPS to obtain and record latitude, longitude, and altitude coordinates (in decimal degrees with at least four decimals) when collecting samples. Ensure the location data is in the WGS84 datum to accurately pinpoint the plant collection location. Alternatively, use a GPS Logger app on a smartphone.

V.	It is also important to record information such as the soil type, as well as the height and diameter of the tree before felling.
VI.	When feasible, collect a sample that encompasses the bark, sapwood, and heartwood.
VII.	Ideally, procure a disc from the entire trunk. This disc should be obtained around 50 cm above the ground to avoid the special characteristics of the root wood, and the north should be marked for possible comparative studies. When unattainable, an wedge-shaped piece that stretches from the centre of the trunk to the bark is ideal.
VIII.	Although these measurements vary greatly, it is advisable to collect the wood so that future samples have a minimum size of 20 cm high, 12 cm wide and at least 3 cm thick.
IX.	Ensure to record the location of sample collection within the specimen at ground height, chest height, or branch.
X.	Collect multiple samples from the same specimen, if possible, for analysis of internal variations and as a backup for lost or destroyed material or future trade with other xylarium.
XI.	Ideally, choose trees without cracks or any visible signs of infestation or infection.
XII.	Avoid using chemicals or pencil marks on the sample during processing as this may affect future stable isotopes, DART, and NIRS analyses.
XIII.	When possible, participate or be present during sample collection. If not possible, work only with samples that have attached information such as species, variety, and geographic origin.
XIV.	Preferably, use xylarium linked to herbarium vouchers when working with donated samples from other collections. If not possible, have the samples identified by an experienced wood anatomist to maintain reliability.

A worldwide index of xylaria is available in the Index Xylariorum 4.1 compiled by Anna H. Lynch and Peter E. Gasson (version March 2010) and updated by IAWA under supervision of Frederic Lens (March 2016) - (Lynch et al., 2016).

3. Herbarium reference collections

Collecting plant specimens to create an herbarium is a precise task that requires certainty that the collected and processed specimen matches the specified species. To ensure scientific credibility and value, confirmation from a taxonomist is necessary. It is essential to consider factors such as the sample's original location and environment typology when conducting research (British Columbia Ministry of Forests, 1996).

Although the procedure for collecting xylarium and herbarium specimens are related, they are not the same. Therefore, Table 2 provides additional relevant points to the previous information.

Table 2 - Protocol for constructing an herbarium (British Columbia Ministry of Forests, 1996; Perkins, 2022; RHS - Royal Horticultural Society, 2013; Schmitz et al., 2019, 2020).

I.	Note the field trip season, as this may impede the collection of leaves, flowers, and fruits, particularly when targeting deciduous species.
II.	Ideally, a botanist should be present for specimen identification before collection.
III.	Use a GPS to acquire latitude and longitude coordinates (in decimal degrees with at least four decimals) and employ WGS84 as the datum to locate the plant collection spot. Alternatively, use a GPS Logger app if in possession of a smartphone.
IV.	Handpick specimens and samples with good condition and without any signs of animal/insect damage, deformities, or diseases.
V.	Whenever possible, include all plant parts that may help with identification. Choose different plant parts that enable identification and not just the biggest leaf or flower.

VI.	It is advisable to collect several samples from the same specimen to allow for the analysis of internal variations and the use of other techniques, as well as providing a backup for lost or destroyed material or future trade with other herbarium.
VII.	A polythene bag should be used to hold the specimen, along with an identifier. Ensure that only one bag is used for each specimen. Any excess air in the bag should be removed before sealing it.
VIII.	To maintain the specimens inside the bag during collection, it is advised to avoid direct sunlight and hot places, and where possible, store them in a cooler. If this is not feasible, sprinkle water inside the bag or add a damp paper towel.
IX.	Avoid collecting fallen leaves from the ground, young trees or sprouts as their morphological characteristics may vary from those of mature trees.
X.	It is recommended to avoid using chemicals or pencil marks on the samples during processing as it may affect stable isotopes, DART, and NIRS analyses.
XI.	In cases where it is not feasible to be present during collection, it is advisable to work only with samples that have attached information, such as species, variety, and geographic origin.
XII.	If it is not possible to have samples with attached information, it is suggested to get the samples identified by an experienced botanist.

A worldwide index of herbaria is available in the Index Herbarium, which was originally published by the International Association for Plant Taxonomy, and subsequently maintained by the New York Botanical Garden - (New Your Botanical Garden, n.d.).

4. Photographic documentation

Wherever feasible, photographic documentation of the sample, surroundings, process, and materials collected should be taken for future reference. This is a vital and valuable source of information. In contrast to previous decades, it is now an essential, cost-effective, and speedy procedure due to digital photography. The protocol specified in Table 3 applies to both xylarium and herbarium specimens.

Table 3 - Procedure for photographic documentation of xylarium and herbarium samples. (Schmitz et al., 2019).

I.	When feasible, employ a standard-sized object (e.g., ruler, coin, or scale bar).
II.	Capture an image of the overall shape and the surroundings of the specimen.
III.	Obtain general images of the bark, leaves, flowers, fruits, thorns, and any other relevant details.
IV.	Take close-up photographs of any notable characteristics such as diseases, malformations, or fissures.

5. Sample labelling

There are several different methods for labelling samples, especially in the field. In this case, we used various authors as references, with particular attention to Schmitz et al. (2019). Table 4 provides information applicable to both xylarium and herbarium collections.

Table 4 - Protocol for xylarium and herbarium field description and specimen labelling. (British Columbia Ministry of Forests, 1996; D. Bridson & L. Forman, 2010; Perkins, 2022; RHS - Royal Horticultural Society, 2013; Schmitz et al., 2019, 2020).

Wherever possible, the identifier should register:	
I.	Taxonomic classification (confirmed/probable).
II.	The number of samples collected.
III.	The full date of collection.
IV.	Season of collection.

