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IN THEIR TRUE COLORS: DEVELOPING NEW METHODS FOR RECOLORING FADED TAXIDERMY

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ABSTRACT

From 2010–11, the American Museum of Natural History completed an ambitious program of renovation to the habitat dioramas in the Hall of North American Mammals. Created in the 1940s, these historic dioramas were conceived as a means to inspire wonder and appreciation for the natural world, and to educate visitors about the fragile ecosystems threatened by unregulated hunting and development. Having been on permanent display for over 70 years, many of the zoological specimens were faded to such an extent that they no longer reflected the natural appearance of living animals, compromising the overall impact and effect of the dioramas.

The renovation arose from a re-lamping project in which the original diorama lighting systems were to be replaced with modern fixtures. Previous testing in the Akeley Hall of African Mammals had demonstrated that it was possible to reduce heat and light levels inside the dioramas – while maintaining the desired visual appearance – through the use of energy-efficient lamps. As the re-lamping project would extend the exhibit life of the materials within the dioramas, the renovation team became motivated to explore complimentary methods of restoring naturalistic color to specimens that had become faded and desiccated in the original harsh lighting environment.

Several important factors limited the materials that could be considered for recoloring. As the lighting design in each diorama reflects a specific location, season, and time of day, the light levels often greatly exceed that of a typical art exhibition space. Additionally, the larger taxidermy mounts are permanently embedded into the wire-and-plaster matrix of the diorama floors and cannot be removed for treatment. Finally, the dioramas themselves are not air-tight and accumulate dust over time. For the treatment to be successful, any materials used had to be lightfast, allow for application in situ with no rinsing of excess colorant, and had to impart minimal alteration to the physical characteristics of the hairs, helping to insure that specimens can be cleaned and groomed in the future.

Preliminary investigation into contemporary taxidermy restoration practices revealed few references to materials used in recoloring faded mounts. Some institutions have reported success with commercial hair dyes, while acrylic paints are commonly used among taxidermists. The American Museum of Natural History conservation team ultimately chose to focus its investigation on Wildlife Colors acrylic paint (commercially available acrylic paints used by taxidermists), Orasol dyes (solvent-soluble metal-complex dyes with uses in conservation treatments), and XSL micronized pigments (water-dispersible pigments).

Conservators worked closely with the project taxidermist and partnered with outside conservation scientists to assess these materials against the necessary criteria. Physical attributes of colored hair samples were examined using scanning electron microscopy, and the lightfastness of dyes and pigments was tested using microfadeometry and accelerated aging. The investigation has contributed to a better understanding of aging properties in these materials, and has led to innovative recoloring methods that prioritize long-term stability and retreatability.

1. INTRODUCTION

In 2010–11 the American Museum of Natural History (AMNH) undertook an ambitious program of renovation to the 45 habitat dioramas in the Hall of North American Mammals and Small Mammal Hall. Some of the earliest collections at the AMNH were mounted taxidermy bird and mammal specimens, and the evolution of the habitat diorama was a natural development in the tradition of using art to teach science. Within the museum, dioramas were created to promote the awareness of wildlife and so-called ‘primitive cultures’ as finite, and to engender concern for the populations and habitats that were threatened by unregulated development and hunting. Fusing art and science, the habitat dioramas at the AMNH depict specific geographic locations and house anatomically correct mounted specimens in their natural habitat (Quinn 2006). On permanent display for over 70 years, with at least one known prior renovation campaign, many of the zoological specimens were faded to such an extent that they no longer reflected their accurate scientific appearance. Real and fabricated floral elements were equally, if not more, deteriorated. This degradation had compromised the overall impact and effect of the dioramas.

The original fabrication of the dioramas was a collaborative effort, combining the talents of artists and scientists to represent the complex inter-relationships between animals and their environment. Alongside the museum's curators, they conducted extensive research, visiting each site to assemble reference sketches, photographs, and specimens for exhibit. Once back at the museum, every detail of the scene was painstakingly recreated, from the narrative moment implied in the postures of the taxidermy and the illusion created by the background painting to the site-specific foreground materials.

2. MATERIALS AND METHODS OF DIORAMA CONSTRUCTION

The major external elements that house the habitat dioramas are the concrete case and the light box, which is situated above the diorama and separated from the exhibition space by panes of glass.

The three main internal elements of the dioramas are: a background painting, foreground materials, and mounted taxidermy specimens. Each diorama is illuminated using a specific combination and placement of lights to create the illusion of a particular season and time of day in the depicted location.

2.1 CASE

The partial dome-shaped enclosure is constructed from vertical angle iron beams and heavy wire mesh that supports a layer of rough-coat plaster (fig. 1). Inside the dome, the rough plaster is smoothed with layers of fine-coat plaster, to which the canvas is adhered with lead white and oil adhesive. A large glass panel, which is angled slightly to prevent reflection, serves as the front face of the diorama. A separated light box with fixtures for interior illumination is located above the enclosure. Access to the dioramas is difficult and can only be achieved by removing the front panes of glass or, in some cases, is attained by narrow ladders on the interior extending from the light box to the diorama floor.

2.2 BACKGROUND PAINTING

The background paintings were examples of the highest form of wildlife artistry in their day, and many consider those in the North American Mammal Hall to be the most accomplished of their kind. The curved oil painting is essential to the overall illusion of space, distance and environment. It draws on Renaissance techniques such as under-painting, plotting perspective, and transferring images with grids (fig. 2).

Painters of note included James Perry Wilson, Frances Lee Jaques, and Charles S. Chapman. Wilson described his diorama work as "art to conceal art", in other words, art intended to imitate nature so closely that the artist's role is not visible (Quinn 2006).

2.3 FOREGROUND MATERIALS

The floor of the diorama was built from a wooden framework over which wire screen was manipulated to simulate the desired topography (fig. 3). Physical features of the landscape

