THE ACCELERATED DEGRADATION OF CONSERVED WATERLOGGED

WOOD

A Thesis

by

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ABSTRACT

There is a great deal of variation in conservation treatments for waterlogged wood. There is also a great deal of variation in the environments where the artifacts are displayed and stored. Accelerated testing could be used as a tool to determine the best treatment for an artifact in a given environment, to adjust the environment to suit the artifact, or as a comparative tool for new conservation treatments. Accelerated testing methods used by manufacturing industries may be too expensive to be commonly used by conservation laboratories, but it is possible for conservation laboratories to create their own accelerated testing chambers that yield accurate comparisons.

In this study, the author treats samples of archaeological waterlogged wood using PEG, freeze drying, and silicone oil treatments, then subjects the wood samples to four accelerated environments inside glass chambers. An "ideal" museum environment acts as a control, maintaining a temperature of 20–22°C (68–71.6°F), a relative humidity of 16%−20% using silica gel, and a lighting cycle of five days with light and two days without light; a museum with little environmental control is simulated by using a heated seedling mat to increase the temperature of the chamber to 28–30°C (82.4–86°F), increasing the relative humidity by adding 5 ml of water weekly, and has a lighting cycle of five days with light and two without light; outdoor storage building conditions are simulated by keeping the chamber in an oven programmed to maintain a temperature of 35°C (95°F), increasing relative humidity by adding 5 ml of water weekly, and limiting light; cool storage conditions are simulated by keeping the chamber in a refrigerator that

maintains a temperature of 4–6°C (39.2–42.8°F), maintaining a relative humidity of 16%−20% using silica gel, and limiting light. At all stages, dimensions and physical changes of each sample were recorded and each sample was photographed. The samples reacted to the accelerated conditions in a predictable way: the samples treated with PEG were the most reactive to increased humidity, the samples treated by freeze drying reacted to a lesser extent, and the samples treated with silicone oil did not visibly react. The resulting conditions of the samples prove that meaningful comparisons can be made between samples, even without the specialized weathering chambers used by industry.

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CHAPTER I

INTRODUCTION

The conservation of waterlogged wooden artifacts has been a concern in nautical archaeology since the inception of the field, as wet, deteriorated wood is quick to biodegrade. Though treatments such as bulking with polyethylene glycol (PEG) and freeze drying are the most commonly employed today, new treatments are researched on a regular basis, old treatments are revisited, and every treatment has a degree of variability depending on the state of the artifact and the desired use or display of it. Generally speaking, these treatments can prolong the life of the artifact for several decades if kept in a controlled environment. However, there is a great deal of variability in museum and storage environments, depending on age, location, and availability of funds, among other issues, and so not all facilities can maintain an ideal environment at all times.

Accelerated degradation testing is a method of materials testing that simulates and exaggerates the environment in order to observe the processes by which a material will degrade in a fraction of the time, thus saving companies both time and money. Though indoor weathering chambers could prove useful in comparing the efficacy of conservation techniques over time in a variety of environments, this method is cost prohibitive unless a laboratory performs these tests frequently enough to warrant the purchase of an accelerated weathering chamber.

By simplifying the methods employed in programming weathering chambers, it is possible for conservators to replicate the effects of weathering chambers in a cost- and time-efficient manner in their own laboratories. In this study, using equipment that can be easily and cheaply obtained, if not already present in a laboratory, waterlogged wood samples were subjected to three conservation treatments—bulking with PEG, bulking with silicone oil, and freeze drying—then subjected to four accelerated environments in order to test whether handmade weathering chambers could be an effective tool in conservation laboratories.

CHAPTER II

LITERATURE REVIEW: ACCELERATED DEGRADATION TESTING

Accelerated Degradation Testing in Industry

According to Nelson (2005:194), accelerated testing "consists of high stress testing that shortens product life, or hastens degradation of product performance…to estimate the life or degradation of the product at lower stress levels encountered in normal use." Over the past 100 years, accelerated testing has become a standard practice in industries such as food, building materials, sealants, and paints in order to provide both a qualitative comparison to other products and an estimated service life (Nelson 1990:6-8, Schulz 2009:10).

Accelerated testing is a general term, and publications tend to use different terms for the wide variety of accelerated testing. Accelerated weathering, or outdoor exposure, "uses the stresses arising from the natural environment" (Schulz 2009:64, Wypych 2008:117). "Elephant" testing involves a single severe level of stress on the samples, while environmental stress screening involves accelerated testing under a combination of stimuli that may include shock, vibration, and temperature (Nelson 1990:37-39). Ageing is the term most often used by paper conservators, who compare artificially aged samples to naturally aged samples or documents. Accelerated degradation is a type of overstress testing that focuses on "product performance as it degrades over time" rather than product life (Nelson 1990:17); this is the type of study described in this paper.

Accelerated degradation testing may be conducted using either of two methods: outdoor weathering or climatic chambers. Outdoor weathering sites use exposure racks equipped with tools such as "black boxes", sprays, and sun-tracking devices to intensify the effects of temperature and UV radiation (Wypych 2008:132-139). Climatic chambers can be programmed with light/dark, humid/dry, and hot/cold cycles with a wide variety of interchangeable instruments such as light sources and filters for the desired simulated climate (Wypych 2008:147-194). Both indoor and outdoor testing are valid, but weathering chambers do have an advantage in that the tests are replicable and can be completed faster than at outdoor weathering sites (Wypych 2008:147). In both cases, those who conducts the tests ensure that the environmental conditions are accelerated so as to decrease the amount of time needed to test a product, but not accelerated to such a degree that the conditions no longer correlate with natural conditions (ASTM G151-10: 685, Schulz 2009:152-153, Wypych 2008:223). However, even if a test does not correlate to natural conditions accurately enough to predict product service life, the test can be used to provide qualitative comparisons between products (Nelson 1990:16-22, 33, 37-43).

Accelerated Degradation Testing in Conservation

Few published works concerning the accelerated degradation of archaeological wood exist. This is not completely unexpected: wood, generally speaking, is fairly stable as long as it is not exposed to excess moisture. However, waterlogged wood, whether it comes from wet ground or a shipwreck, loses a great deal of internal structure that provides wood strength, and the treatments used to prolong the life of the weakened wood cannot perfectly preserve the artifact indefinitely, even under good conditions.

Accelerated degradation studies have been published for a fairly wide variety of archaeological and historical materials. Knight and Thickett (2007:85-88) have studied the effect of cycling high and low relative humidity on wood furniture, noting the formation and increasing size of cracks as the wood swells during humid cycles and shrinks during drying cycles. The accelerated degradation of epoxies and natural resins, widely used in conservation, has been studied using an accelerated climatic chamber to compare the performance of several natural resins (Heesters et al. 2002:55-63); using an oven and a climatic chamber to compare epoxy undergoing differing exposures to temperature and relative humidity (Frigione et al. 1993:888-893); and by using a fluorescent, UV-filtered light source alone to age resins and epoxies (Bilz and Grattan 1993:559-565). Turner-Walker (2011:18-22) used temperature exposure followed by failure testing on faunal bones to study post-mortem deterioration processes.

For many artifacts, the primary reason to conduct accelerated degradation tests is to study fading and discoloration, including objects that contain paint (Cohen et al. 2000,

Odlyha et al. 2000, Tantideeravit et al. 2013) or varnish (Hill et al. 1999), textiles (Carr et al. 2003, Ishii et al. 2008, Nilsson et al. 2010), and feathers (Solajic et al. 1993). In color-based studies, there is also a deeper component, central to determining the accuracy of accelerated degradation: studying the rate of natural fading and discoloration of various materials (Bacci et al. 1999, Bullock and Saunders 1999, Dupont et al. 2008, Del Hoyo-Meléndez et al. 2011, Pretzel 1999). Though plentiful, many of these studies are not applicable to waterlogged wood, or the purposes of this study: wood, without paint or varnish, is not easily discolored by light, and the purpose of this study is to determine the effect of the environment—relative humidity, temperature, and light—on the conserved waterlogged wood and its treatment.

The best examples to draw from to study the degradation of conserved wood are from the field of paper conservation. Accelerated ageing of paper has been studied since at least the late 19th century. Paper is highly reactive to the environment around it, often to the detriment of the material, and the information written and drawn upon it can be precious and unique; these characteristics leads to a situation where conservators need to know what causes degradation, how to prevent it, and to ensure that treatments do not lead to further deterioration. A benefit of studying paper is that there is a large supply of it, both historical and modern.

It has been known since at least 1899 that elevated temperature speeds the ageing of paper (Zervos 2010:31). Though a multitude of studies were conducted in the following decades (Porck 2000:16-18), a standard method of ageing paper was not written until 1963 (Porck 2000:14, Zervos 2010:31-32), though Porck (2000:14-15) notes that,

despite the existence of standards by associations such as the American Society for Testing and Materials (ASTM) and the Technical Association of the Pulp and Paper Industry (TAPPI), many institutions use their own individual standards. Regardless, before this point, the only constant in the tests was that elevated temperature was a variable, but that temperature ranged from 20°C–150°C (68°F–302°F), the oven used could be ventilated or unventilated, the samples sealed or unsealed, and both light and humidity were optional variables (Porck 2000:15-18). Standards have been added and revised in the years since to include moist ageing—as opposed to dry ageing, since water is a very important component to chemical reactions in paper, such as hydrolysis (Zervos 2010:31-32)—and ageing using sealed containers, which allow samples to react with products of chemical reactions produced by accelerated degradation and, presumably, natural ageing (Zervos 2010:32).

   At present, the most common maximums for accelerated ageing of paper are: 80°C (176°F) or 90°C (194°F) for humid ageing and 100°C (212°F) or 105°C (221°F) for dry ageing (Shahani 1995:4, Zervos 2010:12); the most common settings for relative humidity are 25%, 50%, and 65%; the most popular combination is 80°C (176°F) and 65% relative humidity (Shahani 1995:4, Zervos 2010:13). Climatic chambers can be used, but are not necessary: the "humid chambers" used by Reis-Menezes (2011:424) were simply hermetically sealed jars containing small amounts of either distilled water or saturated solutions of monopotassium phosphate (KH2PO4) in distilled water, which were then placed in an oven; Jablonský et al. (2014:109) sealed newsprint paper inside a composite foil bag, also placed in an oven, rather than glass tubes or jars.