V.	Name(s) of collector(s).
VI.	Name(s) of region/city/place of collection and GPS location, if possible.
VII.	Type of material collected (wood, leaves, flowers, fruits, cones, bark or other).
VIII.	The location of collection of the wood sample within the specimen (at ground level, at breast height, or on a branch), in case of a xylarium.
IX.	The circumference or diameter (in centimetres) of the xylarium specimens at breast height. The specimen should be standing or recently felled.
X.	The height of the specimen (in metres) should be estimated using a clinometer and laser meter/tape measure or a hypsometer.
XI.	Ensure that all samples taken (bark, cambium, wood, leaf, flower, and fruit) from the same specimen are labelled with a distinct and consistent sample code.
XII.	Do not repeat the same number, even if the collection site is the same, the plant was collected at a later date, or it was grown in a greenhouse.
XIII.	Canopy shape, growth shape, and height (spreading, scraggly, columnar) must be described.
XIV.	The habitat description, including slope, riparian area, associated vegetation, and soil type, is also necessary.
XV.	The concise description of the specimen including physical attributes, dimensions, and any other pertinent details.
XVI.	The coordinates using a GPS mobile phone application where feasible to accurately determine the plant collection site.

6. Colour charting

The sample colour charting can be a valuable identification factor to consider in certain situations. Accordingly, some relevant factors are underlined in Table 5.

Table 5 - Indicators for colour charting. Adapted from (British Columbia Ministry of Forests, 1996; RHS - Royal Horticultural Society, 2013).

I.	Compare the colour of the fresh material with a plant indicator colour chart (e.g., Royal Horticultural Society colour chart).
II.	When the colour of the sample is as close as possible to the colour on the chart, add the colour names or numbers to the identifier in the bag.
III.	Colour change or loss is inevitable. However, some samples may return to their original colour as the sample ages or dries.
IV.	Avoid using the chart in direct sunlight or artificial light, the light from a north facing window is ideal.
V.	Be aware that you may need to record more than one colour in different parts of a specimen.
VI.	Many cultivars only show differences in colour characteristics.

7. Drying and pressing process for xylarium and herbarium

Especially for xylarium, the drying time depends, among other factors, on the thickness of the sample, the species density, the season of collection and the drying conditions. For a piece of wood to reach a stable level of dryness during air-drying (with normal air circulation) in a stable (without drastic fluctuations in relative humidity) and protected environment (e.g., without exposure to sunlight) usually takes from a few months to several years (Hoadley, 2000). This content can be measured with a good accuracy resorting to a commercial pinless wood moisture meter. This process can be accelerated by kiln drying. Specific kiln schedules have been developed to control temperature and relative humidity in accordance with the moisture content and stress situation within the wood, thus minimizing shrinkage-caused defects (Boone et al., 1988). Moisture content below 20% when introduced into a xylarium, shows minimal susceptibility to biological attacks, few chemical changes over time, and acceptable dimensional changes (Wiedenhoeft, 2014).

In the context of herbarium specimen handling, the main objective is to avoid curling, wrinkling, and warping of specimen leaves, flowers, and thin twigs during drying. Although there is some tolerance (even though not advisable) regarding the dryness of xylarium specimens during storage, the complete dryness of herbarium specimens is the most crucial factor in storage, which is why the following steps are of paramount importance. The materials listed in Table 6 are only indicative and may be replaced by products with similar characteristics or which provide comparable results.

Table 6 – Materials for herbarium samples pressing process.

I.	Pressing boards - consist of a pair of 6mm thick plywood or hardboard sections cut to around 300mm wide x 450 long.
II.	Blotting paper - acid-free 300 gsm blotting paper is the most recommended material for drying out specimens quickly, which also gives the best results in what preservation of colour and other characteristics is concerned.
III.	Corrugated card - Lengths of 450mm minimum is required.
IV.	Foam sheet - sponge/foam sheets cut to format size.
V.	Straps - two 25mm wide x 1.5m long canvas luggage straps with sliding plastic buckles.
VI.	Tensioning bars - wood bars 30mm x 12mm x 460mm long, bevelled at one end to facilitate pushing under the straps.

The protocol for pressing herbarium samples follows a series of steps that, although not rigid, must be followed as closely as possible to obtain similar results. To that end, the process is exposed in Table 7.

Table 7 - Protocol for pressing herbarium samples (British Columbia Ministry of Forests, 1996; Heath et al., 2017; RHS - Royal Horticultural Society, 2013; Vieira, 2023).

I.	Place two pieces of corrugated cardboard (corrugation facing corrugation) over a press board.
II.	Place a double layer of blotting paper on top.
III.	Place your specimen, trying to maintain the natural position of the plant, but making sure that at least one leaf and one flower are visible underneath. If it is not possible to turn the specimen while it is still attached to the plant, remove it, and fix it separately.
IV.	Specimens with long leaves or stems can be folded to fit the given format.
V.	Once the layout has been decided and the appropriate taxonomic classification has been determined, place another double layer of blotting paper over it.
VI.	Place two more pieces of corrugated cardboard (corrugation facing corrugation) on top of the ensemble, followed by another pressing board. If another specimen is to be made, the same procedure is followed, with the press board placed as the last layer before pressing.
VII.	If the specimen is bulky, a sheet of foam should be placed on top of the second set of blotting papers and corrugated board.
VIII.	When all the layers are in place, the second pressing board is placed on top.
IX.	Pressure can be applied by wrapping the straps around the entire assembly, placing them 1/3 from the end of each press board and tying a knot as tightly as possible. Once this is done, place the tensioning rods under the strap at right angles to it and pull them as far as possible towards the side edge of the boards to increase the pressure.

The aim is to dry the specimen as quickly as possible to retain maximum colour and avoid the formation of mould. To this end, some form of low heat source is possible but not essential (Drobnik, 2008), although it is advisable never to exceed 50 ^{o}C (120 ^{o}F) and never to use an oven or microwave for this process (Perkins, 2022; Wilken, 2009). Table 8 shows the steps to be taken once the drying process has begun.