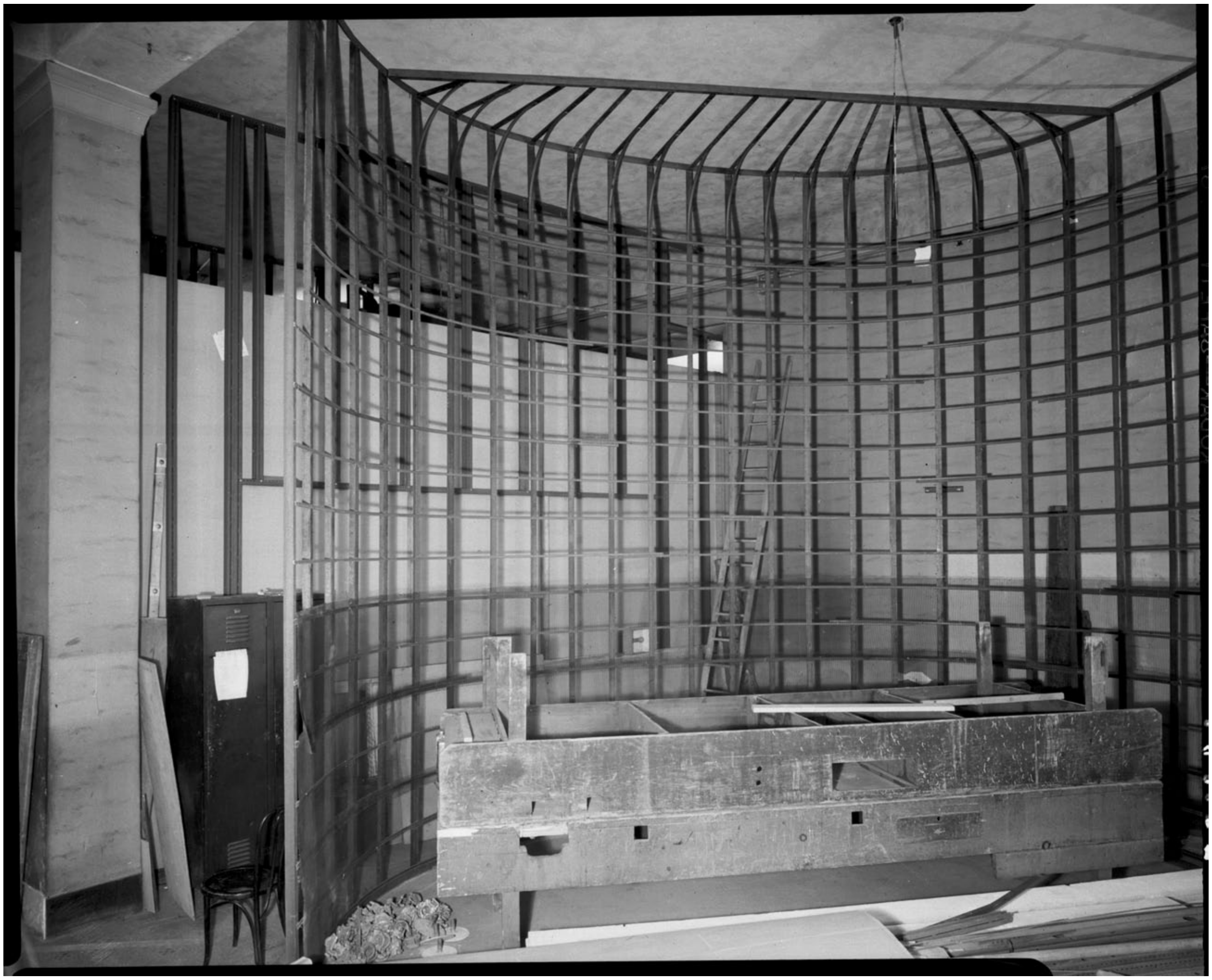

Fig. 1. The curved iron framework on which wire and plaster is applied to create the diorama background curve (1953) (Courtesy of the American Museum of Natural History)

were constructed over the wire screen with a mâché-like mixture composed of plaster, dextrin, whiting, and asbestos fibers. Plant materials were generally fabricated from painted cotton or paper, sometimes flocked or coated with wax, and attached to stems or branches using insulated wire. Broad leaves were often made from vacuum formed acetate sheet and some fleshy plant parts such as cacti pads were carved from wood or cast in wax. Snow was created using combinations of plaster, sand, crushed stone, cotton batting, and shaved plastics. Casts of tree trunks were taken on-site by museum artists, and a limited number of real botanical specimens, such as grasses, evergreen branches, mosses, and leaves for ground litter, were collected, chemically treated with preservatives, and then installed.

2.4 TAXIDERMY

The large mammal specimens were generally mounted in the museum following the procedures adapted from those developed by Carl Akeley in earlier decades (Levinson and Uricheck 2005). The general method involves sculpting an exact model of the animal in the pose to be presented out of water-based clay. A plaster mold is made of the sculpture and a hollow

Fig. 2. James Perry Wilson sketching Devils Tower for the mule deer diorama, with the scale model and his field sketch in the foreground (1942) (Courtesy of the American Museum of Natural History)

Fig. 3. Foreground artist George Frederick Mason laying down wire mesh over wood contours to create the ground terrain in the American bison/pronghorn antelope diorama (1942) (Courtesy of the American Museum of Natural History)

positive is created within it using a modified version of the foreground mâché mix or other materials. An internal wood and metal support is placed inside the hollow form, which is then assembled to create the mannequin. The skin is draped over the mannequin and stitched together, creating fabulously life-like figures. Some of the larger taxidermy specimens are mounted into the diorama floors, and could not be safely removed for treatment. Many of the smaller specimens, however, could be removed.

3. LIGHTING DESIGN AND FIXTURES

The original lighting scheme from the early 1940s is known to have included large theatrical lights (Quinn 2006). Lighting revisions shortly thereafter, in the 1950s, resulted in a combination of fluorescent and incandescent fixtures. This scenario caused a number of unsurprising problems. Temperature inside the dioramas was elevated, often reaching the high 80s °F. The relative humidity was low, with daily and seasonal fluctuations. Light levels were far higher than those recommended for museum collections and, until recently, the lights were not screened for ultraviolet emissions. These conditions resulted in deterioration, desiccation, and fading of most exhibit materials.

Informed by a 2003 conservation survey of the dioramas in the Akeley Hall of African Mammals undertaken at the museum, testing had demonstrated that it was possible to reduce heat and light levels inside the dioramas while maintaining the desired visual appearance through the use of energy-efficient lamps.

In 2010, as a result of the Museum's participation in a citywide effort to decrease energy consumption, funding was provided to replace the diorama lights with more energy-efficient fixtures. The goal of the re-lamping project was to achieve a 50% reduction in electric power consumption. A lighting design firm was contracted to research and select retrofit fixtures to reproduce the visual appearance of the original design. A combination of lamps was used that included energy efficient fluorescents for indirect lighting, and LED flood lights and metal halide spot fixtures as accent lights. All new lighting fixtures were filtered for UV emissions using UV filters over the fluorescent tubes and glass filters over the metal halide lamps; the LED flood lights have a 411 nm cutoff and were left unfiltered.

The re-lamping project provided the impetus for a broader renovation of the North American Mammal dioramas. The renovation team began to explore possible methods of restoring naturalistic color to specimens that had become faded and desiccated in the previous damaging lighting environment in hopes of extending their exhibit life. Just as the dioramas' construction was necessarily achieved through collaboration, this conservation effort involved a diverse team of participants, including curators, objects and paintings conservators, exhibition department staff, outside scientists, and a master taxidermist.