Even though paper ageing studies have been conducted for over a century, there remains the question of whether ageing procedures correlate to natural ageing. There are two primary reasons for this: one argument follows the logic that because paper degradation involves a series of chemical reactions, elevated temperature, which speeds chemical reactions, may in fact fundamentally change the nature of the degradation process (Shahani 1995:3, Zervos 2010:5); another reasons that, because paper, both historical and modern, is complex and has differing compositions, no single standard can apply to all types of paper (Zervos 2010:5). To this end, from early in the study of paper ageing, there have been projects to store paper to be analyzed after a set amount of time: in 1980, Wilson and Parks published a study comparing artificially aged paper to paper that had aged naturally for 36 years, finding that some samples corresponded well to the artificially aged samples, and others showed more deviation (Porck 2000:21); in 1996, Zou et al. published a study comparing artificially aged lignen-free paper to lignen-free paper that had aged naturally for 22 years, showing good correlation. The question of correlation may not be answered very quickly: in 2000, the Library of Congress began the "ASTM/ISR Research Program on the Effects of Aging on Printing and Writing Papers," a 100 year natural ageing project during which 10 institutions will store 15 types of custom-made papers for 100 years, with periodic analysis of the papers conducted every 10 years (Zervos 2010:6). Though the answer to whether accelerated ageing corresponds to natural ageing may not be answered until a long-term study such as this is complete, that does not mean that accelerated testing is without merit. It is still

not possible to predict the life expectancy of paper, but it is possible to qualitatively

analyze paper and treatments, providing valuable information to conservators.

CHAPTER III

LITERATURE REVIEW: THE MUSEUM ENVIRONMENT

The primary responsibility of public museums is to allow for the display of their collections and safely store collections not presently on display. In order to fulfill this responsibility, the collections must be maintained to the best of the ability of the staff, which requires the maintenance of the museum environment in order to prolong the life of the artifacts. Guidelines have been developed over time, particularly since the development of HVAC (heating, ventilating, and air conditioning) systems beginning in the late 1800s (Erhardt et al. 2007:11; Legnér 2011). However, given the variety, age, and funding of buildings that are considered museums, it is impossible for any single set of guidelines to be applied in all buildings.

There are three factors that regularly affect artifacts, regardless of location: relative humidity, temperature, and light, which affect each other and are present in all museums. In addition to these three, there is also the problem of pest activity and pollutants, which are affected by humidity, temperature, and light, and which vary from museum to museum. The monitoring and control of these factors are part of the preventative conservation practices that all museums strive to accomplish, if with varying degrees of success.

Relative Humidity

Relative humidity is defined as "the ratio, expressed as a percent, of the absolute humidity of sampled air to that of air saturated with water at the same temperature" (MacLeod 1978:3). As defined, relative humidity is closely associated to absolute humidity and temperature, and the three are linked in a predictable manner, as illustrated in Figure 1. A relative humidity of 100% indicates that the air is saturated, holding the maximum amount of water. Warm air can hold a greater amount of water than cold air before it is saturated. According to Thomson (1986:68), "saturated air at 10°C holds about 10 g/m^3 moisture, at 20°C about 17 g/m^3 and at 30°C over 30g/m^3."
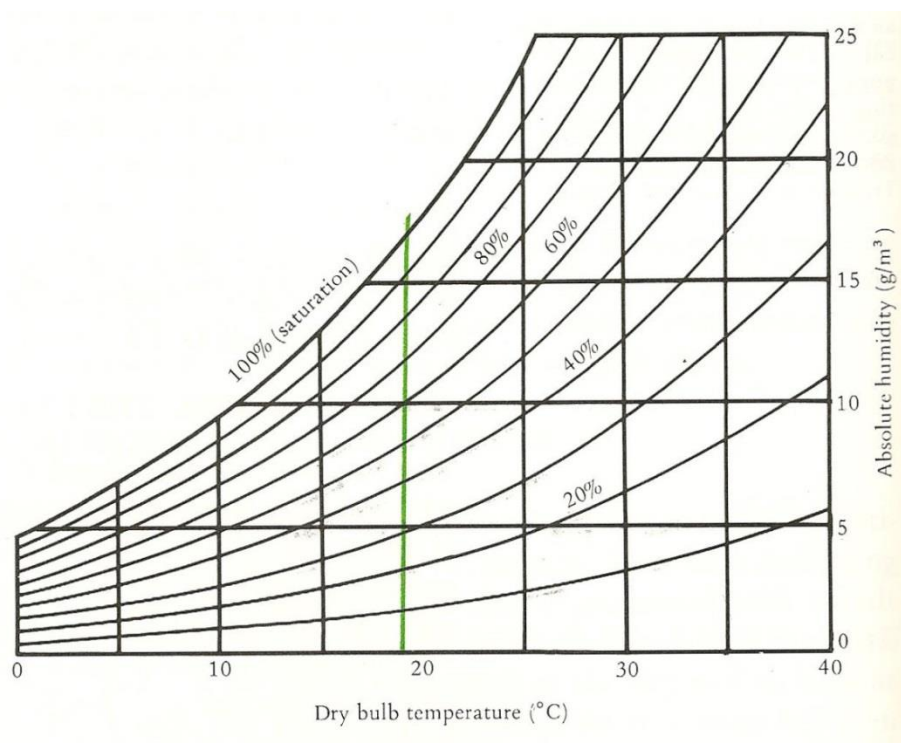

FIGURE 1. A simplified hygrometric chart (Thomson 1986:78)

Relative humidity is often not homogenous throughout a building, or even a room. This can be caused by several factors: stone walls tend to be cooler than the ambient temperature of a room, which has an effect on artifacts on or near the wall (Ligterink and Di Pietro 2007; Legnér 2011:130); improperly maintained or badly placed humidifiers or dehumidifiers (Ferdyn-Grygierek 2014:36); an HVAC system in use only during visiting hours (Bernardi 1990:171; Camuffo 2002:157-158). Interestingly, this last factor may lead to conditions where the museum microenvironment is actually more stable on days that the museum is closed (Camuffo 2002:160).

Visitors can also affect relative humidity. On a day that outdoor conditions do not cause sweating, a body will emit both heat and moisture, but the heat of many bodies in an exhibit area will increase the temperature slightly and lower, or maintain, the relative humidity (Thomson 1986:230). Relative humidity will remain at a certain level until the visitors leave, at which time the temperature will decrease, but the moisture remains; if ventilation or insulation are poor, or the walls are cold, condensation may occur (Thomson 1986:119-120, 230). This situation applies to fairly dry outdoor conditions; visitors that enter a museum damp from a rainstorm or humid conditions may not produce enough heat to negate the moisture they bring with them, inadvertently causing damage during and after their visit. This is the situation that caused further damage to the *Vasa* timbers. The rainy summer of 2000 combined with a greater number of visitors than the HVAC system could counterbalance led to fluctuating relative humidity (sometimes as much as a 10% change overnight) and is believed to have

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caused, in part, the "oxidation and migration of sulfur compounds, including sulfuric acid" (Sandström et al. 2003: 22; Hocker et al. 2012:178).

Relative humidity, whether high or low, has a negative effect on all ethnographic materials, but affects organic materials, such as wood, to the greatest degree. When relative humidity is too high, wood will absorb the excess water vapor, causing the wood to swell (Thomson 1986:82). If the wood is part of a composite artifact, the dimensional changes can affect other components; for example, a wooden frame that swells from moisture absorption can cause the canvas to stretch and paint to crack (Ligterink and Di Pietro 2007; Mecklenburg 2007:23). If left in a state of high relative humidity—typically cited as 70% or more—for a prolonged period of time, the excess moisture can lead to mold growth (Thomson 1986:86; Camuffo 2014:95). Organic materials naturally have a certain amount of water within them, and when relative humidity is too low, the loss of water from wood can lead to shrinking, cracking, warping, and brittleness; surface paint or consolidants may chip away (MacLeod 1978: 5-6; Thomson 1986:82-84). Whether a wooden artifact will respond to slow changes in relative humidity (such as the changing of seasons), or diurnal changes (such as those caused by turning off an HVAC system during closing hours) depends on the "thickness, surface geometry and orientation with respect to the axis of the tree" (Knight and Thickett 2007: 86).

It is important to maintain a balance between the two extremes, since it is when relative humidity changes from high to low that the greatest amount of damage occurs. To this end, most sources recommend maintaining relative humidity between 40% and 65%, advising that the smaller the range in relative humidity, the better the condition of

the collection, with exceptions made for more delicate or unstable artifacts (Thomson 1986:87; Erhardt et al. 2007:15; La Gennusa et al. 2008:126-127). Thomson (1986:88-89) states that in some cases, it may be best to maintain relative humidity as close to outdoor conditions as possible (while remaining below 70% relative humidity), as the timbers and ethnographic objects are already accustomed to that relative humidity, and money can be saved.

Museums use a variety of methods to maintain a steady relative humidity. HVAC systems are used in most new buildings and some historic buildings. If a building cannot be renovated to accommodate an HVAC system, portable humidifiers and dehumidifiers are commonly used (Camuffo 1999:236; Camuffo 2002:156; Worobiec et al. 2008:100; Ferdyn-Grygierek 2014:34), and most historic buildings were built with open ventilation in mind; for example, since its completion in 1504, the microclimate in the Malatestiana Library in Cesena, Italy has been maintained solely through the opening and closing of windows (Fabbri and Pretelli 2014:16-17). Porous building materials such as wood, brick, and plaster can act as buffers to humidity changes (Camuffo 2001:137); silica gel (Thomson 1986:108-109; Bosshard 1994; Stolow 1994:93-94) and agricultural products such as rice (Kamba 1987), both of which react to changes in relative humidity faster than wood, can easily be implemented in display cases.

Temperature

Temperature alone can affect and speed up any chemical and biological processes that may be occurring in an artifact (Thomson 1986:43-44; Schulz 2009:45), and it is for this reason that most artificial degradation studies concerning artifacts or conservation use increased temperature as a variable. The temperature "safety zone" is between 55−74°F (12.78−23.33°C), above which chemical activity increases, and below which many plastics, varnishes and paints lose mechanical stability; this does not imply that an artifact will always maintain stability between these temperatures (Camuffo 2014:15-17).

As described above, temperature affects relative humidity: as air temperature increases, the relative humidity decreases. For example, a study by Maekawa and Toledo (2002) proved that using heaters to decrease relative humidity in tropical areas is just as effective as, and cheaper than, installing an entire HVAC system since the heaters need only run for short periods. In studies that apply to climates with cold winters (Bernardi 1990: 171, 180; Legnér 2011:126, 130), the use of heating elements without the use of humidifiers is discouraged (Thomson 1986:119-120).