Table 8 – Drying process protocol (British Columbia Ministry of Forests, 1996; Perkins, 2022; RHS - Royal Horticultural Society, 2013; Vieira, 2023).

I.	An inspection should be made after 24 hours. Care should be taken when handling the blotting paper to avoid tearing the specimen, which is likely to be in a limp state.
II.	If any of the leaves or petals are accidentally folded, they can be placed in the correct position and temporarily fixed with a post-it note.
III.	Ideally, if the blotting paper and corrugated cardboard are found to be damp, they should be replaced with dry ones, but if they are not damp or show no signs of mould, it's more common to keep the same materials until the whole ensemble is completely dry.
IV.	Make sure that the corrugated cardboard is not crushed and that there is room for air to circulate.
V.	Tighten the strap daily and allow the whole ensemble to dry for at least a week.
VI.	It can be difficult to conclude that a specimen is completely dry, but if the specimen lifts off the paper easily, is stiff and light to the touch, it should be ready for storage. If in doubt, continue the drying process for a longer period.

8. Mounting specimens

Methods of preparing, mounting, and storing herbarium specimens vary widely between herbarium, depending primarily on the type of plant specimen to be processed (Perkins, 2022;

Wilken, 2009). While most plant parts can be easily stored and pressed, bulbs, fruits, cones, bark, or even large diameter woody stems may need to be cut or dried in boxes or paper bags and stored in acid-free boxes, depending on space requirements (D. Bridson & L. Forman, 2010; Perkins, 2022; Wilken, 2009). Despite the different options in the bibliography consulted, Table 9 summarises the most frequently mentioned materials used.

Table 9 - Materials used for mounting herbarium specimens.

I.	Acid-free or PH-neutral mounting card. Colour and size are optional, but usually white and around A3 size (297 x 420 mm).
II.	Acid-free adhesive, ideally non-water soluble (Drobnik, 2008). Wilken (2009) suggests the reversible adhesive grade A methylcellulose with a molecular weight of 4000, and Cabral (2018) and Heath (2017) suggest a white water-soluble adhesive with a neutral pH. The use of poly(vinyl acetate) emulsion adhesives is discouraged as these tend to become acidic as they age (Down et al, 1996 cited in Wilken, 2009).
III.	Gummed linen hinging tape.
IV.	Transparent polypropylene covers (Cabral & Sales, 2018).

The protocol for mounting specimens also varies between authors and is summarised in Table 10.

Table 10 - Protocol for mounting herbarium specimens.

I.	Place your cardboard label template on the right-hand corner of the mounting sheet.
II.	Fragments such as seeds, petals, leaves or others, should be preserved. For that, they should be placed in a fragment pouch. Usually, it is placed in the bottom left-hand corner.

III.	Fragment pouches can be made of the same acid-free mounting card by folding an A4 sheet into an A6 or A7 size (D. Bridson & L. Forman, 2010; Heath et al., 2017; Perkins, 2022; RHS - Royal Horticultural Society, 2013).
IV.	The specimen may be fixed to the mounting card resorting to small dabs of glue on its underside, which can also be done with a cocktail stick or dissecting needle dipped in glue for finer work (RHS - Royal Horticultural Society, 2013). On the other hand, small strips of gummed linen hinging tape can be glued to the card while trapping the specimen underneath. In this way, the specimen is always free of glue and because of that, manageable. Bigger or more abundant strips of gummed tape should be used on the stalk and flower stems.
V.	To guarantee the fixation of the glue in the desired place, use small sandbags to press it down.
VI.	As extra protection, the entire ensemble may be placed inside a polypropylene transparent cover (Cabral & Sales, 2018).
VII.	In addition to the procedure referred, a more dated and less frequently used method is stitching. In this case, parts of the specimen, usually the bigger and bulbous ones can be stitched to the paper sheet instead of glued. It is mainly used in stems, bulbs, or fruits (Cabral & Sales, 2018; Heath et al., 2017; Perkins, 2022).

9. Label template and archival material

The label on xylarium and herbarium specimens should contain all the essential information and be as durable as possible to avoid unidentified specimens. Loss of this element is one of the most damaging factors for the scientific validity of old xylarium and herbarium. The longevity of labels, particularly handwritten but also printed, is limited, mainly due to the chemical nature of these materials, which results in a relatively rapid degradation that can occur as little as 3 years after the information was written.

In the specific case of xylarium, this problem can be avoided by impact marking the sample's numerical code. In this case, we're talking about the primitive but highly effective use of a set of numbered digits punch and a hammer.

The label degradation process is mainly visible as a change in the original colour (black ballpoint pens and inks become brownish-grey, while blue ones tend to become reddish, pinkish, or very pale). The disappearance of the colour in the paper is also a common occurrence, resulting in the appearance of an increasingly wider band around all characters, often leading to the complete disappearance of the written message (Drobnik, 2008). The same applies to low quality inks for computer inkjet printers, as most of them are not water resistant. Of course, paper, as a highly absorbent material, favours the reaction of these materials with water and accelerates their rapid degradation (Drobnik, 2008).

Another issue to be considered is the chemical composition of the ink, since, despite the colourfastness of some brands, many of them contain acidic components and microelements such as iron (Fe) and chromium (Cr), which contribute to the acidification of the paper. This will cause the decomposition of the cellulose present in it, but also promote the development of bacteria and microscopic fungi with the transfer of those ions to these microorganisms (Szostak-Kotowa, 2001 cited in Drobnik, 2008; Perkins, 2022).

Nevertheless, the material limitations do not end there. The quality of the ink can be improved by purchasing special archival inks or heritage grade pen inks with a special composition, but it is also important to be aware that the adhesives used have a direct impact on the material they are used to affix. In particular, dense liquid adhesives can gradually dissolve some of the ink's constituents, resulting, for example, in the purpling of the white bars on barcode adhesive labels, which reduces contrast and makes the label unrecognisable to barcode scanners.