4. OBJECTIVES AND LIMITATIONS IN RECOLORING TAXIDERMY

4.1 PROJECT TIMELINE

One of the most immediate difficulties was the short project timeline, which imposed limitations on the type and extent of materials investigation. The renovation project gained last-minute approval after the re-lamping project was well underway, leaving one year for the work to take place from start to finish. Because of a multitude of institutional deadlines, only a maximum of two months within that year could be allotted for research and testing of possible colorants for the faded mammals. In order to prioritize which specimens were in the greatest need of recoloring, a survey was carried out in consultation with exhibit personnel and mammalogy curators knowledgeable about species and seasonal variations that may be present in fur coloration. Specimens in the dioramas were compared to study skins from the AMNH collection and others borrowed from the Smithsonian Institution.

Several important factors restricted the materials that could be considered for recoloring. Even with the new energy efficient lights, the naturalistic lighting design in each diorama precluded reduction of light levels to those generally considered acceptable for museum collections. The highest recorded light levels are 65 fc on the top of the highest mountain goat and 50 fc at the head of the cow in the bison diorama, whereas the recommended level for fur at the museum is 5 foot candles. Therefore, even with somewhat reduced light exposure, it was clear from the outset that any colorant considered for use would require high lightfastness ratings.

4.2 SPECIMEN ACCESSIBILITY

Many of the larger taxidermy mounts are deeply embedded into the wire and mâché of the diorama floors, and had to be treated in situ. Safe access for in situ treatment could only be achieved by providing custom-built platforms with strategically placed feet in order to avoid crushing fragile diorama ground cover. Sandbags on the bottom of the platform feet distributed the weight of the platform and its occupants across the weak floor structure. Because specimens were fixed in place, washing and rinsing excess colorant from the specimen were precluded, and ease of colorant preparation, application, and clean up were all important considerations for colorant selection.

4.3 PUBLIC SPACE

The use of certain solvents was restricted because of the limited possibility of effective fume extraction within the dioramas. Furthermore, because half of the exhibition hall was required to remain open to the public over the duration of the project, control of solvent fumes was critical.

4.4 RETREATABILITY/REVERSIBILITY

Finally, because the dioramas would probably not be renovated again for at least 25 years due to associated costs, favorable aging characteristics, reversibility, and ease of retreatment were significant factors in material choice. The material selected should not cause the hairs to clump or mat in a way that would inhibit their grooming or surface cleaning. If not fully reversible, it should not prevent future recoloring campaigns on these irreplaceable taxidermy mounts.

5. COLORANT RESEARCH

Historically, some recoloring of specimens at AMNH was done using spray application of oil paints thinned with trichloroethane. These treatments did not meet our criteria for long-term stability, retreatability, or personal safety. Investigation of the conservation literature on contemporary methods revealed few references for recoloring faded taxidermy mounts. Through personal correspondence, the Canadian Museum of Nature reported success recoloring some of their taxidermy mounts using Clairol commercial hair dye, but their situation allowed for the removal of the specimens from the diorama for treatment. A recent study investigated the use of fiber-reactive dyes for feather recoloring (Palumbo 2012), but concerns about aqueous treatments having an adverse effect on the tanned hides, as well as the long-term effects of the acidic or basic dye residues, ruled out this approach.

5.1 CONTEMPORARY TAXIDERMY COLORANTS

Aqueous and solvent-based acrylic paints are commonly used among contemporary taxidermists, but in this application reversing acrylic paints for retreatment would be very problematic. Also, due to their low glass transition temperature, there is potential for the paints to soften in the heat of the diorama, entrapping dust and hindering future surface cleaning.

Nevertheless, the project taxidermist's familiarity with commercially available acrylic paints and their primary mode of application by airbrush played a critical role in determining what alternative colorants would be considered. His method for restoring faded specimens consisted of layered airbrush applications of colorant with constant grooming and positioning of the hair throughout the process in order to control the hue and intensity of the color. Any alternative colorant would need to be able to be applied in a similar manner, in order to fully utilize the taxidermist's tremendous skill in this method and to meet the tight deadline.

5.2 ALTERNATIVE COLORANTS

Two colorants offered initial promise as suitable alternatives to acrylic paint: Orasol dyes and XSL micronized pigments.

5.2.1 Orasol Dyes

Orasol dyes (Ciba-Geigy; currently marketed by BASF for coatings, printing inks, and specialty industries) are commercially available 1:2 pre-metallized dyes that are insoluble in water and soluble in organic solvents. They can be applied without acidic salts or peroxides, and require no rinsing. They are available in a palette of 17 colors, sufficient to mix the range of tones characteristic of the North American mammals. Members of this dye class consist of a transition metal ion such as chromium, copper, or cobalt complexed to two symmetrical dye molecules. The latter are typically monoazo structures with a chromophore(s) (imparts color) and an auxochrome(s) (modulates the color and intensity and may enable hydrogen bonding, ionic bonding, or dipole-dipole interactions with the substrate).

In general, the lightfastness of 1:2 metal complex dyes is superior to that of other dye classes, due to the stability of the chelated complex and their large particle size; this has been the basis for their past use in conservation contexts, principally in wood stains and tinted resin fills. However, chromophore and auxochrome structures vary, making some dye colors more susceptible to photochemical degradation. The manufacturer reports a marked range in both lightfastness and solubility from color to color (fig. 4). All previous studies, however, were done in binding media (nitrocellulose and vinyl acetate), and the stability of the dyes alone was unreported. In order to assess the lightfastness of the Orasol dyes in a manner more applicable to taxidermy restoration, it was necessary to design a customized course of analyses.