Though temperature has an effect on artifacts and relative humidity, it is also one of the least contentious aspects of maintaining the museum environment: from the beginning, it has been acknowledged, often to the dismay of conservators, that the temperature in the administrative and public parts of museums are maintained within human comfort levels (Bordass 1994:10; Erhardt et al. 2007:13; Camuffo 2014:7-8), so

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it would be exceedingly rare for a public area to be heated much above human comfort levels even though this would efficiently lower relative humidity in tropical climates, or for air to be cooled below human comfort levels even though this could better preserve some artifacts such as paper or photographs by slowing down chemical reactions.

Light

Light is a necessity to view collections, but exposure to light—specifically, UV rays—causes fading and discoloration, and though all artifacts can be affected by light, it is of particular concern to museums that display paintings, paper and textiles. The extent of degradation depends on: the intensity of light, exposure time (damage is cumulative), the spectral characteristic of the light, and the capacity of the material to be affected by light (Carver 1994:74). Light degradation can also be influenced by temperature, relative humidity, and pollutants (Carver 1994: 74).

There is no single lighting schema that every museum follows, though studies have led to basic guidelines, such as the use of UV filters. In order to slow fading due to light exposure, Lafontaine (1980:9) and Turner (1980:34-35) suggest a maximum value of 50 lux to illuminate sensitive objects, and 150 lux for stable objects; and this figure continues to be repeated over time, though the maximum is often adjusted to 200 lux (Thomson 1986:23; Turner 1998:44; Illuminating Engineering Society of North America 1996:14; Camuffo 2014:159). Turning off lights after visiting hours, using sensors to turn on lights only when a visitor is in an area, rotating collections between display and

storage, filtering and limiting daylight, and the use of replicas are common methods of reducing light exposure (Thomson 1986:37-38).

The extent to which wood is affected by light is a complex issue: Schaeffer (2001:64-66) cites several studies of light exposures on different species of wood, with each species showing varying levels of change, restricted to the surface of the wood; however, she notes, no studies have been conducted on wood that has been treated with waxes, resins, or other coatings, which are far more likely to be affected by light than the wood itself. Thus, the primary concern for wood in relation to lighting is the heat, and therefore drying effect, produced by lamps and natural light (Thomson 1986:44). Fortunately, as technology develops, more lighting sources are available that emit less heat, such as fluorescent bulbs and LEDs, or reflect heat to the rear of the lamp, such as dichronic reflector lamps (Carver 1994:79-82; Turner 1998:48).

Pests and Pollutants

Artifacts are constantly influenced by humidity, temperature and light, regardless of the location of the museum or storage facility. Degradation can also be caused by pests and pollutants, which can vary both by location and by season.

Pests such as insects cause immediate, obvious damage to artifacts: they eat artifacts, particularly organics. For a description of the most common insects found in museums, as well as their habitats and damage to artifacts, see Szent-Ivany (1967:53-65), Pinniger (1994), Hillyer and Blyth (1994:217-220, 229-232), and Pool et al. (2005:

5-10). The human reaction to pests can be damaging as well, as the use of biocides, most of them toxic chemicals, is one of the few effective methods of pest control; biocides are commonly used in the form of sprays and fumigants, which may travel through the air to the surface of artifacts (Szent-Ivany 1967:53-54; Entwistle and Pearson 1994; Hillyer and Blyth 1994:219, 222-223).

Pollutants—airborne particles, fungi, bacteria, pure elements, and various compounds—vary in composition and concentration depending on location and season. Many are produced through burning, so the air in an industrial or heavily trafficked city has a greater concentration of pollutants than the air in a rural town; likewise, more pollutants may be present in winter months, when greater amounts of fuel are burned for heat. In most cases, pollutants originate from outside air—the most common being sulfur, nitrogen oxides, and ozone (Grzywacz 2006:2)—entering the museum through windows and doors, ventilation systems, and on visitors' clothing and shoes (Worobiec et al. 2008:102; Krupińska et al. 2012:53; Fabbri and Pretelli 2014:18); the simple act of walking through exhibit halls can cause particles that have already settled to re-suspend (Camuffo 2001:137, 138, 139; Yoon and Brimblecombe 2001: 237-239). These pollutants can all be produced through the act of burning fuel, and so can also be produced indoors by candles, fireplaces, and ovens, and both nitrogen dioxide and ozone can be produced by equipment that generates strong electric fields (Thomson 1986:149-151; Grzywacz 2006:3, 97-105). Other common indoor-generated pollutants that can pose a risk to artifacts include "acetic acid, formic acid, acetaldehyde, formaldehyde, hydrogen sulfide, carbonyl sulfide, and ozone" (Grzywacz 2006:2-3, 97-105). These

pollutants may be introduced by building materials, exhibition case materials, or even artifacts themselves, as explained in the example below, that off-gas and can affect artifacts in a variety of ways including corrosion, discoloration, embrittlement, and cracking (Baer and Banks 1994:136-138, 140-143; Grzywacz 2006:11-19).

Sulfur on its own is fairly innocuous, but can combine with oxygen in the air to form sulfur dioxide, a weak acid; it can then combine with oxygen again to form sulfur trioxide and further combine with water molecules to form sulfuric acid; these reactions can take place in the air or after deposition (Thomson 1986:136-139). Even as a weak acid, sulfur dioxide affects, to varying degrees, most ethnographic materials, from marble statues to wood to iron (Thomson 1986:138-147). Recent uses of sulfur are widespread: it has been used as an adhesive, an electrical insulator, and a component of Plasticine and other modeling clays (Benson 2012: 175, 186, 197). Sulfur can also enter a museum as part of an artifact: it was used as a strengthener in Roman and Byzantine hollow gold jewelry; as inlay material with an appearance similar to mother-of-pearl; and in the creation of Ebonite, first made in 1839, used to make a variety of objects (including smoking pipe, clarinet, and saxophone mouthpieces, buttons, and buckles), and often mistaken for plastic (Benson 2012:179, 184, 193). The most famous example of sulfur entering a museum inside an artifact is the *Vasa,* which is now being slowly destroyed by the same elemental sulfur, sulfur salts, and sulfur acids that preserved it for centuries (Sandström et al. 2003:22-28, 38-43). The *Vasa* is not the only ship to contain sulfur in its timbers: the Viking ships of Skuldelev in Denmark, the *Batavia* in the

Western Australia Maritime Museum, and the *Mary Rose* in Portsmouth, among others, all contain trace amounts of sulfur (Sandström et al. 2003:43).

Pests and pollutants are affected by relative humidity, temperature, and light in that, though they exist throughout the world, both tend to thrive in warm to moderate, humid climates (Pinniger 1994:6; Camuffo 2001:137; Camuffo 2014:95). In fact, submitting artifacts to extreme temperatures, or extremely low relative humidity (less than 10%), are among the few methods of non-toxic pest and mold control (Hillyer and Blyth 1994:224-228; Pinniger 1994:36-39; Pinniger 2003:11). However, maintaining buildings at such low temperatures and relative humidity is economically unfeasible and outside the interests of human comfort and the wellbeing of the artifacts, with exceptions for some artifacts such as documents and photographs (Adams 2008:24). It is best to ensure that degradation is not actively encouraged by setting the upper limits of temperature and relative humidity to 23°C (73.4°F) and 70%, respectively.

The presence and elimination of pests and pollutants is a complex issue that must be dealt with on a case-by-case basis. In most cases, as long as staff maintain a clean environment and monitor the artifacts and facilities carefully, the presence of pests and pollutants are minimal.

CHAPTER IV

TREATMENT OF WOOD SAMPLES

Characterization of the Wood

The wood samples used in this study were obtained from two fragments of wood without provenience from *La Belle,* a French ship that wrecked in Matagorda Bay, off the coast of Texas, in 1686; the cut and size of the wood suggests that they were part of the oak barrels that carried various trade goods and liquids (Bruseth and Turner 2005:83-84). Fragment A was divided into nine roughly equal samples, and Fragment B was divided into five roughly equal samples (Figure 2). Exact dimensions of the samples are provided in Table 1. One sample from each was weighed and then oven dried to establish the percent of water in the wood as an indication of the degree of degradation using the following formula:

$$\% \text{ water} = \frac{\text{Weight of wet wood } - \text{ weight of oven-dried wood}}{\text{Weight of oven–dried wood}} \times 100$$

Fragment A contained 784.61% water. Fragment B contained 1411.11% water. Both can be categorized as Class I, a category of waterlogged wood containing at least 400% water (Grattan 1987:64-67, Hamilton 1999:24, de Jong 1977).

The twelve remaining wood samples were divided into three treatment groups: bulking using polyethylene glycol (PEG); bulking using PEG, followed by freeze drying; or bulking using silicone oil. This treatment period lasted six weeks.

FIGURE 2. *Top,* Fragment B. *Bottom,* Fragment A (photo by author, 2013)

TABLE 1
DIMENSIONS OF WOOD SAMPLES BEFORE AND AFTER TREATMENT.

Treatment	Pre-Treatment Radial Dimension (mm)	Post-Treatment Radial Dimension (mm)	Percent Change	Pre-Treatment Tangential Dimension (mm)	Post-Treatment Tangential Dimension (mm)	Percent Change	Pre-Treatment Weight (g)	Post-Treatment Weight (g)	Percent Change
PEG1	48.40	49.91	3.12	8.90	9.64	8.31	17.40	11.40	35.74
PEG2	58.20	57.29	1.56	9.10	8.42	7.47	16.30	11.00	32.52
PEG3	46.20	47.75	3.35	9.40	8.25	12.23	15.30	9.30	39.22
PEG4	57.50	56.64	1.50	11.90	10.40	12.61	18.90	13.10	30.69
FD1	57.90	53.79	7.10	8.67	5.75	33.68	19.50	4.20	78.46
FD2	54.30	47.83	11.92	9.35	5.85	37.43	22.10	5.80	73.76
FD3	50.90	45.15	11.30	9.80	6.35	35.20	20.90	5.50	73.68
FD4	60.05	54.03	10.02	9.65	6.19	35.85	21.40	7.10	66.82
SO1	52.10	49.28	5.41	10.20	10.04	1.57	21.10	15.50	26.54
SO2	56.30	53.22	5.47	9.90	9.07	8.38	22.10	14.80	33.03
SO3	55.40	52.48	5.27	12.40	11.66	5.97	22.20	17.00	23.42
SO4	48.00	46.65	2.81	10.40	9.42	9.42	19.10	13.00	31.94

Note: Longitudinal dimensions excluded. Percent change of longitudinal dimensions are less than 3%.