A proven material is graphite or carbon. These materials have low reactivity, are not water-soluble and do not oxidise, resulting in a permanent black material that has been proven to be still present and legible in the Linnaeus samples. The only limiting factor is the ability to be deliberately erased with a rubber (Drobnik, 2008).

A relatively new technique is the laser printing and xerographic copies (printed or photocopied labels), which, although considered to be a durable material, have yet to be tested. They are made of a solid material that is melted (not dissolved) and consists mainly of black polymers, which reduces the possibility of diffusion in the printing paper as well as in an adhesive layer (Drobnik, 2007).

Most of the paper produced until the 1990s is acidic, which causes embrittlement and yellowing of the material due to oxidation of the lignin and changes in the structure of the cellulose chains (Zyska, 1995 cited in Drobnik, 2008). Therefore, it becomes clear that acid-free (pH neutral or alkaline) paper and adhesives are absolutely necessary for the construction of an herbarium (Drobnik, 2008).

A common adhesive used to fix specimens to the paper sheet is generally referred to as 'white glue' and is based on PVA - polyvinyl acetate. This widely used water-soluble adhesive has as its main disadvantage the fact that it tends to become acidic with age (Down et al., 1996 cited in Wilken, 2009).But most importantly, it is susceptible to degradation by filamentous fungi, and more rarely by algae, yeasts, lichens and bacteria (Cappitelli & Sorlini, 2008), especially when the relative humidity in the herbarium room increases, making its use highly controversial among specialists, as the long term effects of this potential substrate for bacteria are still unknown. Nevertheless, the two main methods of mounting herbarium specimens, the Archer method (Archer, 1950) (in which the specimen is fixed to the herbarium sheet by narrow strips of plastic or paper) and the pasting method (in which the entire specimen is glued to the sheet) both use this type of adhesive.

The alternative methods of stitching specimens to the sheet (Cabral & Sales, 2018; Heath et al., 2017; Perkins, 2022) or pinning are more expensive and labour-intensive methods but are still chosen by some herbarium (Drobnik, 2008). Table 11 lists the materials and information that should be present.

Table 11 – Materials and mandatory information items.

Materials	
I.	Archival quality, acid-free labels.
II.	Acid-free adhesive. Wilken (2009) suggests the reversible adhesive Grade A methylcellulose with a molecular weight of 1500.
Mandatory information items	
I.	Item number.
II.	Origin. Ideally with GPS coordinates.
III.	Wild collection vs. breeding.
IV.	Date of collection.
V.	Collector.
VI.	Taxonomic classification of specimen. Should include scientific classification and family name.
VII.	Always indicate if the sheet is part of a larger specimen that had to be mounted on more than one sheet (e.g., 1 of 2; 2 of 3, etc.). If this is not the case, always mark the sheet as 1 of 1.
VIII.	Additional space for relevant information specific to the item.
IX.	The definition and inclusion of a barcode can be a valuable addition to save time and avoid errors (Cabral & Sales, 2018).

10. Main pests of xylaria and herbaria

Pests in a xylarium and their effects vary according to the geographical location of the storage. In addition to the well-known xylophagous insects, fungi and bacteria are also important microorganisms. All these species have a destructive effect on this type of biological material.

The most common xylarium pests found in Southern Europe are *Anobium punctatum* (furniture beetle); *Hylotrupes bajulus* (house longhorn beetle); *Nacerdes malamura* (wharf borer); *Lyctus brunneus* (brown powder post beetle); *Cryptotermes brevis* (powder post termite); *Reticulitermes lucifugus* (subterranean termite); *Coptotermes acinaciformis* (subterranean termite) (Lieutier et al., 2004; Toriti et al., 2021).

Although the same pests can also attack herbarium specimens, there are other protagonists that have a specific impact on herbarium deposits. Again, depending on the geographical location of the repository, the nature of the pests and their effects vary considerably. For that reason, it is important to a concise knowledge of the main insect species present in your geographic location (D. Bridson & L. Forman, 2010). In addition to the fungi and bacteria already mentioned, beetles, spiders and other insects can also have a destructive effect on this type of biological material. The most common herbarium pests are: *Lepisma saccharinum* (Silverfish); *Psocoptera* order (Booklice); *Lasioderma serricorne* (Cigarette or tobacco beetles); *Trogoderma angustum* (Herbarium Beetle); *Dermestidae* family (Cockchafer) and *Stegobium paniceum* (Drugstore beetles) (British Columbia Ministry of Forests, 1996; Child, 1998; D. Bridson & L. Forman, 2010; Edinburgh, 2022; Wilken, 2009).

11. Conservation methods for xylarium and herbarium

Occasional infestations are almost inevitable in any museum or repository, even when preventive measures are taken. However, when they do occur, curative measures must be carried out as soon as possible. Actions such as:

I. Immediately isolate any objects suspected or found to be infested to prevent the spread of the infestation.
II. If possible, seal items immediately in polyethylene zip-lock bags.
III. Thoroughly clean the area where the infested items were located.
IV. It is important to identify the pest in order to understand its life cycle and behaviour.

With this information, decisions can be made on the best treatment for the object(s), collection, or storage type (D. Bridson & L. Forman, 2010; Pinniger, 1998).

Most of the methods, materials and intervention parameters described below apply to both xylarium and herbarium with minor differences. However, it should be borne in mind that the conservation of herbarium is a highly complex area, as the material to be protected is much more sensitive to degradation than, for example, the wood samples that make up a xylarium. Furthermore, herbarium is more sensitive to certain treatments due to the very nature of the material they preserve, whereas xylarium, as a collection of solid wood samples, can withstand more aggressive and simpler treatments.

The most common threats to the permanence of a herbarium are factors such as past infestations, the natural ageing of the paper used for labels, sheets, covers or envelopes, together with the degradation of inks, adhesives and printed texts (Drobnik, 2008). Nevertheless, it is important to stress the high susceptibility of these collections to factors such as fluctuations in environmental humidity and, consequently, uncontrolled drying or fungal attack.