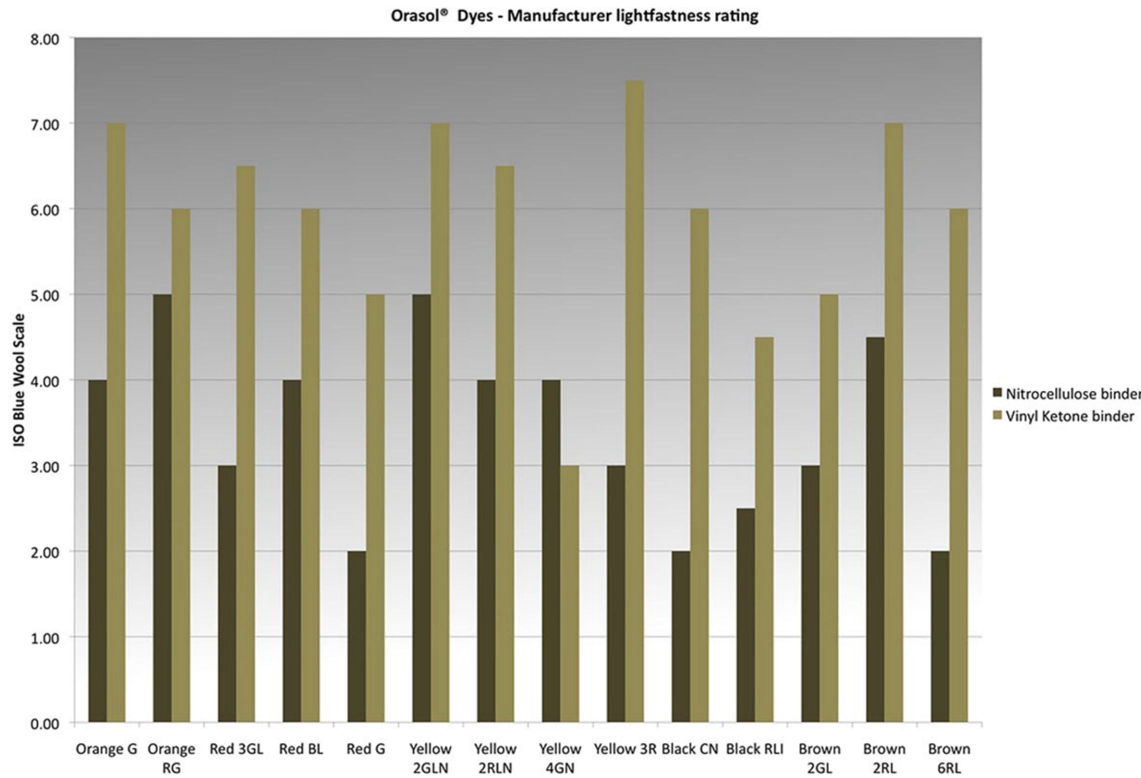

Fig. 4. Manufacturer's provided lightfastness ratings for Orasol dyes, measured using the ISO Blue Wool Scale (Courtesy of the American Museum of Natural History)

5.2.2 XSL Micronized Pigments

Water-dispersible micronized XSL pigments (from Kremer Pigments) were also explored for recoloring. These pigments have an extremely fine particle size and are treated with dispersing agents that allow them to form a homogeneous suspension in water. This suspension will pass easily through an airbrush, giving them the ability to create naturalistic, lightfast color using a non-toxic system. The XSL pigments are available in a limited palette of eight colors that lack brown tones. They are not soluble in organic solvents or solvent mixtures containing less than 15% water, so there is some potential for adverse effects on skin or other water-sensitive materials used in taxidermy preparation.

6. EXPERIMENTAL

Having initially limited the colorant choices by working properties, a course of analysis was developed that focused on comparing the acrylic paints favored by the project taxidermist to the Orasol dyes and XSL pigments. Conservators worked closely with the taxidermist and partnered with outside conservation scientists to assess the materials against these necessary criteria: minimal physical alteration to the hairs, retreatability/reversibility, and high lightfastness.

The greatest challenge to finding an acceptable recoloring method would be for application in the iconic bison diorama. It is one of the most visible and brightly lit scenes and contains a multitude of mounted specimens. Additionally, the faded bison taxidermy stood in stark contrast to the vibrant illustrations of the animal in the painted background. Swatches of bison hair colored with the acrylics, dyes, and pigments were prepared for testing. Due to time constraints, it was impossible to test all of the colorants on samples of all of the mammal species displayed in the hall. It was hoped that a successful outcome in the bison diorama would determine the methodology for treatment of other types of fur.

6.1 PHYSICAL CHARACTERISTICS

The physical appearance of the colored bison hairs was examined using optical light and scanning electron microscopy. Bleached bison hair[1] was brushed out with a solution of each of the colorant types being studied: acrylic taxidermy paint (water based emulsion), “lacquer” taxidermy paint (solvent-based acrylic emulsion), Orasol dyes, and XSL pigments. Longitudinal and cross-section samples were prepared.

At the macro level, all of the colored samples appeared somewhat similar. The acrylic paints produced a matted and stiff feel, whereas the Orasol dyes and XSL pigments produced a more natural look and feel. Physical manipulation of the samples colored with XSL pigments and the Orasol dyes caused some transfer of colorant, though more so with the XSL pigmented samples, which also had a somewhat duller appearance.

Microscopic examination revealed, as expected, that the binder in the acrylic paints covered and obscured the hair cuticle unevenly, creating a non-cohesive coating around the hair, with some visible peeling and lifting (fig. 5). The Orasol dyes and XSL pigments were only just

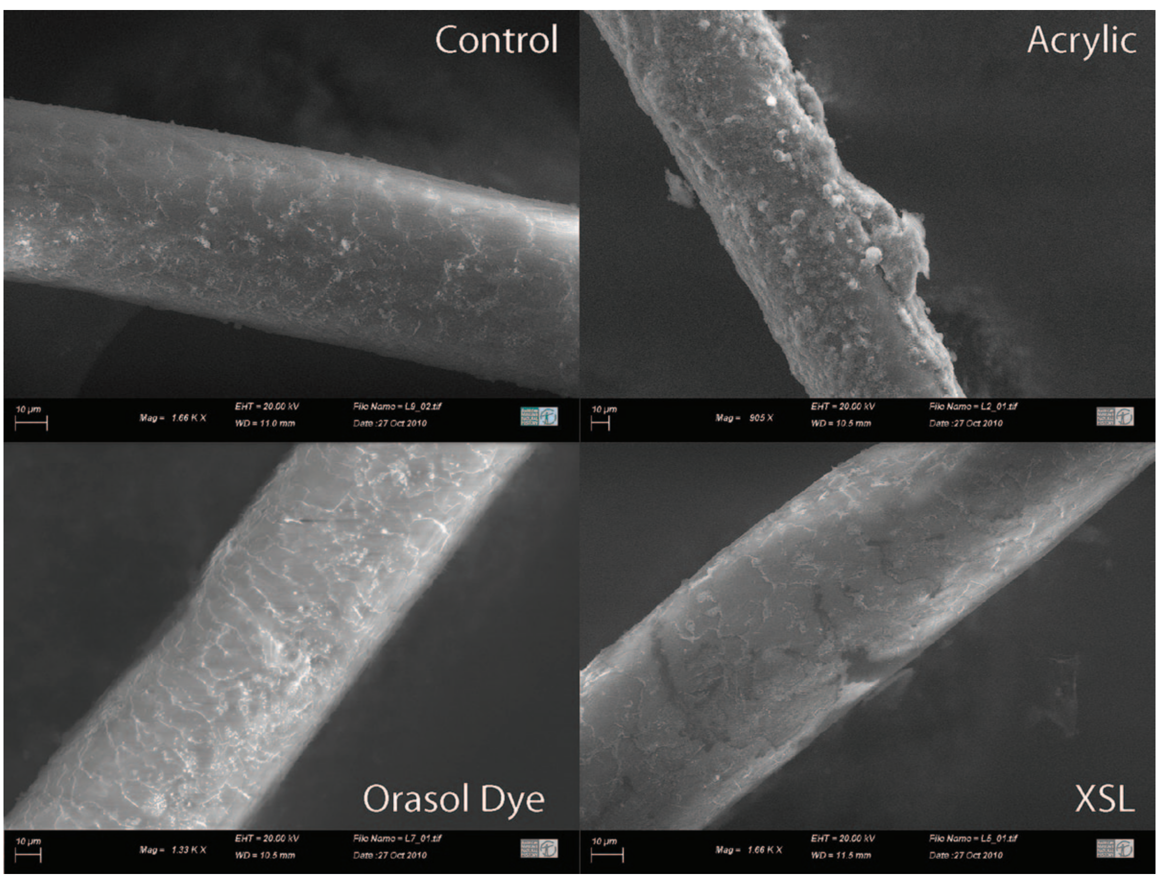

Fig. 5. SEM images of bison hairs: uncoated, with acrylic paint, Orasol dyes and XSL pigments (Courtesy of the American Museum of Natural History)

visible on the hair fibers and did not appear to cover or coat the hair shaft. The team was not able to determine the level of dye penetration into the hair.