Treatments

Polyethylene Glycol

As wood degrades in water, water-soluble bonding substances within the wood, such as sugars and starches, are leached; eventually the cellulose that provides structure to the cell wall disintegrates, leaving only the lignin network, which will also eventually disintegrate. Water replaces the substances and structures that upheld the integrity of the wood, weakening it. Impregnation of wood using polyethylene glycol (PEG) is a process by which the water content within degraded wood is slowly replaced with PEG, a wax–like substance which can be liquid or solid at room temperature, depending on the molecular weight: the greater the molecular weight, the more solid PEG is at room temperature. For this treatment, PEG is added to water in small increments until the PEG has replaced the water content; though uncommon, organic solvents such as alcohol or ethanol may be used. The wood is removed from the PEG solution and allowed to air dry; the PEG remains within the wood and acts as a bulking agent, with only minor changes in dimension and weight.

The wood samples were placed into a solution of 50% deionized water and 50% acetone; the acetone acts as a biocide and allows for faster penetration of the PEG into the wood (Hamilton 1999:25). The container was kept in an oven at a temperature of 60°C (140°F). It is generally recommended to maintain the oven at 52°C (125.6°F), but the increased temperature was chosen in order to speed up the bulking process, which

can, in some cases, take months to complete. A container of PEG3350 was also kept in

the oven so that it could be added to the solution as a liquid and allow for easier mixing.

PEG3350 was added in increments of 2% (by volume) every day until it reached a 10%

solution of PEG3350. Following this, PEG3350 was added in increments of 5% (by

volume) every two days until 75% saturation was achieved, then the lid was removed

from the container, allowing the remaining water to evaporate. At the end of the six

week treatment period, the wood fragments were removed from the PEG3350, lightly

rinsed in warm water to remove excess PEG, and allowed to air dry. Table 1 displays the

changes in dimensions of the wood samples treated with PEG. Treating wood with low

molecular weight PEG commonly causes an increase in weight, while higher molecular

weight PEG replaces the weight of the water it displaces. The decrease in weight noted

here may be accounted for by the loss of some material while in treatment due to the

highly degraded nature of the wood, or by an excess of water when the sample was

weighed prior to treatment.

Freeze Drying

Freeze drying is a process by which a waterlogged object is first frozen, and then

placed under a vacuum. The frozen water sublimates so quickly that the wood undergoes

little change in dimension, though becomes significantly lighter than other treatments.

Although wood can be placed directly from a water bath into a freeze dryer, pre-treating

with a low molecular weight PEG is almost always used prior to freeze drying because

this additional step can not only eliminate the growth of microorganisms, but can also greatly decrease the possibility of cracking due to ice crystal formation in the cells of the wood (Grattan and Clarke 1987:174, Hamilton 1999:28).

The wood samples were placed into a solution of 50% deionized water and 50% acetone to act as a biocide and to allow for faster penetration of the PEG; the container was kept in an environmental oven at a temperature of 60°C (140°F). PEG400 was added in increments of 2% (by volume) every day until it reached a 10% solution of PEG 400. PEG3350 was added in increments of 5% (by volume) every two days until a 15% solution was achieved. These wood fragments remained in the solution for two weeks before being removed, rinsed briefly in warm water to remove excess PEG, patted dry and placed in a freezer in a sealed bag for 24 hours before being placed in a freeze dryer. At the end of the freeze drying cycle, excess PEG was removed with a soft paintbrush.

Table 1 displays the changes in dimensions of the wood samples treated by freeze drying. Though the dramatic change in weight is expected for freeze drying treatments, the decrease in tangential and radial dimensions has several possible explanations. The decrease may be due to error during the bulking or freeze drying process. The samples originated from Fragment A, which, though not as degraded as Fragment B, were still very weak; it is possible that, with only 25% PEG to act as bulking material, the vacuum in the freeze dryer was too powerful for the degraded wood structure. The decrease in longitudinal dimension may be due in part to the loss of material during the treatment process.

Silicone Oil

Bulking using silicone oils is a process by which polymer chains bind to the carbonols on the cell surfaces of the wood through the aid of a crosslinker and stabilized by a catalyst (Klosowski 2003:ix). For best results, water must first be completely removed using baths of organic solvents. Silicone oil is mixed with a silane crosslinker such as methyltrimethoxysilane (MTMS). This solution can be applied topically, by immersion, or if the artifact is strong enough, immersed and placed under a low vacuum. When the solution has fully penetrated the artifact, excess is wiped off the artifact and the artifact and a small tray of a liquid catalyst such as dibutyltin diacetate are placed together in an airtight container, allowing the silicone oil solution to solidify relatively quickly. This treatment is irreversible, but extensive testing of many polymers concludes a service life of at least 250 years (Smith 2003:68).

The wood samples were dehydrated in successive baths of 50% deionized water and 50% ethanol, then 100% ethanol, then 100% acetone. They were then placed in a solution of Q1–3563 silicone oil and 10% (by volume) methyltrimethoxysilane (MTMS). The solution was kept under a weak vacuum for 24 hours. The fragments were removed from the solution, the excess silicone oil removed using dry paper towels, and the fragments placed in a closed container with 10ml dibutyltin diacetate (DBTDA) in an oven set at 50°C (122°F). The container of DBTDA was replaced every 24 hours until the silicone oil set completely three days later. Table 1 displays the changes in

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dimensions of the wood samples treated with silicone oils. The decrease in weight noted here is expected; some may be partially accounted for by the loss of some material while in treatment due to the highly degraded nature of the wood.

CHAPTER V

ACCELERATED DEGRADATION STUDY

Chamber Setup

Four accelerated micro environments that artifacts may be subject to in a museum or storage area were simulated and accelerated for the purposes of the study: a Control environment, representing a museum, or display case, that can fully control the environment; a Variable environment, representing a museum that cannot fully control the environment; a Cool Storage environment, representing the cool, dry storage environment commonly used for archival materials and some three dimensional objects; and an Outdoor Storage environment, representing storage spaces in warm, humid climates with little to no means of regulating the environment. This variety of testing conditions allows for temperature, relative humidity and light to be evaluated both individually and as interacting forces using a minimal number of testing chambers.

There is no prepared set of standards for the accelerated testing of conserved archaeological materials. As such, the author followed as closely as possible the guidelines given in American Society for Testing and Materials (2010) standard G151, which provides guidelines for accelerated testing of nonmetallic materials using laboratory equipment. Similarly, as most lighting standards refer to UV-emitting lamps, the author referred to ASTM (2010) standard D4674-02a, which provides guidelines for testing plastics in indoor office conditions.

The setup for each chamber was the same: the wood samples were placed on clear, perforated acrylic stands inside clear glass aquariums measuring 10in x 5in x 8in. The conditions within each chamber were monitored by a digital AcuRite brand thermometer and hygrometer. Each chamber was set up and monitored without samples for one week in advance of the study in order to determine expected ranges and make any changes necessary to the chambers. Once the samples were placed in the chambers, an effort was made to ensure that their positions were maintained, so that they were placed in the same order on the stand, and with the same side facing upward. Artifacts in museums are often left in the same position for years; maintaining the position of the samples reflects that, and allows for the comparison of the two sides.

Chamber 1: Control

This environment was based on what for many years had been considered the ideal museum environment, as described by Thomson (1986: 84-85) and more recently

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Hatchfield (2011:42) as a relative humidity of 50% ± 5% and temperature of 21°C ± 1°C (69°F ± 1.8°F)

The chamber was subject to as little acceleration as possible. The samples were exposed to the ambient temperature in APRL which, over the course of a week, measured between 20–22°C (68–71.6°F). Because atmospheric conditions caused the relative humidity to change drastically within the week of monitoring, sachets of DriSplendor silica gel were placed in the chamber to maintain a steady relative humidity between 16%–20%; the silica gel was replaced once it reached its saturation point, indicated by a change in the color from blue to pink. A cool white fluorescent lamp was positioned over the chamber; the light remained on for five days and off for two days for the duration of the study in order to reflect the cycling of lights at museums for open and closed hours. The light cycling also allows for "critical dark reactions" (ASTM G151 2010:692) to occur, though it should be noted that some consider dark phases to be wasted time in accelerated testing (Schulz 2009:132). To limit influence from external lighting, the window blinds were closed and the ceiling lights turned off when the room was not in use.

Chamber 2: Variable Environment

This chamber was set up to replicate conditions for museums that are not able to maintain perfect environmental control. Several sources state that a temperature between 15°C (59°F) and 25°C (77°F) (human comfort levels) and a relative humidity between

40% and 60% is an allowable annual range to prevent both bacterial growth and embrittlement, though the goal remains to maintain the temperature and relative humidity in the tightest range possible (Thomson 1986:86-87, Erhardt 2007:15, Hatchfield 2011: 52).

In order to increase the temperature, the chamber was placed on a Viagrow Seedling Mat, which maintains a temperature of 6–8°C (42.8–46.4°F) above ambient room temperature. Over the course of a week, the temperature of the chamber measured between 28–30°C (82.4–86°F). To cause temperature fluctuations, the mat could be removed and the temperature of the chamber would return to the ambient temperature in APRL; for simplicity, the mat remained in place for the duration of the experiment. In order to replicate changes in humidity due to weather and visitors, 5ml of water in a small tray was placed in the chamber weekly; because the small size of the chamber did not allow for the water to be kept an equal distance from all samples, the location of the tray of water changed weekly so that a single sample was not affected more than the other samples. A cool white fluorescent lamp was positioned over the chamber; the light remained on for five days and off for two days for the duration of the study. To limit influence from external lighting, the window blinds were closed and the ceiling lights turned off when the room was not in use.

Chamber 3: Outdoor Storage

This chamber was set up to replicate storage in a location with a warm, humid climate without environmental controls. Public spaces within museums are usually maintained at a temperature within human comfort levels (Erhardt 2007), hence Hatchfield's (2011:52) recommendation of 15–25°C (59–77°F); storage areas do not necessarily need to meet this standard. To determine a reasonable accelerated temperature, a warehouse building located on the Texas A&M Univeristy Riverside Campus in Bryan, Texas was monitored for one week, with an average temperature of 30°C (86°F) and average relative humidity of 64%. The chamber was placed in an oven and kept at a temperature of 35°C (95°F). In order to simulate changes in humidity due to weather, 5ml of water in a tray was placed in the chamber weekly. Light exposure was limited to the time removed from the chamber for weekly photographs.

Chamber 4: Cool Storage

This chamber was set up to replicate cool storage rooms, most often used to preserve documents on paper, parchment, and similar writing materials, but which can also contain three dimensional artifacts. Cool storage rooms are recommended to maintain temperatures between 10–15°C (50–59°F) with a relative humidity between 30%–50% (Michalski 2000:6, Adams 2008:24). The chamber was placed in a refrigerator and kept at a temperature between 4–6°C (39.2–42.8°F); silica gel

maintained a relative humidity between 16%–20% in the chamber, and was replaced when saturated, as indicated by a color change from blue to pink. Light exposure was limited to the time removed from the chamber for weekly photographs.