11.1. Fumigation of the collection

One of the most common methods of curing and preventing infestation and infection was the fumigation of collections. Despite its relative success, the main limitation of this method is that the specimens and the paper sheets (in the case of herbarium) often remained toxic to human handlers for extended periods of time. From the mid-18th century to the end of the 20th century, highly toxic chemicals were used in xylarium and herbarium, as shown in Table 12.

Table 12 - Chemicals most commonly used for fumigation of collections (Briggs et al., 1983; D. Bridson & L. Forman, 2010; Hawks, 2001; Hawks et al., 2004; Kurmanow, 2019; U.C., 2008; Whitmore, 1965; Whitten et al., 1999).

• Mercuric chloride - HgCl2 • Potassium cyanide – KCN • Carbon tetrachloride - CCl4 • Dichlorodiphenyltrichloroethane (DDT) - C14H9Cl5 • Lauryl Pentachlorophenol - C6HCl5O	• Arsenic trioxide - As2O3 • Carbon disulfide - CS2 • Naphthalene - $C_{10}H_8$ • Lindane - C6H6Cl6 • Organofosforado 2,2 diclorovinil dimetilfosfato (DDVP) - C4H7Cl2O4P

The absorption of these toxic compounds through the skin and by inhalation is still a real threat today, mainly because their remnants are still present in all parts of old plant sample deposits (Drobnik, 2008). The use of moth balls (naphthalene or paradichlorobenzene) has been discontinued because of their toxicity (Pereira & Hammond, 2001; Pereira & Wolf, 2001), as the use of commercial insecticides such as Raid and Vapona has been described as more dangerous to the user than to the pest (RHS - Royal Horticultural Society, 2013). A 'newer' problem that many of the old plant specimens have, is the fact that most toxic compounds have a deleterious effect on the DNA of the specimens, making their use for genetic research unviable (Drobnik, 2008).

This method is particularly harmful to herbarium users because the materials stored are more absorbent than most woods, adding to the absorbent properties of the mounting paper sheets and folders, which remain toxic to human handlers for long periods of time.

Because of the high risks and extreme hazards associated with the use of highly toxic chemicals, other approaches have been developed. This chemical-free perspective, commonly referred to as Integrated Pest Management (IPM), involves the use of multiple techniques to achieve the same result, which is the destruction of the infestation or vector (Edinburgh, 2022).

11.2. Modified Atmosphere Treatment (Anoxia)

This method has been used to replace fumigation methods, which are much more dangerous for humans. Anoxia takes place in an airtight space (metal chambers or portable special plastic bags) where the oxygen level is extremely low (less than 0.1%). The duration of treatment depends on factors such as temperature (at 25 ^{o}C or above it can take 2 to 3 weeks, while at 20 ^{o}C or below it can take 4 to 5 weeks), preferentially between 30-38 ^{o}C as mentioned in Bridson & L. Forman (2010) and the size of the objects (nitrogen can be introduced for large objects). However, other chemicals such as carbon dioxide and argon are increasingly used. This method is now widely available commercially and is particularly applicable to most collection typologies because of its portability (Burke, 1999; Pinniger, 1998).

11.3. Microwaves and ultraviolet radiation

Ultraviolet (UV) radiation and microwave heating are much more damaging to herbarium specimens than to xylarium specimens because of the rapid ageing of paper due to cellulose and lignin degradation, which also increases the loss of paper flexibility and the intense drying of specimens that are often very fragile by nature. In addition, UV light and microwaves damage the DNA of the specimens, making their use for genetic research unviable (Drobnik, 2008).

At present, the most effective, ecological, and beneficial measures to control degradation are temperature and humidity control, regular or even permanent freezing of samples and the use of vacuum chambers.

11.4. Temperature and relative humidity control

Temperatures below 13 ºC prevent egg hatching and full metamorphosis of all herbarium insects and reduce their motility (Rumball & Pinniger, 2003), while relative humidity (RH) below 55% combined with temperatures below 18 ºC stops the growth of moulds (British Columbia Ministry of Forests, 1996; Rumball & Pinniger, 2003). The Royal Botanic Garden Edinburgh (2022) maintains a stable temperature of 20 ºC and 50% relative humidity.

11.5. Freezing samples

Sample freezing temperatures and time vary widely between authors. Table 13 summarises these values and time periods.

Table 13 - Freezing temperatures and time periods.

Authors	Degrees (Celsius, ºC)	Freezing time
Strang (1992) Rumball & Pinniger (2003)	set values that range from -18º C to -32 ºC	minimum of 72 hours
Raphael (1994)	-20 ºC	7 to 10 days
British Columbia Ministry of Forests (1996)	-20 ºC	48 hours
Bridson & L. Forman (2010)	Minimum -18º C, ideally -30 ºC	17 hours
Royal Horticultural Society (2013)	No temperature mentioned	36 hours
Royal Botanical Gardens Kew (2017)	-40 ºC	4 days
The Royal Botanical Garden of Edinburgh (2022)	-29 ºC	5 days

Although less damaging to herbarium than to xylarium, it is important to note that water vapour tends to condense on the surface of the specimen and must evaporate before the specimens return to the shelf (Drobnik, 2007). To avoid this, the Royal Horticultural Society (2013) recommends sealing the specimen(s) in a sealed polythene bag prior to freezing, emphasising the importance of keeping the bag sealed during the defrosting period to prevent moisture absorption by the specimen.

It should be noted that the freezing equipment used must be able to reduce the temperature inside the object in less than 24 hours, since, especially in cold climates, if the freezing process is too slow, some insect species may acclimatise and survive the freezing process (Pinniger, 1998).

The parameters for temperatures and exposure times are the same as above, but it should be noted that tightly rolled tapestries and skins (Pinniger, 1998), large volume boxes or large fascicles require a longer freezing time due to their natural insulation against cold (D. Bridson & L. Forman, 2010; Drobnik, 2008). If possible, the temperature in the centre of these large items should be registered (Pinniger, 1998). Freezing should be a routine annual procedure, or more frequently if pests or the result of pest metabolic activity is detected (RHS - Royal Horticultural Society, 2013).