The taxidermist also found that the Orasol dyes could be reduced or removed entirely when wiped or rinsed with ethanol. Although initially taken aback by this revelation, the team quickly recognized the potential of its reversibility, and gained a greater understanding of its working properties, such as localized reduction or removal of color to achieve special effects.

6.2 LIGHTFASTNESS

With the Orasol dyes having gained the approval of the taxidermist in terms of application, and the deadline for determining a conservation-approved colorant swiftly approaching, the lightfastness of the dyes was tested using microfadeometry and accelerated light-aging. Microfade testing was chosen because it could return results quickly. To complement this work and broaden the range of dye samples tested, accelerated light aging was conducted following the ASTM Standard for Lightfastness of Artists' Materials Colorants (ASTM 2010).

6.2.1 Sample Preparation

Test swatches for the Orasol dye family were produced by airbrushing 1% solutions of dye dissolved in ethanol onto unbleached 100% worsted wool and Whatman filter papers. A select number of colors were also applied to swatches of bleached bison[1].

One wool swatch was produced for each dye color in each of three application weights: light, medium, and heavy. One gram of dye was weighed to within 1/100 of a gram and added to 100 mL of ethanol. The dye was mixed by hand using a wooden stick until no clumps remained. Some of the dye colors were prone to various degrees of clumping, and it was occasionally necessary to decant the mixture several times to ensure that all clumps were adequately broken up. The dye was loaded into an airbrush canister, and each swatch was sprayed with a relatively wide pass using smooth broad strokes executed in a variety of directions (horizontal, vertical, and diagonal). Variation in application weight was achieved by increasing the number of passes with the airbrush, rather than by changing the concentration of the dye. Swatches receiving a light application were sprayed with 15 passes, depositing approximately ½ oz. of dye onto the fabric. Swatches receiving a medium application were sprayed in 30 passes, depositing approximately 1 oz. of dye onto the fabric. Swatches receiving a heavy application were sprayed with 60 passes, depositing approximately 2 oz. of dye onto the fabric. The test swatches were allowed to dry in the fume hood, and were then removed and examined for consistency. One by three inch samples for testing were cut from areas judged to be representative.

A customized palette of eight dye mixtures was developed to replicate the natural color range of the American bison, referred to as 'bison brown' mixes. These mixtures contained various proportions of the Orasol dye solutions prepared as outlined above. Test swatches were produced for each dye mixture in light, medium, and heavy applications; each dye mixture was airbrushed onto fabric swatches as well as a 2 x 3 inch piece of bleached bison fur. In this case, each fur swatch was placed with the flesh-side down on a flat surface, and sprayed using short, smooth strokes in a variety of directions. The swatch was frequently groomed and rotated through 360 degrees to ensure thorough coverage of the hairs. Fur swatches were sprayed with approximately 30 passes, depositing approximately ½ oz. of dye onto the fur.

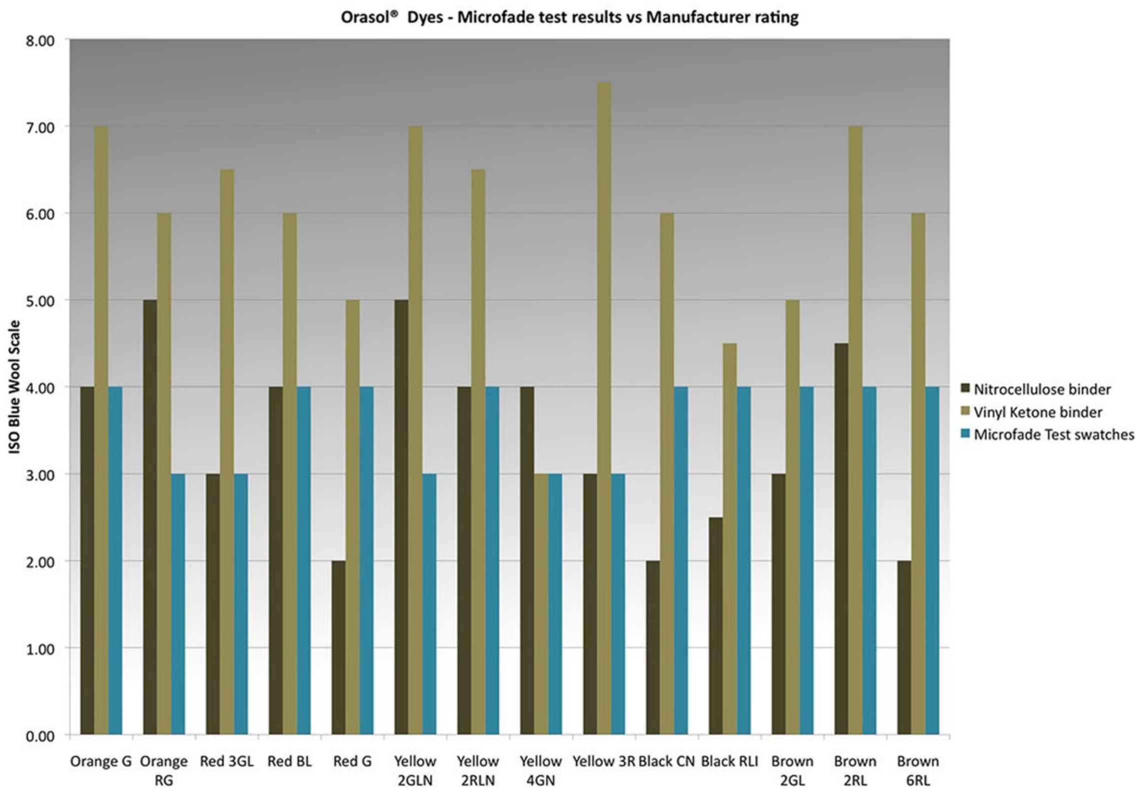

Fig. 6. Microfade test results plotted with manufacturer lightfastness rating (Courtesy of the American Museum of Natural History)

6.2.2 Microfade Testing

Twenty-eight single-color dye samples of textile were sent to Dr. Paul Whitmore, Director and Research Professor at the Art Conservation Research Center at Carnegie Mellon University, who conducted microfade testing on the wool and bison fur swatches[2]. Developed primarily as an instrument to identify fugitive colorants, the micro-fading tests were designed to relate the lightfastness of a test material to a fading reference material such as a Blue Wool card (Whitmore et al. 2001).