A Note on Relative Humidity

In both Chamber 1 and Chamber 4, the silica gel used to regulate relative humidity takes the relative humidity much lower than recommended for either environment. However, in this case, the priority was to maintain a steady relative humidity, which could not be maintained without the use of silica gel. Further, as described in Chapter III, researchers often state that relative humidity below 30% causes artifacts to become brittle; using such a low relative humidity in two chambers allows for the testing of this statement as it applies to wood.

Deionized, or otherwise purified, water was considered as the agent to increase the humidity in Chamber 2 and Chamber 3; ultimately, tap water was chosen. ASTM G151 (2010:693) advises against removing pollutants from the chambers, as their removal could end with unrealistic results. As described in Chapter III, there is too great a variety of pollutants that can affect artifacts in museums and storage to account for them in this study, though it can be assumed that pollutants are present. It is realistic to expect that moisture in museums and storage would have impurities, and it would be unrealistic to remove them for this study.

Documentation

Each wood sample was evaluated by a series of objective and subjective tests. Prior to accelerated testing, each sample was photographed. The maximum length, width and thickness of each sample were measured and each sample was weighed. The color was evaluated using Munsell Color Charts.

Determining the strength of samples often results in their destruction, since many tests, such as "Elephant Tests" (Dodson and Schwab 2006:179) are designed to precipitate failures. In order to test the strength of the samples without breaking them, a modified test based on the Pilodyn (FIGURE 3), a test that measures the density of the wood at the surface in particular, was used. In a normal Pilodyn test, a striker pushes a needle into the wood with a set force and the resistance is measured on a scale attached to the Pilodyn (Tannert et al. 2013:780). The Pilodyn has previously been used successfully in archaeological investigation: the condition assessment for the hull of the *Mary Rose,* a Tudor ship that sank in 1545 and was discovered in 1971, was conducted using the Pilodyn, though the authors do not recommend its use for samples of a thickness less than 40mm, since it is impossible to predict how far the needle will penetrate (Clarke and Squirrell 1985:182). For this study, in a simplified version of the Pilodyn test, a needle was inserted into each using a small amount of force to test the hardness. A three point system was used to rate the hardness of each sample: (1) Needle can pass through entirety of sample; (2) Needle can pass through surface of sample; (3) Needle cannot penetrate sample.

FIGURE 3. Pilodyn 6J Standard with its component parts (Tannert et al. 2013:781).

Once accelerated testing began, photographs were taken every week, and any physical changes were noted. Temperature and relative humidity were recorded daily, and the thermometers and hygrometers reset daily to record new data.

At the end of testing each sample was photographed. The maximum length, width and thickness were measured and each sample was weighed. The color was evaluated using Munsell Color Charts. A needle was inserted into each using a small amount of force to test the hardness.

For this kind of study, some changes to the samples are directly due to the conditions of the chambers. However, some change may be due to human or equipment error, such as not taking a measurement in exactly the same place as at the beginning of the study, which may occur due to the irregular shape of the samples. For that reason, to

be deemed significant, dimensional changes to the samples must be greater than 1.0 mm

and weight changes greater than 0.1 g.

Results

Environmental Data

The chambers were maintained at their target environmental settings throughout

the study, with a few particularly high or low numbers that may be considered outliers

(Table 2). In Chamber 1, the relative humidity spiked at 28% for one day when the silica

gel needed to be replaced; with the exclusion of this day, the relative humidity remained

constantly at 16%. The relative humidity in Chamber 4 generally stayed between 22%

and 28%, but occasionally rose 10% or more above that; this may be due to the contents

of the refrigerator and the frequency with which the door was opened.

TABLE 2
TEMPERATURE AND RELATIVE HUMIDITY DATA.

Chamber	Temp. Min. (°C)	Temp. Max. (°C)	Temp. Average (°C)	RH Min. (%)	RH Max. (%)	RH Average (%)
1: Control	18	23	20.358	16	28	16.142
2: Variable Env.	25	32	28.376	16	84	47.3935
3: Outdoor Storage	33	37	35.629	27	93	66.505
4: Cool Storage	2	6	4.3125	22	46	28.125

PEG-Treated Samples

Prior to placement in the accelerated degradation chambers (Figure 4), the samples were given a hardness rating of 2. The color was Munsell 10YR 3/3 Dark Brown. The samples were dry to the touch, with a slight waxy feeling.

Chamber 1: Control

No perceptible change occurred in the PEG–treated samples during the 12 week testing period that could definitely be attributed to the chamber conditions. In the first week, three small fragments flaked off the PEG sample; together they weighed approximately 0.1g. Though the dry conditions within the chamber may be the cause, it is most likely that these fragments were loose prior to placement in the chamber and handling the sample for photos caused them to fall off. Light did not cause a perceptible change to the wood or PEG during the 12 week period. At the end of the 12 week period, there was no significant change in dimensions. However, there was a slight decrease of 0.3g in weight; this may be at least partially due to loss of small fragments as mentioned above.
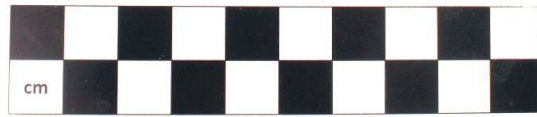
FIGURE 4. Samples treated with PEG, obverse and reverse. (Photo by author, 2013.)

Chamber 2: Variable Environment

Only one significant change occurred to the sample during the testing period. Beginning in Week 6, the sample became damp and slightly sticky when handled, as PEG began to perspire due to temperature and humidity. Each week, when the humidity dissipated, the sample dried; when humidity was reintroduced, the sample became damp and sticky again. This repeated for the remainder of the testing period. The tactile change was accompanied by a slight darkening of color (Figure 5). At the end of the testing period, there were no significant dimensional changes, but the sample had decreased in weight by 0.9g. Some residue remained on the stand and the floor of the chamber, leading to the conclusion that the loss of PEG is accountable for some of the weight loss.

FIGURE 5. *Above*, sample PEG2, Week 1. *Below,* sample PEG2, Week 6. (Photo by
author, 2013.)

Chamber 3: Outdoor Storage

The greatest amount of change occurred in Chamber 3, beginning early in the study.

At the end of Week 2, a white smudge appeared where the sample was handled as it was removed from Chamber 2 for the weekly photos (Figure 6). This smudge was likely caused by the powder in the latex glove clinging to the damp PEG on the surface of the sample.

The photos for Week 3, Week 4, and Week 5 (Figure 7) show the sample becoming darker—presumably as moisture is absorbed and the PEG begins to perspire— but the white smudge remains visible. Despite changes in color, the sample felt dry and waxy as in the beginning of the study.

FIGURE 6. Sample PEG3, Week 2. (Photo by author, 2013.)

FIGURE 7. *Above,* sample PEG3, Week 4. *Below*, sample PEG3, Week 5. (Photos by author, 2013.)

At the end of Week 6, the sample further darkened to Munsell 10YR 2/1 Black and both looks and feels wet and sticky (Figure 8). During the following week, as relative humidity decreased, the wet appearance faded, though it never completely returned to the original appearance. When moisture was added to the chamber during Week 7 and Week 8, the sample became wet and sticky again, indicating the degree to which the shift in relative humidity affects PEG treated wood.

FIGURE 8. Sample PEG3, Week 6. (Photo by author, 2013.)

In order to determine whether the temperature or humidity was the greatest factor in the change of the sample, water was not added to the chamber for the following two weeks. The sample began to dry and to lighten in color, beginning at the edges, until the

majority of the sample lightened to 10YR 8/4 Medium Yellow Gray Brown during Week

10 (Figure 9). In addition to the dramatic color change, the sample also appeared to the

eye to be crumbling; though much dryer, and without a waxy feel on the surface, it was

not brittle when handled. White deposits appeared—likely crystallized PEG—as well as

small dark spots, which may be mold that may have been present earlier in the study, but

could not be seen on the darker wood.

FIGURE 9. Sample PEG3, Week 10. (Photo by author, 2014.)

When water was reintroduced to the chamber in Week 11, the color began to

darken again, and the white deposits decreased. At the end of Week 12, the sample was

dark and wet as it had been during Week 6, Week 7, and Week 8.

The sample was removed from the chamber and allowed to stay in the ambient laboratory environment for one additional week (Figure 10). The color changed to 10R 3/6 Moderate Reddish Brown, and the smudge noted in the first weeks was still noticeable, as well as a few white deposits. The black spots were not visible.

At the end of the study period, there was no significant change in dimensions; however, sample PEG3 decreased in weight by 0.7g, in comparison to the control which decreased only 0.3g. While some of the decrease in weight may be due to loss of small fragments, some may be due to loss of PEG as it reacted to the humidity and leached out of the wood and deposited on the stand and surfaces below it.

FIGURE 10. Sample PEG3, Week 13. (Photo by author, 2014.)

Chamber 4: Cool Storage

No significant change occurred in Chamber 4. The sample remained dry with no color or tactile changes throughout the study period. Small fragments did fall off the sample when handled; as in Chamber 1, this could be caused by dry conditions, or simply by brushing against loose fragments when handled for photographs.