11.6. Vacuum chambers

Vacuum chambering is considered the most effective method of pest control. This method destroys the protoplasts within the cell wall, thereby terminating any animal, fungal or bacterial life (Drobnik, 2008).

Particularly for newly acquired or loaned specimens, these procedures are mandatory to ensure the continued stability of herbarium specimens. Concerning of the protection measures taken, all specimens should be regularly inspected for moisture, mould, or insect infestation.

11.7. Regular inspections

Regular inspection and cleaning of xylarium and herbarium cabinets, shelves, work areas, floors and files is the most effective and economical way to prevent pest introduction. Particularly in the case of herbarium, due to its fragile and less resistant nature, the use of a vacuum cleaner is preferred to the use of wet cloths, mops, or similar systems, as these methods introduce moisture into the environment. Detailed information on this point can be found in the National Park Service Museum Handbook, Part I, Chapter 5, Biological Infestations and Chapter 13, Museum Housekeeping (NPS National Park Services., 2000) (British Columbia Ministry of Forests, 1996; Edinburgh, 2022; KSU Herbarium, 2002; Wilken, 2009).

11.8. Continuous monitoring devices

As mentioned above, regular inspections are an effective method of control, but constant surveillance is not possible. Therefore, devices such as sticky traps provide a 24/7 defence against these constant enemies of museum objects and buildings.

This method can be used to trap a wide range of pest species, both crawling and flying, from their mobile larval stages to their adult stages. In addition to the capture itself, data can be obtained on their numbers, seasonal cycles and hiding places. However, this tool should not be used as a pest control device, but only as a pest monitor (Child, 1998).

The forms, shapes, sizes, and brands are numerous and readily available on the market, being the two main types of traps, suspended tent traps for catching flying insects and sticky cardboard traps for the ground. The latter may sometimes contain a general food attractant. Typically, funnel traps and UV electrocution types do not have a regular presence in museums.

Another mechanism is the use of semiochemicals, which is essentially the use of chemicals produced by a particular species to influence the behaviour of another individual of the same or a different species. In this specific case, the use of female pheromones to attract the male

(Guarino et al., 2020). As shown in Table 14, the use of the synthesised version of these pheromones has been developed for specific insect species that affect both xylarium and herbarium.

Table 14 - Insect species for which synthetic pheromones have been developed.

• *Anobium punctatum* - Furniture beetle	• *Tineola bisselliella* - Webbing clothes moth
• *Stegobium paniceum* - Drug store beetle	• Lasioderma serricorne - Cigarette beetle

This strategy, particularly when combined with a food attractant (Guarino et al., 2020) and sticky traps, is highly effective, especially when a particular insect species is suspected of becoming a potential hazard. Specially, in enclosed areas, this option is very successful in attracting large numbers of male insects and is therefore a valuable indicator of likely total insect numbers (Child, 1998; Edinburgh, 2022). The placement of these traps should follow the protocol shown in Table 15.

Table 15 - Trap placement protocol.

I.	Traps should be marked with the date of installation.
	Traps should be placed:
-	On the walls, as most insects do not cross open areas.
-	At wall/floor junctions, corners, near doors, ventilation systems or other entry points.
-	In any dark, hidden area that is difficult to access and inspect.
-	In display cases (if possible).
II.	Hanging tent traps should preferably be placed near windows.
III.	Place on windowsills to catch insects that may be attracted by light.

IV. The Royal Botanic Garden Edinburgh (2022) also uses UV lights on windowsills and under workstations.

The purpose of these traps is to catch insects, but also to identify them. Traps should be inspected regularly, and the insects caught (adults or larvae) should be identified, counted and, if possible, the direction in which they entered the trap should be noted, as this may indicate a source of entry. Basic room hygiene is essential, otherwise the sticky part of the traps will be filled with dirt and fluff instead of insects (Child, 1998; Edinburgh, 2022), but traps should still be checked weekly and more frequently in the summer months. These traps should be replaced over time as the captured insect may become a food source for other insects and, despite the longevity of the glue, it will eventually dry out. New traps should be set after a disinfestation treatment to monitor the success of the operation (Child, 1998) and all this information should be recorded.

12. Storage, Archiving and Handling of xylarium and herbarium samples

The methods of storing and archiving xylarium specimens are limited. Most xylarium organise their specimens in open racks, shelves, drawers, or closed cabinets with specimens arranged side by side. This furniture typology is mostly dependent on the size and scope of the collection, the physical and spatial conditions, and the economic resources available. There are, however, parameters that are not, such as the paramount importance of the specimens being completely dried and free of pests before storage.

It is important to emphasise that the presence and storage of histological slides associated with the xylarium, and herbarium will facilitate and speed up their use by researchers, avoiding the need for constant recourse to the wood or herbarium specimens for sectioning (Beeckman, 2003; Lamb & Curtis, 2005). Table 16 shows the materials and protocol for storing xylarium.

Table 16 - Materials and protocol for xylarium storage.

Materials	
I.	Open or preferably closed metal racks, shelves, drawers, or cabinets.
II.	Archival quality acid free labels.
III.	Acid-free glue. Wilken (2009) suggests the reversible adhesive grade A methylcellulose with a molecular weight of 1500.
Protocol	
I.	The height, width and thickness of the specimen will depend largely on what the original specimen allows and other issues such as availability, level of protection, transport, market value etc.
II.	Xylarium specimens are usually placed side by side.
III.	The identification label should face outwards if possible.
IV.	No coatings of any kind (varnish, wax or other) should be applied to the specimens as this may interfere with future application of analytical techniques.
V.	Samples should not be exposed to direct sunlight and should ideally be stored in a light-free environment to preserve, as far as possible, the natural colours of the different specimens.
VI.	If possible, a sheet of blotting paper should be used as a divider between each wood sample.