Microfade testing indicated 9 of the 14 colors in the sample set had lightfastness values equivalent to ISO Blue Wool 4 or higher (fig. 6). Because the xenon light in the instrument was filtered to remove UV, it was not feasible to get Blue Wool equivalent values higher than 4 without an extremely long exposure period. The lack of UV mimicked the new diorama lighting system, but left the longer-term stability of the dyes in question. Further investigation into the parameters that define the Blue Wool Scale and the estimated exposure time to just perceptible fading quickly illustrated that further testing was required.

6.2.3 The ISO Blue Wool Scale

The British Blue Wool Scale is often interpreted as Years to Perceptible Fading at a particular exposure level, usually 50 lux for 3000 hours per year (8.2 hrs/day, 365 days/year) (International Commission on Illumination 2004, 19). Feller (1978, 128) translated the three classes of photochemical stability into Intended Useful Lifetime “based on exposure on a

Table 1. Estimated years to 'just perceptible fading' at illumination levels of 50 lux per hour, 8 hours per day, 365 days per year (150,000 lx·hrs per year) (Courtesy of the American Museum of Natural History)

ISO Blue Woll rating	Years to noticeable fade, UV rich (50 lux/hr @ 3000 hrs yr)	Years to noticeable fade, no UV (50 lux/hr @ 3000 hrs/yr
1	1.5	2
2	4	7
3	10	20
4	23	67
5	53	200
6	130	670
7	330	2000
8	800	7300

well-illuminated museum gallery wall at about 150,000 footcandle hours of exposure per year." The higher the Blue Wool Number, the more lightfast the material. Table 1 illustrates how filtering ultraviolet radiation can make a large difference in projected lifespan. Based on this classification, most literature recommends using materials with a Blue Wool rating of 4 or higher.

These parameters are easily applied to normal museum or gallery environments, but the most brightly-lit areas inside the bison diorama experience light levels of over 538 lux (50 fc), 24 hours a day, 365 days a year, for a total yearly exposure of 4,380,000 lux hours. Historically, the lights were turned off after public hours, but testing of the internal diorama environment in the 1980s revealed that this led to large swings in T/RH as the unlit diorama cooled at night and warmed again the next day. At these light exposure levels, it was essential for us to be able to determine whether the materials had a lightfastness rating equivalent to Blue Wool 6 or higher.

6.2.4 Accelerated Light-Aging

A second group of samples was sent to Dr. Cory Rogge at Buffalo State College to be exposed in a QSun Xenon light aging chamber according to ASTM D4303 testing procedures[3]. This larger sample set included single-color dye swatches and bison brown mixes applied to both wool and fur. This test helped to characterize the dyes in more discrete stability classes, as well as to define total lux hours of exposure to "just perceptible fading" in terms of ΔE*.

In the QSun chamber, samples were exposed to a spectrum that included a UV component (approximating daylight filtered through glass with a UV component from 400 nm - 340 nm), causing them to fade more quickly than the initial set tested at Carnegie Mellon. This allowed determination of specific lightfastness ratings above the threshold imposed by the microfader. Inclusion of an ultraviolet component also allowed a "worst-case scenario assessment" of the dyes. A material that tested well in the UV-rich chamber was projected to have a long lifespan inside the bright but UV-free bison diorama.

Each ASTM lightfastness category corresponds to an established range of ΔE* values. Materials with a lightfastness rating of 1have low ΔE* values and display the least color change. Initial results from the QSun testing indicated that of the 17 dyes applied to wool, the majority tested as lightfastness 1 or 3 (fig. 7). Of the bison brown mixtures applied to wool and fur, most were lightfastness category 2, and half of the dye mixtures showed the same lightfastness even on different substrates (fig. 8).

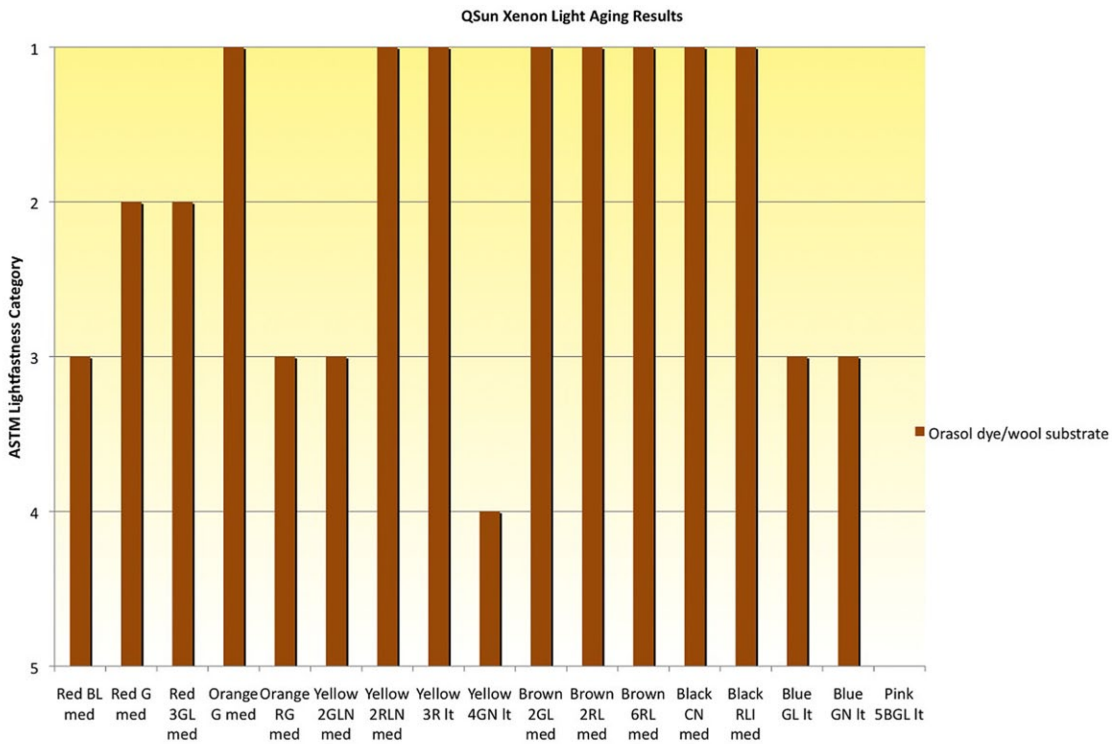

Fig. 7. ASTM lightfastness ratings of single-color Orasol dyes applied to wool (Courtesy of the American Museum of Natural History)