Freeze Dried Samples

Prior to placement in the accelerated degradation chambers (Figure 11), the samples rated a hardness of 2. The color was Munsell 10YR 6/3 Pale Brown. The samples were dry to the touch.
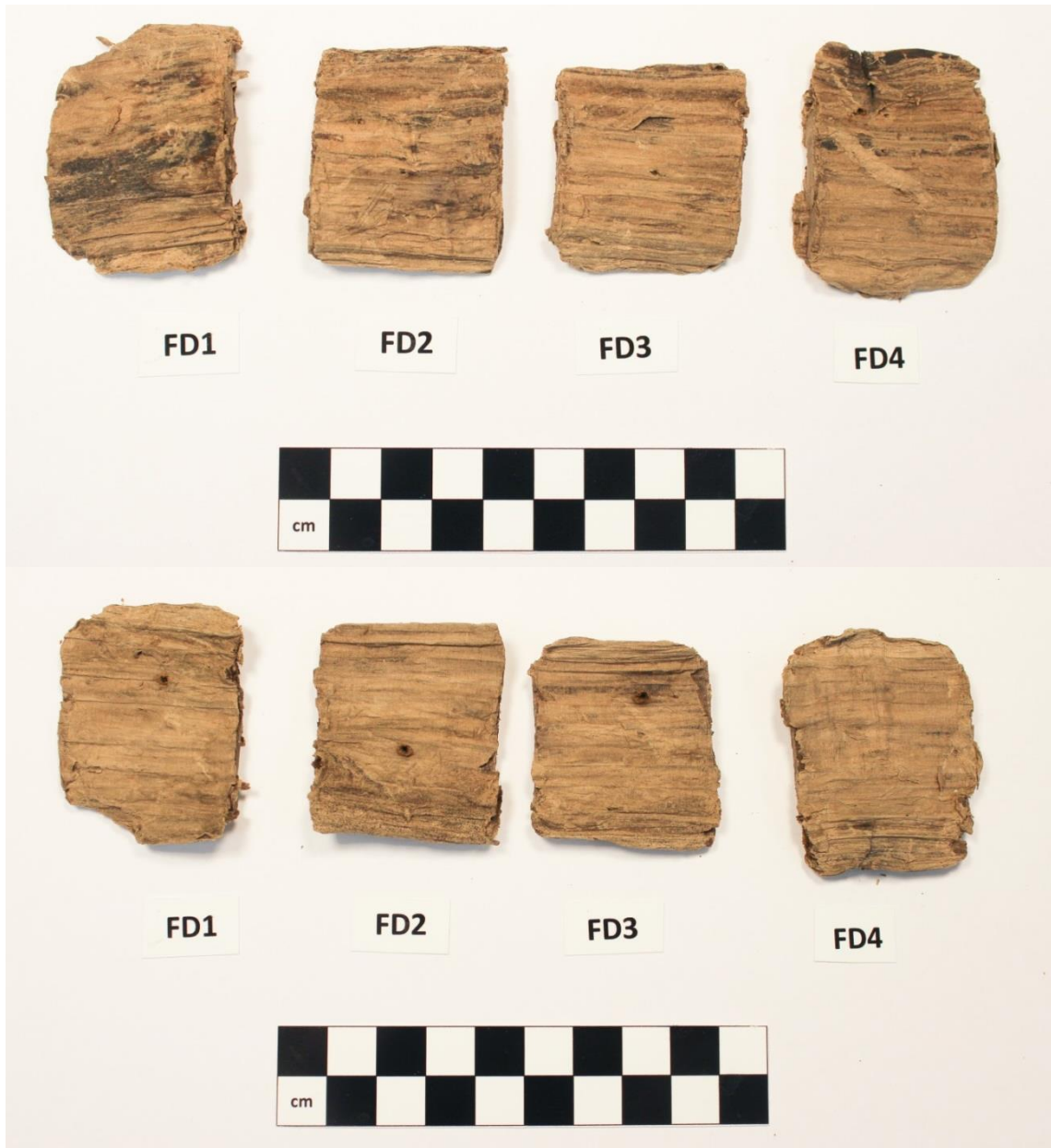
FIGURE 11. Samples treated by freeze drying, obverse and reverse. (Photos by author, 2013.)

Chamber 1: Control

No perceptible changes occurred in Chamber 1. The sample remained dry to the touch and light had no visible impact. Occasionally, small fragments fell from the edges when handled. This may explain the slight (–0.2g) decrease in weight.

Chamber 2: Variable Environment

Beginning in Week 8, a slight change in color begins, accompanied by the development of a damp exterior and delamination of the outermost layer of the wood at the center of the sample. The color change slowly continued to the end of the testing period (Figure 12), but there was no further delamination.

FIGURE 12. *Above,* sample FD2, Week 8. *Below,* sample FD2, Week 12. (Photos by author, 2013.)

Chamber 3: Outdoor Storage

The greatest amount of change occurred in Chamber 3. Beginning in Week 4, the sample felt slightly damp, though initially there was no color change associated with the tactile change. A slight darkening in color, though only in some parts of the sample, was visible in Week 6 (Figure 13). The surface of the sample also began to delaminate at this time.

FIGURE 13. Sample FD3, Week 6. (Photo by author, 2013)

During Week 8, dark spots began to appear on one side of the sample (Figure 14). During Week 9, dark spots also appear on the opposite side. By Week 10, the dark

spots are visible across both sides of the sample. Much like sample PEG3, these spots

are most visible when the moisture has been removed from the chamber. When moisture

is reintroduced during Week 11, there is a slight darkening of the sample and the spots

become less prevalent, though they remain visible. Wood with small holes that are filled

in with debris have a similar appearance, but since these dark spots do not appear in the

Control or Cool Storage chambers, it is more likely that the spots that appear on samples

FD3 and PEG3 are a mold or fungus.

FIGURE 14. Sample FD3, Week 8, with a closer look at the dark spots (Photo by author,

2013.)

At the end of the testing period, the sample was set out for a week in the ambient laboratory environment. The color lightened, close to the original color; with this lightening, the dark spots became much more prevalent again (Figure 15). The slight delamination that occurred remained, though the sample no longer felt damp.

FIGURE 15. Sample FD3, Week 13. (Photo by author, 2014.)

Chamber 4: Cool Storage

No perceptible change occurred in Chamber 4. The sample remained dry, with no discoloration. When removed from cold storage for weekly photos, and temporarily in a different environment, no perceptible changes occurred.

Silicone Oil-Treated Samples

Prior to placement in the accelerated degradation chambers (Figure 16), the samples were given a hardness rating of 2. The color was Munsell 10YR 3/3 Dark Brown. The samples were dry to the touch, with a slight waxy or oily feeling in some areas.

No perceptible changes occurred to any of the silicone oil treated samples during the twelve week testing period. This does not mean that no changes at all took place; it is possible that detrimental changes, such as mold growth, developed, but that the darkness of the wood has prevented changes from being noticed to the naked eye, as seen in PEG Sample 3. It is also possible that a longer duration of testing, or more extreme conditions, would have led to perceptible changes.

All samples lost a small amount of weight (between 0.2 to 0.5 g) which, like the PEG and freeze dried samples, may be due to the loss of small, loose fragments when handled. There was no residue left behind on the acrylic stands or the base of the chambers to suggest that the silicone oil had perspired from the wood, as in the case of samples PEG2 and PEG3.
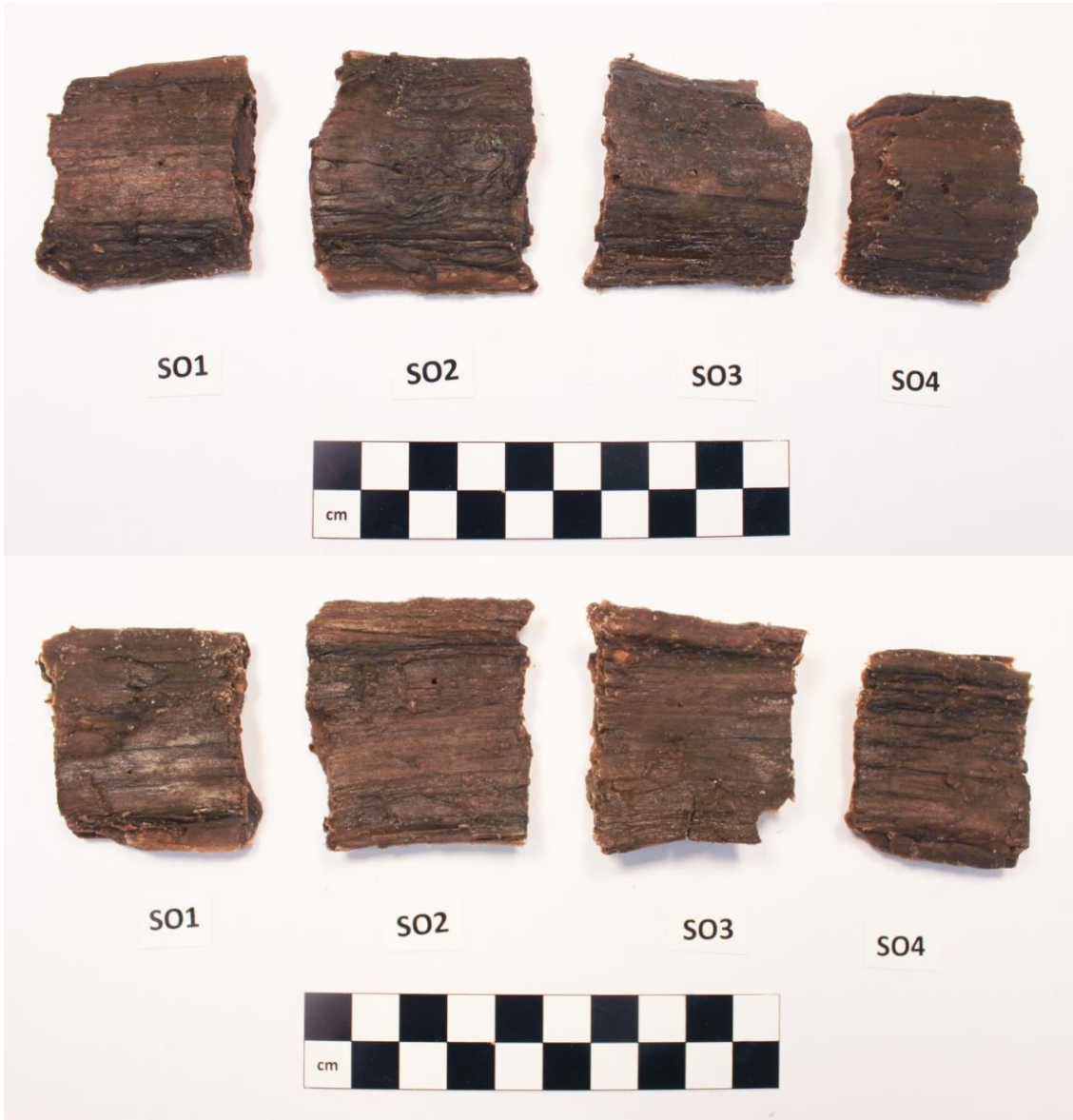
FIGURE 16. Samples treated with silicone oil, obverse and reverse. (Photos by author, 2013.)

CHAPTER VI

CONCLUSION

The goal of this study was to determine whether a simplistic accelerated climate chamber can be used as a method of qualitative comparison for conservation treatments. Of course, one could debate the extent of the acceleration. However, even under fairly conservative accelerated environments, the samples did undergo changes to such a degree that they could justify the effectiveness of accelerated degradation testing. These changes occurred within the first two months of testing; after this point, the changes, such as the perspiration of PEG, simply continued to occur in the same manner. If the testing had occurred over a longer duration, or the environments had been accelerated more dramatically, it is possible that further changes would have occurred, such as proliferation of mold. The accelerated conditions were conservative to remain as close to natural ageing as possible.