There are various methods and furniture typologies to archive herbarium specimens, which are, once again dependent, like in the xylarium case, on the collection's size and other factures. As an addiction to the parameters referred earlier, the language used on the archiving and labelling procedures, should be objective, balanced, and formal, devoid of ornamental, biased phrases. Additionally, the text's grammar, spelling, and punctuation must be correct and consistent. Subjective evaluations should be avoided, unless clearly marked as such.

It is important to note that xylarium samples do not require any specific material for proper storage. In contrast, herbarium necessitate the use of particularly high-grade materials. Table 17 presents the materials and protocol for herbarium storage.

Table 17 - Materials and protocol for herbarium storing.

Materials	
I.	Protective bags are constructed from flimsy acid-free paper with a weight of 60 gsm.
II.	Genus covers - archival natural history herbarium folders.
III.	Large format sealable (zipper) polythene bags.
Protocol	
I.	Attach the specimen to a mounting card using a thin adhesive and label the bottom-right corner accordingly.
II.	Place the document in a folder with a clear label, ensuring the label is also placed in the bottom-right corner.
III.	The specimen is ready for filing (RHS - Royal Horticultural Society, 2013).
IV.	Herbarium specimens are typically stacked atop one another in a standard format.

12.1. Storage facilities

Wooden shelves and cabinets are no longer used in storage facilities due to their susceptibility to infestation (British Columbia Ministry of Forests, 1996). As a result, metal furniture cabinets are the prevailing storage mechanism for xylarium and herbarium collections (British Columbia Ministry of Forests, 1996). The most common herbarium storage system for small and medium-sized samples involves metal cabinets with movable shelves and drawers. Although not strictly necessary, closed metallic cabinets can effectively reduce damage caused by dust, insects, rodents, air pollutants, and light and provide a stable microenvironment with controlled relative humidity and temperature fluctuations (Donald R. Cumberland, 1993; Vieira, 2023; Wilken, 2009).

One significant aspect of these cabinets is the gasket lining the door jamb, which creates a positive seal against air infiltration and biological infestations. Older gaskets oxidised rapidly, losing flexibility and structural integrity in around two to five years primarily due to exposure to ultraviolet radiation. Furthermore, these materials were made from felt impregnated with arsenic or mercuric chloride, intended to kill any insects seeking access to the interior of the cabinet. Consequently, these materials pose a serious hazard for herbarium staff (Donald R. Cumberland, 1993). Long-lasting, chemically inert, and stable silicone polymer is a more suitable material for this purpose (Donald R. Cumberland, 1993; Edinburgh, 2022).

12.2. Archival System

The most prevalent approach for storing xylarium and herbarium samples is to file them in alphabetical order, with the genus and species being alphabetically arranged. Family classifications can also be maintained in alphabetical order or organized according to a phylogenetic sequence (British Columbia Ministry of Forests, 1996; Wilken, 2009).

A prevalent problem is the new samples addition issue. Although the numerical record makes it easier to organise the samples and catalogue them, when new specimens are added, it can happen that related samples (of the same species or genus) have to be separated in the archive in order to keep the numbering in order. Organising in alphabetical order, on the other hand, allows new samples to be introduced between specimens from the same family, genus or species. This issue is also related to the space available for the collection, which can mean that, as the collection grows, samples have to be routinely relocated and reorganised on different shelves, cabinets and drawers.

An important factor to consider is the need to record all the movements of each individual sample in the collection. This record should include the dates the sample left and entered the collection, but also who requested it, which institution it belongs to, for what purpose, what tests it was subjected to, as well as any other information that seems relevant for future reference. This extra information will have an impact on writing the history of the collection, on its social, scientific, and industrial influence and on collaboration between communities, institutions, and countries.

12.3. Handling procedures

Handling procedures for xylarium samples differ from those for herbarium specimens. Generally, no specific requirements exist for handling xylarium samples. However, when the xylarium houses highly degraded, old, or fragile specimens, such as palm trees, centenarians, or archaeological samples, precautions should be taken to avoid accidents.

Wearing surgical gloves prevents the deposition of hand grease, which could result in oxidation in the future. Additionally, it is necessary to wear gloves when handling known toxic species to protect the handler. Even if the wood is free of dangerous chemical compounds, it is important to consider potential allergic reactions that some people may have to specific types of wood (Meier, 2022; Osborn, 2022).

Handling specimens, irrespective of their nature, should always be considered a challenging operation that necessitates thoughtful planning and focus. Especially with herbarium specimens, the careless handling of excessively dehydrated, delicate, and occasionally harmed vegetative samples can be exceptionally taxing and destructive. Consequently, Table 18 outlines the procedure that must be pursued.

Table 18 – Herbarium handling protocol (British Columbia Ministry of Forests, 1996; KSU Herbarium, 2002; RHS - Royal Horticultural Society, 2013; Wilken, 2009).

I.	Whenever feasible, please ensure the specimen remains affixed to the sheet and prevent any potential bending.
II.	To transport the specimen's folder from the storage cabinet to the examination table, use a rolling cart, a sturdy surface such as a plywood board or stiff cardboard, or a box.
III.	Always examine the specimen on a flat, sturdy, and horizontal surface, avoiding standing.
IV.	When stacking folders, be mindful of their weight to prevent damage to the specimens at the bottom.
V.	When carrying out microscopic observations, it is preferable to use a microscope equipped with task lights that can be attached to an adjustable arm (similar to a boom stand).
VI.	It is recommended to avoid flipping through sheets inside a folder. Instead, take out all the sheets together and analyse each one individually.
VII.	Ensure that mounted specimens are placed specimen-side up in the sheets and avoid turning them over.
VIII.	Finally, replace the specimen sheets in the same order as previously organized.
IX.	Before refiling, it is advisable to carry out a preventive conservation revision to identify pests, signs of pests, broken fragments, or incorrect labels. In certain institutions, regardless of the destination, loan period or use given to the sample, it is always subjected to a freezing process before it is refiled.
X.	It is not recommended to leave specimens outside of the cabinets in the herbarium room overnight because most herbarium beetles are more active during the night.