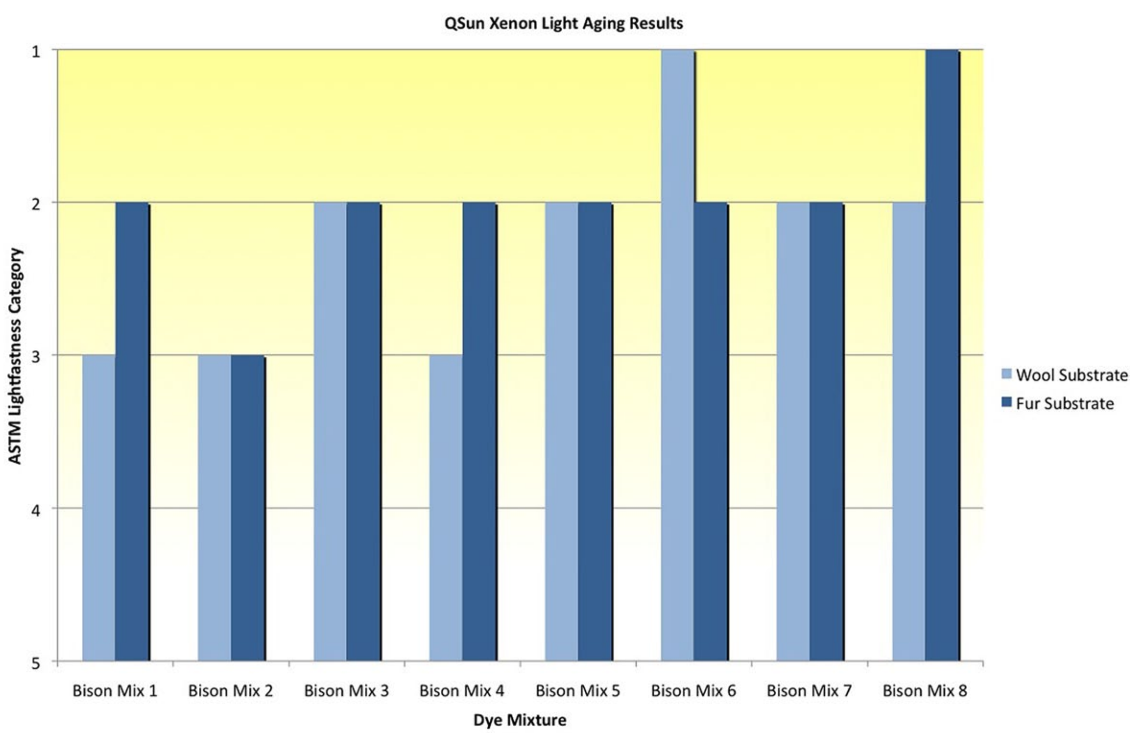

Fig. 8. ASTM lightfastness ratings of the bison brown dye mixes applied to wool and bison fur (Courtesy of the American Museum of Natural History)

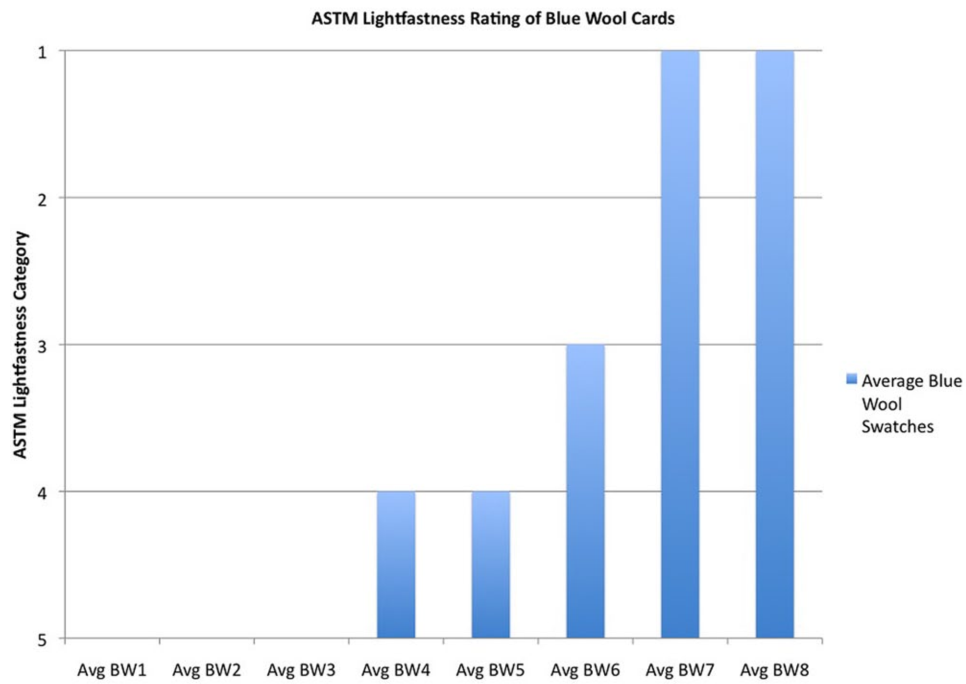

Fig. 9. Average ASTM lightfastness ratings for three Blue Wool standard cards tested using ASTM D4303 (Courtesy of the American Museum of Natural History)

7. INTERPRETATION OF RESULTS

Though it is possible to plot Blue Wool ratings provided by the manufacturer against the microfade test results as seen in figure 6, substrate-dye interactions are known to play a role in lightfastness. Direct extrapolation from the manufacturer's data does not yield meaningful information about the stability of the dyes when applied to keratin in the absence of a binder.

While the ASTM test characterizes materials according to its five categories of lightfastness, the standard does not attempt to correlate these categories to a projected material lifespan. There are a number of references in conservation literature that characterize materials into variously named "Classes of Photochemical Stability" which are often further refined with projections of "Intended Useful Lifetimes" and theoretical ties to Blue Wool ratings.

However, there is a growing body of evidence that while use of Blue Wool cards allows for a rough estimate of cumulative light exposure, it does not necessarily predict how a material will actually fade. While relied upon by many industries, the Blue Wool test is less precise at determining lightfastness, and fading is assessed more subjectively relative to quantitative instrument-based tests. The fading rates of the dyes are temperature and RH dependent, and changes in dye formulas used to create the cards cause batch-to-batch inconsistencies (fig. 9). The ASTM committee on lightfastness has tried to find connections between ASTM D4303 ΔE^* values and the fading of the Blue Wool cards, but thus far has found no correlations of any significance between these two methods.

As all of our diorama lamps in the North American Mammals Hall are now screened for UV emissions, and the majority of specimens are located in dioramas with low to medium light levels, these results represent a worst-case scenario assessment of lightfastness. Nevertheless, in

Fig. 10. Coyote diorama before (left) and after (right) treatment (Courtesy of the American Museum of Natural History)

those dioramas with higher light levels, it is acknowledged that the dyes may fade with time, and consequently their reversibility and retreatability played a major factor in their approval for use. Real-time monitoring of cumulative light exposure is continuing with the strategic placement of dyed swatches and a Blue Wool card inside the bison diorama out of sight of visitors, as well as covering sections of dyed bison to be able to directly compare to exposed hair.