Accelerated testing has several potential benefits in the field of conservation. In the case of established conservation treatments, this method could be used to quickly determine which treatments best suit a specific museum environment and thus further prolong the life of an artifact; or vice versa, it could be used to determine how best to adapt the museum environment, or showcase microclimates, to the artifact treatments. Change tends to occur slowly for artifacts, and this can make validating new conservation treatments slow. Accelerated degradation testing could be used to compare the experimental treatment to established treatments to quickly provide a reasonable

comparison, allowing researchers to either validate the new treatment against established treatments, or revise the method. It can also allow researchers to investigate topics such as reversibility of treatments and re-conservation of artifacts and how these actions may affect the life of the artifact.

Accelerated degradation testing could prove to be very useful for the treatment of waterlogged wood and other delicate artifacts in that it allows for qualitative analysis. It is also minimally destructive—it is performed with the understanding that the samples will be subjected to adverse conditions, causing degradation to the artifact, but not so destructive that further methods of analysis, such as SEM, cannot be investigated. The purpose of accelerated degradation testing is to study the processes of degradation, not to attempt to age the artifact a specific degree. Accelerated degradation testing provides a foundation for the method, the next step is to refine the ageing method through study of available statistical models for accelerated life testing, exhaustive testing of samples, and in-depth analysis of conserved waterlogged wood currently in museums and storage facilities.

REFERENCES

Adams, Jeanette
2008   Fort Meade is Cool, CALM, and Collected. *Library Services Journal* 1(3):21–27.

American Society for Testing and Materials
2010   D4674-02a: Standard Practice for Accelerated Testing for Color Stability of Plastics Exposed to Indoor Office Environments. ASTM International, West Conshocken, PA. DOI: 10.1520/D4764-02AR10.

American Society for Testing and Materials
2010   G151: Standard Practice for Exposing Nonmetallic Materials in Accelerated Test Devices that Use Laboratory Light Sources. ASTM International, West Conshocken, PA. DOI: 10.1520/G0151-10.

Bacci, Mauro, Marcello Picollo, Simone Porcinai, and Bruno Radicati
1999   Indoor environmental monitoring of colour changes of tempera-painted dosimeters. In *12th Triennial Meeting, Lyon, 29 August–3 September 1999: Preprints, Vol. 1*, Janet Bridgeland, editor, pp. 3–7. James & James, London, UK.

Baer, Norbert S. and Paul N. Banks
1994   Indoor air pollution: effects on cultural and historic materials. In *Care of Collections,* Simon Knell, editor, pp. 135–146. Routledge, London, UK.

Benson, Paul L.
2012   Some Unusual, Hidden, Surprising, or Forgotten Sources of (Possible) Sulfur Contamination in Museums and Historic Structures. In *AIC Research and Technical Studies Specialty Group Postprints Volume 3, 2012, 40th Annual Meeting, Albuquerque, New Mexico*, Corina Rogge, compiler, pp.175–204. The American Institute for Conservation of Historic and Artistic Works, Washington, DC. <http://www.conservation-us.org/docs/default-source/periodicals/rats-postprints-vol-03-2012.pdf?sfvrsn=4>. Accessed 28 October 2014.

Bernardi, Adriana
1990   Microclimate in the British Museum, London. In *Museum Management and Curatorship* 9(2):169–182.

Bilz, Malcolm and David Grattan
1993   The Development of an Apparatus for Studying the Effect of Light Exposure on Museum Materials. In *ICOM Committee for Conservation 10th Triennial Meeting, Washington, DC Preprints,* Janet Bridgeland, editor, pp.559–565.

Bordass, William T.
1994   Museum Environments and Energy Efficiency: Are Our Current Priorities Right?
In *Museums Environment Energy,* May Cassar, editor, pp. 5–16. HMSO, London, UK.

Bosshard, Emil
1994   Paintings: the (show) case for passive climate control. In *Care of Collections,*
Simon Knell, editor, pp. 88–92. Routledge, London, UK.

Bruseth, James E. and Toni S. Turner
2005   *From a Watery Grave: The Discovery and Excavation of La Salle's Shipwreck,*
La Belle. Texas A&M University Press, College Station.

Bullock and Saunders
1999   Measurement of cumulative exposure using Blue Wool standards. In *12th
Triennial Meeting, Lyon, 29 August–3 September 1999: ICOM Committee for
Conservation Preprints, Vol. 1*, Janet Bridgeland, editor, pp. 21–26. James & James,
London, UK.

Camuffo, Dario, Peter Brimblecombe, René Van Grieken, Hans-Jürgen Busse, Giovanni
Sturaro, Antonio Valentino, Adriana Bernardi, Nigel Blades, David Shooter, Lieve De
Bock, Kristin Gysels, Monika Wieser, and Oliver Kim
1999   Indoor air quality at the Correr Museum, Venice, Italy. In *The Science of the
Total Environment* 236:135–152.

Camuffo, Dario, René Van Grieken, Hans-Jürgen Busse, Giovanni Sturaro, Antonio
Valentino, Adriana Bernardi, Nigel Blades, David Shooter, Kristin Gysels, Felix
Deutsch, Monika Wieser, Oliver Kim, and Ursula Ulrych
2001   Environmental Monitoring in four European museums. In *Atmospheric
Environment* 35(Supplement 1):S127–S140.

Camuffo, Dario, Adriana Bernardi, Giovanni Sturaro, and Antonio Valentino
2002   The microclimate inside the Pollaiolo and Botticelli rooms in the Uffizi Gallery,
Florence. In *Journal of Cultural Heritage* 3(2):155–161.

Camuffo, Dario
2014   *Microclimate for Cultural Heritage: Conservation, Restoration, and
Maintenance of Indoor and Outdoor Monuments*. 2nd edition. Elsevier Science &
Technology, Amsterdam, NLD.

Carr, D.J., M. Odlyha, N. Cohen, A. Phenix, and R.D. Hibberd
2003   Thermal Analysis of New, Artificially Aged and Archival Linen. *Journal of
Thermal Analysis and Calorimetry* 73:97-104.

Carver, Michael
1994   Lighting Design and Energy Efficiency in Museums and Galleries. In *Museums Environment Energy,* May Cassar, editor, pp. 73–96. HMSO, London, UK.

Clark, R.W. and J.P. Squirrell
1985   The Pilodyn: An Instrument for Assessing the Condition of Waterlogged Wooden Objects. *Studies in Conservation* 30(4):177-183.

Cohen, Neil S., Marianne Odlyha, Roberto Campana, and Gary M. Foster
2000   Dosimetry of paintings: determination of the degree of chemical change in museum exposed test paintings (lead white tempera) by thermal analysis and infrared spectroscopy. *Thermochimico Acta* 365:45–52.

de Jong, J.
1977   Conservation Techniques for old waterlogged wood from shipwrecks found in the Netherlands. In *Biodeterioration Investigation Techniques,* A.H. Walters, editor, 295-338. Applied Science Publishers, London, UK.

del Hoyo-Meléndez, Julio M., Marion F. Mecklenburg, and María Teresa Doménech-Carbó
2011   Determination of the Annual Light Exposure Received by Two-Dimensional Museum Objects Displayed on Vertical Surfaces using Photometric Measurements. *Studies in Conservation* 56(1):31–40.

Dodson, Bryan and Harry Schwab
2006   *Accelerated Testing: A Practitioner's Guide to Accelerated and Reliability Testing.* SAE International, Warrendale, PA.

Dupont, Anne-Laurence, Costanza Cucci, Claudine Loisel, Mauro Bacci, and Bertrand Lavédrine
2008   Development of LightCheck® Ultra: A novel dosimeter for monitoring lighting conditions of highly photosensitive artefacts in museums. *Studies in Conservation* 53(1):49–72.

Entwistle, R.M. and J. Pearson
1994   Rentokill bubble: results of test. In *Care of Collections,* Simon Knell, editor, pp. 212–216. Routledge, London, UK.

Erhardt, David, Charles S. Tumosa and Marion F. Mecklenburg
2007   Applying Science to the Question of Museum Climate. In *Museum Microclimates, Contributions to the conference in Copenhagen 19–23 November 2007,* T. Padfield and K. Borchersen, editors, pp. 11–18. National Museum of Denmark.

Fabbri, Kristian and Marco Pretelli
2014   Heritage buildings and historic microclimate without HVAC technology: Malatestiana Library in Cesena, Italy, UNESCO Memory of the World. In *Energy and Buildings* 76(1):15–31.

Ferdyn-Grygierek, Joanna
2014   Indoor environment quality in the museum building and its effect on heating and cooling demand. In *Energy and Buildings* 85(1):32–44.

Frigione, M., M. Lettieri, A.M. Mecchi, U. Santamaria
1993   Durability of an epoxy resin employed in restoration of historical buildings. In *ICOM Committee for Conservation 13th Triennial meeting, Rio de Janeiro, 22–27 September 2002 Preprints,* pp. 888–893. James & James, London, UK.

Grattan, D.W.
1987   Waterlogged Wood. In *Conservation of Marine Archaeological Objects,* Colin Pearson, editor, pp. 55-67. Butterworths, London, UK.

Grattan, D.W. and R.W. Clarke
1987   Conservation of Waterlogged Wood. In *Conservation of Marine Archaeological Objects*, Colin Pearson, editor, pp. 164-206. Butterworths, London, UK.

Grzywacz, Cecily M.
2006   *Monitoring for Gaseous Pollutants in Museum Environments.* Getty Conservation Institute, Los Angeles, CA.

Hamilton, Donny L.
1999   *Methods of Conserving Archaeological Material from Underwater Sites.* <http://nautarch.tamu.edu/CRL/conservationmanual/ConservationManual.pdf> Accessed 28 February 2015.

Hatchfield, Pamela
2011   Crack Warp Shrink Flake: A New Look at Conservation Standards. *Museum* (January-February):41-43, 51-52.

Hocker, Emma, Gunnar Almkvist, and Malin Sahlstedt
2012   The *Vasa* experience with polyethylene glycol: A conservator's perspective. In *Journal of Cultural Heritage* 13 (Supplement 3):S175–S182.

Heesters, Raymond, Henk van Keulen, and Wilma G.T. Roelofs
2002   Natural Resins, Artificially Aged in Steps. In *Contributions to Conservation: Research in Conservation at the Netherlands Institute for Cultural Heritage (ICN),* Jaap A. Most and Norman H. Tennent, editors, pp. 55–63. James & James, London, UK.

Hill, A.E., T. Fourrier, J. Anderson, A. Athanassiou, and C. Whitehead
1999   Measurement of the light absorption length of 308nm pulsed laser light in artificially aged varnishes. In *12th Triennial Meeting, Lyon, 29 August–3 September 1999: Preprints, Vol. 1*, Janet Bridgeland, editor, pp. 299–303. James & James, London, UK.