13. Discussion

The factors presented highlight, firstly, the undeniable necessity for clear, concise, and, most importantly, applicable preventive conservation policies when managing any type of collection, particularly those consisting of easily perishable organic materials. Secondly, they underscore the feasibility and effectiveness of these procedures, materials, and techniques for the preservation or disinfestation of such collections.

It is evident that preventive conservation now plays an essential role in the environmental and heritage sectors. The idea of preventing degradation before it occurs is no longer seen as applicable only to the most valuable works of humanity but as a standard practice for all that represents our built, cultural, artistic, and philosophical heritage.

In the context of xylaria and herbaria, the primary agents of degradation are insects and xylophagous fungi, which thrive when collections are stored in environments with fluctuating or consistently high relative humidity. However, other factors, such as not storing items in closed cabinets, also have a significant impact. Open storage facilitates insect access and exposes collections to photo-oxidation, increased absorption of environmental contaminants, and greater susceptibility to fluctuations in humidity and temperature. Additionally, less commonly mentioned factors like the adhesives or inks used for labels can cause significant acidification and subsequent degradation. Poor handling of collection items is often a primary cause of breakage and disintegration, particularly in herbaria.

To mitigate these issues, preventive conservation measures include ensuring the thorough drying of wood and other plant materials before their final storage. Specifically, for herbaria, using appropriate materials and techniques to mount specimens correctly on mounting cards can greatly reduce future degradation and maintain specimen integrity for future studies. Permanent humidity control mechanisms and continuous monitoring devices, such as sticky traps for crawling and flying insects, enable 24/7 surveillance of the storage environment and are among the most effective barriers currently available for collection conservation. However, this effectiveness is maximised only when accompanied by regular inspections of the storage space.

It becomes clear that these collections require continuous surveillance and control rather than curative measures alone. Despite preventive conservation measures not being excessively costly, their infrequent use raises questions. This may be attributed to ignorance and a continued reliance on outdated methodologies. Ultimately, there may be an unintentional and often unnecessary lack of updates among museum staff and curators.

Thus, it is evident that solving these problems involves acquiring the mechanisms and technologies discussed above. However, obtaining sufficient funding for cultural and scientific heritage is often as challenging as preventing occasional infestations. Consequently, promoting the preventive conservation of such collections across various institutions, primarily involves updating the methodologies and technologies used by staff and management; participation in conferences and online courses in order to reduce travel costs; inviting experts to identify and address key issues can enhance the institution's visibility and ease access to funds and support. Finally, focusing the funds available on the most cost-effective and efficient mechanisms is crucial. These include simple, inexpensive technology for permanent humidity control with weekly fluctuation records, the application of continuous monitoring devices with regular replacement of sticky traps, and, most importantly, regular inspections of these mechanisms and the overall space by institution staff.

14. Xylaria and Herbaria trends and future prospects

As far back as 1973, William L. Stern lamented the ongoing decline of institutional wood collections (Stern, 1973). The future trajectory of xylaria and herbaria collections presents however an intriguing and evolving narrative, since, historically, the vitality of most collections has been closely tethered to the commitment of one or more devoted researchers within a particular institution. With the departure of such researchers, activities and, at times, the very existence of the xylarium and herbarium have been imperilled. The reason for this, lays frequently in the undeniable difficulty of articulating the value of biocultural collections to the general public. Demonstrating the tangible benefits that stem from the resources and dedication invested in establishing, curating, and expanding such collections remains an ongoing hurdle for most scientists who advocate for them. However, recent societal developments have transformed this landscape for the better.

Concerning the case of xylaria, many venerable collections have witness closures or amalgamations. For instance, in the past 55 years, the Forest Products Laboratory (FPL) in Madison, WI, has absorbed the Yale University xylarium, the Chicago Field Museum xylarium, the Jessup wood collection, and the Houghton, Michigan xylarium (Wiedenhoeft, 2014). It is worth noting, however, that in certain regions of the world, particularly in Brazil, new xylaria are sprouting, suggesting that rather than an overall decline, we may be witnessing a shift in the epicentres of active xylaria (Wiedenhoeft, 2014).

With a growing emphasis on combatting illegal logging, species extinction and climate change, xylaria and herbaria has witnessed a growing in inquiries from botanists, historians, and federal law enforcement agents, seeking scientific expertise for all types of identifications. The strength of these identifications fundamentally hinges on the robustness of the reference collection underpinning them; hence, collections are central to ensuring scientifically sound forensic identification. Through such undertakings, it has become possible to enhance the recognition and appreciation of the scientific and societal value of a xylaria and herbaria. Demonstrating that a xylaria, with its seemingly unassuming assemblage of wooden blocks, and herbaria with its collection of old dried plants possesses tangible worth may serve as a means to elevate public awareness regarding all biocultural collections, thereby encouraging their meticulous curation, expansion, and preservation for posterity.

15. Conclusion

In conclusion, implementing measures to prevent degradation, decrease contamination risk, and limit the exposure of collected objects to degradation factors would lead to maintenance that is less demanding, restoration-focused, and consumes fewer time and economic resources for any collection, storeroom, or museum. Preventing or mitigating collection deterioration directly affects the scientific, cultural, and economic value of a museum institution. This is particularly crucial when managing storage areas with highly degradable and consumable materials, such as wood samples and dried plants.

Although producing a sturdy, scientifically-sound and future-proof xylarium and herbarium requires significant amounts of time, physical effort, and economic and material resources, it is crucial that the construction and structuring of this research tool conform to the necessary steps in order to achieve high-quality results.

Acknowledgements

We would like to acknowledge the Portuguese Fundação para a Ciência e Tecnologia (FCT) for the PhD grant (UI/BD/151009/2021) for José Luis Amorim Silva and for funding the Strategic Projects UID/EAT/0622/2016 of CITAR - Research Center for the Science and Technology of the Arts, Porto, Portugal

The authors report there are no competing interests to declare.

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