8. AVENUES FOR FURTHER RESEARCH

The AMNH conservation/exhibition team was able to successfully recolor the bison, and subsequently many more specimens in the North American Mammal Hall (figs. 10–11). The treatment protocol that was developed provided an acceptable visual solution within the limitations of the project while meeting most of the key conservation criteria. Associated dye research has generated numerous new questions and will be a valuable starting point for further work in support of future taxidermy restoration projects at the AMNH. It has also informed a better understanding of changes that should be made to the diorama environment to support the longevity of these treasured exhibits.

8.1 DECREASING LIGHT EXPOSURE

It is evident that the light levels in the most brightly-lit dioramas should be lowered to retard fading of the dyes. The lights in the North American Mammal dioramas currently remain on 24 hours a day. The museum is investigating possibilities for turning off the lights for a portion of each night, while minimizing concomitant swings in relative humidity. While the hall is air-conditioned, full climate control is not possible because the hall adjoins a museum entrance, and a request for the installation of doors was not approved. Installation of microclimate generators presents a host of problems, making them impractical within our context.

Fig. 11. Coyote specimen before (left) and after (right) treatment (Courtesy of the American Museum of Natural History)

8.2 DUST MITIGATION

Another issue noticed during the treatments was the large amount of dust that accumulated on surfaces within the dioramas. To help diminish this and prolong time between interventions, the dioramas were re-gasketed. Air exchange testing performed in three representative cases indicated that the air turnover is comparatively low. Installation of a positive-pressure environment is being planned for the bison diorama, where dust accumulation would be very evident on the newly darkened fur.

8.3 DYE PENETRATION

Since the conclusion of the project and the reopening of the hall, study of Orasol dyes and recoloring procedures has continued. The focus of recent work has been the lack of dye penetration into the keratin fibers. For the project described in this paper, non-penetration was advantageous, imparting reversibility and the ability to manipulate the dye colors on the specimen to achieve naturalistic effects. Nevertheless, it is important to better understand the factors that may influence dye penetration. Development of a means of improving penetration would expand the existing toolkit of recoloring techniques in the service of future projects.

It has been hypothesized that the rapid evaporation rate of ethanol and the delivery of the dye solution as a fine mist almost certainly allows the solvent to volatilize before penetration of the keratin fibers can be achieved. Orasol dyes are soluble in a variety solvents and solvent mixtures other than ethanol. Among them are low-toxicity alternatives like propylene glycol monomethyl ether (PGME) and ethyl acetate.

In order to characterize the effect of the solvent on the depth of dye penetration, and to determine whether penetration depth correlates with variation in lightfastness, cross-sections of dyed hairs were analyzed using SEM-EDS. Samples of bleached bison hair were dipped into chromium- and cobalt-based dye colors (Brown 6RL and Orange G), each dissolved in three solvents (ethanol, PGME, and ethyl acetate). In all samples, metals were detected on the surface of the hair, but no measurable penetration into the keratin substrate was observed, regardless of the improved contact afforded by dipping the samples rather than airbrushing them (Pollak et. al 2012). It appears likely that even on degraded fibers, some form of chemical manipulation would be necessary to open up the hair cuticle and allow penetration of the dye.

9. CONCLUSION

This investigation of the Orasol dyes and XSL pigments has contributed to a better understanding of their aging properties and allowed for development of an acceptable solution for a specific challenge in a very short time frame. It has led to innovative recoloring methods that prioritize long-term stability and retreatability. It should be stressed, however, that the treatment applied to this group of mounted specimens at the Museum would not be appropriate for all situations in which recoloring of taxidermy is desired. Its use must be confined to specimens housed in closed exhibit cases. The dye is somewhat transferable, and vacuuming or other cleaning could lead to its unintentional removal. Moreover, opening the possibility for contact with the chemicals by unsuspecting people, such as in a historic house or a private residence, is not advised.

In conclusion, this research has made stunningly clear the difficulties encountered when published product data does not correlate with the information needed to solve the problem at hand. Test results produced by industry cannot necessarily be accepted wholesale without thorough investigation of testing methods and conditions. This project has provided one means to solve the problem of faded taxidermy, and has suggested a number of avenues for further investigation.

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NOTES

1. Bison fur samples were obtained through the project taxidermist. The hair of the tanned pelt was bleached using Clairol peroxide bleach to obtain a faded tone comparable to those of the taxidermy in the dioramas, rinsed repeatedly to remove residual peroxides, and cut into swatches.

2. Although there are substantial differences between wool prepared as a textile and a bison pelt that has been tanned, mounted, and aged by exhibit for over 70 years, there are also substantial differences between the hairs of a bison and those of other faded specimens in the halls that

would potentially be recolored. As a flat substrate comprised of keratin fibers, the wool textile was chosen as the most reasonable substrate to utilize for measurement of color changes using a colorimeter. Due to time constraints, none of the filter paper samples were tested at this time, but were retained for future analysis.

3. Model Xe-1-SC. The samples were exposed to an irradiance of 0.35 W/m^2 of light at 340 nm for 410.5 hours for a total of 510 kJ/(m^2 nm), the equivalent of 1260 MJ/m^2 of total solar radiation. The un-insulated black panel in the light aging chamber was held to 63^{o}C. Colorimetry was performed using a GretagMacbeth ColorEye XTH colorimeter, interfaced to a PC running Color iControl. The spectrophotometer was calibrated using a diffuse white standard with a D65-10 standard illuminant. To account for instrumental drift, a stable green standard was measured before each set of colorimetry data was obtained and any changes in the L*, a* or b* readings of the standard between measurements were corrected for. The L*, a* and b* values of each sample were measured before and after fading at least three times in different locations on the sample, and each reading was the average of two measurements. The L*, a* and b* values obtained before and after fading were used to calculate the ΔL*, Δa*, Δb* and ΔE* '94 values of the samples. The ΔE* '94 values were used to determine the ASTM lightfastness ratings as follows: Lightfastness 1 has $\Delta E^* \leq 4$; Lightfastness II has $4.0 < \Delta E^* \leq 8.0$; Lightfastness III has $8.0 < \Delta E^* \leq 16.0$; Lightfastness IV has $16.0 < \Delta E^* \leq 24.0$ and Lightfastness V has $24.0 < \Delta E^*$.

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SOURCES OF MATERIALS

Clairol peroxide bleach – sourced locally

Orasol® Dyes and XSL Pigments
Kremer Pigments Inc.
247 West 29th Street
New York, NY 10001
(212) 219-2394 or (800) 995-5501
www.kremerpigments.com

Wildlife Artist Supply Company (WASCO) and Smith Wildlife colors
McKenzie Taxidermy Supply
PO Box 480
Granite Quarry, NC 28072

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