Hillyer, Lynda and Valerie Blyth
1994   Carpet beetle: a pilot study in detection and control. In *Care of Collections,* Simon Knell, editor, pp. 217–233. Routledge, London, UK.

Illuminating Engineering Society of North America
1996   Museum and Gallery Lighting: A Recommended Practice. IESNA, New York, NY.

Ishii, Mie, Takayoshi Moriyama, Masahiro Toda, Kohtaro Kohmoto, and Masako Saito
2008   Color Degradation of Textiles with Natural Dyes and of Blue Scale Standards Exposed to White LED Lamps: Evaluation of White LED Lamps for Effectiveness as Museum Lighting. *Journal of Light & Visual Environment* 32(4):370–378.

Jablonský, Michal, Martina Botková, Štefan Šutý, Lukáš Šmatko, and Jozef Šima
2014   Accelerated Ageing of Newsprint Paper: Changes in Swelling Ability, WRV and Electrokinetic Properties of Fibers. *Fibres & Textiles in Eastern Europe* 22(2):108–113.

Kamba, Nobuyuki
1987   A study of natural materials as RH buffers and application to a showcase. In *ICOM Committee for Conservation 8th Triennial Meeting, Sidney,* Kirsten Grimstad, editor, pp. 875–879.

Klosowski, J.M.
2003   Foreword. In *Archaeological Conservation Using Polymers: Practical Applications for Organic Artifact Stabilization,* C. Wayne Smith, author, pp. ix-xi. Texas A&M University Press, College Station.

Knight, Barry and David Thickett
2007   Determination of response rates of wooden objects to fluctuating relative humidity in historic properties. In *Museum Microclimates, Contributions to the conference in Copenhagen 19–23 November 2007,* T. Padfield and K. Borchersen, editors, pp. 85–90. National Museum of Denmark.

Krupińska, Barbara, Anna Worobiec, Giuliana Gatto Rotondo, Velibor Novaković, Velichka Kontozova, Chul-Un Ro, René Van Grieken, and Karolien De Wael
2012   Assessment of the air quality (NO_2, SO_2, O_3 and particulate matter) in the Plantin-Moretus Museum/Print Room in Antwerp, Belgium, in different seasons of the year. In *Microchemical Journal* 102(1):49–53.

Lafontaine, Raymond H.
1980   *Recommended Environmental Monitors for Museums, Archives & Art Galleries.*
National Museums of Canada, Canadian Conservation Institute, Technical Bulletin No. 3, Ottowa, Canada.

La Gennusa, Maria, Giovanni Lascari, Gianfranco Rizzo, Gianluca Scaccianoce
2008   Conflicting needs of the thermal indoor environment of museums: In search of a practical compromise. In *Journal of Cultural Heritage* 9(2):125–134.

Legnér, Mattias
2011   On the Early History of Museum Environment Control: Nationalmuseum and Gripsholm Castle in Sweden, c. 1866–1932. In *Studies in Conservation* 56(2):123–137.

Ligterink, Frank J. and Giovanna Di Pietro
2007   Canvas paintings on cold walls: relative humidity differences near the stretcher. In *Museum Microclimates, Contributions to the conference in Copenhagen 19–23 November 2007,* T. Padfield and K. Borchersen, editors, pp. 27–38. National Museum of Denmark.

MacLeod, Kenneth J.
1978   *Relative Humidity: Its Importance, Measurement and Control in Museums.* National Museums of Canada, Canadian Conservation Institute, Technical Bulletin, No. 1, Ottowa, Canada.

Maekawa, Shin and Franciza Toledo
2002   Controlled Ventilation and Heating to Preserve Collections in Historic Buildings in Hot and Humid Regions. In *ICOM Committee for Conservation Preprints, 8th Triennial Meeting, Rio de Janeiro*, Janet Bridgland, editor, pp. 58–65. James & James, London, UK.

Mecklenburg, Marion F.
2007   Micro climates and moisture induced damage to paintings. In *Museum Microclimates, Contributions to the conference in Copenhagen 19–23 November 2007,* T. Padfield and K. Borchersen, editors, pp. 19–26. National Museum of Denmark.

Michalski, Stefan
2000   *Guidelines for Humidity and Temperature for Canadian Archives.* Canadian Conservation Institute Technical Bulletin #23. Ottawa, Canada.

Nelson, Wayne B.
1990   *Accelerated Testing: Statistical Models, Test Plans, and Data Analyses.* Wiley Series in Probability and Mathematical Statistics, New York, NY.

Nelson, Wayne B.
2005   A Bibliography of Accelerated Test Plans. *IEEE Transactions on Reliability*
54(2):194–197.

Nilsson, Johanna, Francisco Vilaplana, Sigbritt Karlsson, Jonny Bjurman, and Tommy
Iversen
2010   The Validation of Artificial Ageing Methods for Silk Textiles Using Markers for
Chemical and Physical Properties of Seventeenth-Century Silk. *Studies in Conservation*
55(1):55–63.

Odlyha, Marianne, Neil S. Cohen, Gary M. Foster, Robin H. West
2000   Dosimetry of paintings: determination of the degree of chemical change in
museum exposed test paintings (azurite tempera) by thermal and spectroscopic analysis.
Thermochimica Acta 365:53–63.

Pinniger, David
1994. *Insect Pests in Museums.* Archetype, London, UK.

Pinniger, David
2003   Saving Our Treasures: Controlling Museum Pests with Temperature Extremes. In
Pesticide Outlook 6(1):10–11.

Pool, Marilen, Nancy Odegaard, and Melissa J. Huber
2005. Identifying the Pesticides: Pesticide Names, Classification, and History of Use. In
*Old Poisons, New Problems: A Museum Resource for Managing Contaminated Cultural
Materials*, Nancy Odegaard and Alyce Sadongei, editors, pp. 5–32. AltaMira Press,
Walnut Creek, CA.

Porck, Henk J.
2000   *Rate of Paper Degradation: The Predictive Value of Artificial Aging Tests*.
European Commission on Preservation and Access, Amsterdam, Netherlands.

Pretzel, B.
1999   Colour changes of Portland stone in the V&A's façade. In *12th Triennial
Meeting, Lyon, 29 August–3 September 1999: Preprints, Vol. 1*, Janet Bridgeland, editor,
pp. 88–92. James & James, London, UK.

Reis-Menezes, Adriana Araujo, Walderez Gambale, Mauro Cintra Giudice, and Márcia
Aiko Shirakawa
2011   Accelerated Testing of mold growth on traditional and recycled book paper.
International Biodeterioration & Degradation 65:423–428.

Sandström, Magnus, Yvonne Fors, and Ingmar Persson
2003   *The* Vasa*'s New Battle: Sulphur, Acid and Iron*. National Maritime Museums, Stockholm, Sweden.

Schaeffer, Terry T.
2001   *Effects of Light on Materials in Collections: Data on Photoflash and Related Sources.* Getty Publications, Los Angeles, CA.

Schulz, Ulrich
2009   *Accelerated Testing: Nature and Artificial Weathering in the Coatings Industry*. Vincentz Network, Hannover, Germany.

Shahani, Chandru
1995   *Accelerated Ageing of Paper: Can It Really Foretell the Permanence of Paper.* Library of Congress, Preservation Research and Testing Series No. 9503, Washington, DC.

Smith, C. Wayne
2003   *Archaeological Conservation Using Polymers: Practical Applications for Organic Artifact Stabilization*. Texas A&M University Press, College Station.

Solajic, M.R., Boris Pretzel, M. Cooper, J.H. Townsend, T. Seddon, J. Ruppel, J. Ostapkowicz, and T. Parker
1993   A collaborative examination of the colourfastness of Amazonian featherwork: assessing the effects of exposure to light and laser radiation. In *ICOM Committee for Conservation 13th Triennial meeting, Rio de Janeiro, 22–27 September 2002 Preprints,* pp. 701–707. James & James, London, UK.

Stolow, Nathan
1994   Silica gel and related RH buffering materials, conditioning and regeneration techniques. In *Care of Collections,* Simon Knell, editor, pp. 93–100. Routledge, London, UK.

Szent-Ivany, J.J.H.
1968   Identification and control of insect pests. In *The Conservation of Cultural Property with Special Reference to Tropical Conditions,* pp. 53–70. UNESCO, Paris, FRA.

Tannert, Thomas, Ronald W. Anthony, Bohumil Kasal, Michal Kloiber, Maurizia Piazza, Mariapaola Riggio, Frank Rinn, Robert Widmann, and Nobuyoshi Yamaguchi
2013   In situ assessment of structural timber using semi-destructive techniques. *Materials and Structures* 47(5):767-785.

Tantideeravit, S., M.N. Charalambides, D.S. Balint, and C.R.T. Young
2013   Prediction of delamination in multilayer artist paints under low amplitude fatigue loading. *Engineering Fracture Mechanics* 112:41–57.

Thomson, Garry
1986   *The Museum Environment,* expanded and revised from 1978 edition. Butterworths, London, UK.

Turner, I.K.
1980   *Museum Showcases: A Design Brief*. British Museum, Occasional Paper, No. 29, London, UK.

Turner, Janet
1998   Public Places: Lighting solutions for exhibitions, museums and historic spaces. Rotovision, Crans-près-Céligny, CHE.

Turner-Walker, Gordon
2011 The Mechanical Properties of Artificially Aged Bone: Probing the nature of the collagen-mineral bond. *Paleogeology, Paleoclimatology, Paleoecology* 310(1):17–22.

Worobiec, Anna, Lucyna Samek, Pawel Karaszkiewicz, Velichka Kontozova-Deutsch, Elżbieta Anna Stefaniak, Katleen Van Meel, Agnieszka Krata, László Bencs, René Van Grieken
2008   A seasonal study of atmospheric conditions influenced by the intensive tourist flow in the Royal Museum of Wawel Castle in Cracow, Poland. In *Microchemical Journal* 90(2):99–106.

Wypych, George
2008   *Handbook of Material Weathering*, 4th edition. ChemTec Publishing, Toronto, Ontario.

Yoon, Young Hun, and Peter Brimblecombe
2001   The Distribution of Soiling by Coarse Particulate Matter in the Museum Environment. In *Indoor Air* 11(4):232–240.

Zervos, Spiros
2010   Natural and Accelerated Ageing of Cellulose and Paper: A Literature Review. In *Cellulose: Structure and Properties, Derivatives and Industrial Uses*, A. Lejeune, and T. Deprez, editors.
<http://users.teiath.gr/szervos/__objects/docs/zervos_av_nova_132.pdf>. Accessed 12 December 2014.