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Case study

A survey on the light-fastness properties of organic-based Alaska Native artifacts

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ABSTRACT

A series of light-fastness tests were conducted on a group of ethnographic objects that will be on exhibit at the Smithsonian Institution Arctic Studies Center, a recent addition to the Anchorage Museum at Rasmuson Center in Alaska. The objects surveyed belong to the collections of the Smithsonian National Museum of Natural History and the Smithsonian National Museum of the American Indian. This work was designed as a feasibility study on the use of a micro-fading tester as a non-contact and non-destructive technique to evaluate the light-stability of materials present in ethnographic collections. A broad range of objects containing a wide variety of materials were selected for the study. The materials investigated included a variety of dyes applied on silk, cotton, and wool substrates along with some unusual materials such as tanned skin and seal gut skin. The results from this investigation have allowed establishing exhibition recommendations taking into consideration the sensitivity of each object, light levels in the museum building, and estimated light exposures based on the duration of the exhibit. The micro-fading tester has proven to be a very useful tool for determining the light-stability of ethnographic materials without causing any harm to the objects. Objects containing equivalent materials are usually classified under a general category based on their probable sensitivity to light. However, micro-fading test results have permitted the detection of dissimilarities among some of these objects, which could be associated to variations in prior fading histories, the quality of raw materials, and different preparation methods.

1. Introduction

The light-sensitivity of ethnographic artifacts in museum collections is a subject of great concern for curators and conservators. The light-fastness properties of ethnographic materials are typically unknown and most museum exhibits are planned using the traditional illumination guidelines assuming that these objects have high sensitivity to light [1]. This is mainly due to the limited amount of information available on the light-fastness of these materials. Ethnographic materials may contain impurities, which increase their sensitivity to light relative to materials used in fine arts. Conversely, an ethnographic object which is believed to have poor light-fastness may contain materials that are stable under controlled museum lighting or the artifact may have reached a maximum fading stage in which no further color changes take place. The effect of light on museum artifacts has been investigated by numerous authors [2–6]. It is known that environmental parameters such as temperature, relative humidity, and atmospheric gases acting in conjunction with light increase the risk of damage to museum artifacts [7–9]. Although objects in ethnographic collections are associated to specific cultural groups and to a history of use, there is usually little information available about their composition. Various authors have conducted analytical studies on ethnographic objects determining that they often consist of heterogeneous mixtures of organic and inorganic materials [10–12]. Even though some researchers have evaluated the effect of light exposure on ethnographic collections, the amount of scientific information on this subject is still very limited. The majority of these investigations have been conducted using laboratory materials, which resemble the actual artifacts due to evident limitations of conducting accelerated light aging tests on samples taken from the objects [13–15]. Therefore, additional light-fastness studies are essential before establishing adequate preventive conservation and exhibition strategies for ethnographic collections.

A total of 14 artifacts, which represent the full spectrum of materials present in a collection of approximately 600 Alaska Native heritage objects, were chosen for the study. Surveyed objects range in date from 1868 to early 20th century. These dates are mainly associated with the museum acquisition date or the year in which the artifact was collected in the field. Due to the diversity of materials found within an artifact, several areas of each object were tested to determine their relative light-sensitivity. This paper presents detailed micro-fading data for three of the objects along with a summary, which includes light-fastness information for all 14 artifacts tested. The objects surveyed are associated to various Alaska Native

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Table 1
Description of ethnographic objects surveyed with the micro-fading tester (MFT).

Object	Culture	Catalog number	Dimensions: length, width, depth (cm)	Materials
Mittens	Athabascan	E072842	32.5, 15.5, 2.5	Semi-tanned hide, quill, wool, dye, sinew
Leggings	Tlingit	E341202B	39.5, 21.0, 8.0	Silk, wool, dye, cedar bark, hide, puffin beak
Baby carrier	Tlingit	E209580	62.0, 36.0, 15.0	Tanned skin, cloth, beads
Hat	Sugpiaq	E072477	24.0, 24.0, 11.2	Semi-tanned leather, gut skin, wool, hair
Hat	Unangan	E006555	26.0, 28.0, 10.0	Leather, mica, wool, fur, gut skin, natural fiber thread
Basket	Athabascan	E339747	31.0, 27.0, 15.5	Birch bark, root, wood
Grass matt	Unangan	E365225	137.0, 44.0, 1.6	Grass, wool, dye
Pipe	SLI Yupik	E280451	17.5, 3.9, 7.2	Lead, copper alloy, wood, ivory, tanned leather
Gut skin parka	Yup'ik	E424209	119.0, 160.0, 20.5	Seal gut, cotton, grass
Woman's boots	Chukchee	245954.000	44.0, 8.0, 25.0	Caribou hide, fabric, thread
Man's boots	Eskimo	116764.000	45.0, 17.0, 26.8	Seal fur, seal skin, sinew, caribou hair, wool
Tobacco bag	Athabascan	E021582	64.5, 20.0, 1.9	Wool, silk, glass, sinew
Hood	Chukchee	245952.000	30.0, 29.0, 22.0	Animal fur, hide thongs
Tunic	Tlingit	E168297A	79.0, 151.0, 4.0	Tanned hide, black velvet, red cloth

SLI: Saint Lawrence Island.

cultures such as Athabaskan, Chukchee, Eskimo, Saint Lawrence Island (SLI) Yupik, Sugpiaq, Tlingit, Unangan, and Yup'ik. The materials investigated included a series of dyes applied to silk, cotton, and wool substrates along with a variety of unusual materials such as animal fur, grass, gut skin, leather, natural fiber thread, and tree bark. A general description of the artifacts surveyed is presented in Table 1. Additional information about the objects that form the exhibit can be found in the Smithsonian Alaska Native Collections Sharing Knowledge website [16].

The objective of the study was to evaluate the use of a micro-fading tester (MFT) to conduct real time light-fastness tests on ethnographic artifacts since this technique offers the opportunity of obtaining spectrocolorimetric information directly from the object without making any contact with its surface. In recent years, the number of cultural institutions around the world making use of micro-scale fading testing equipment has increased considerably as museum conservation professionals are becoming aware of the multiple advantages offered by this technique. Additional studies on the light-fastness of ethnographic artifacts are evidently needed since they will permit establishing more informed illumination guidelines for these particular collections. **The MFT is exclusively used for determining if the objects are susceptible to light-induced color changes as a result of exhibition lighting. Other aspects of damage resulting from light exposure remain outside the scope of this technique.**

2. Methods

2.1. Instrumentation

The MFT used in this study was developed by Whitmore and co-workers from the Art Conservation Research Center at Carnegie Mellon University in Pittsburgh [17]. Individual components of this instrument are manufactured by Newport Oriel Corporation (California) and are sold as Oriel 80190 Fading Test System. The device consists of a reflectance spectrophotometer coupled to an accelerated light fading micro-tester. The sensitivity of objects to high intensity visible light can be determined by using short increments in exposure time to a 75-watt xenon arc light source. Spectrocolorimetric data are recorded periodically and their change is evaluated in real time. The instrument uses a 0/45 geometry for illumination of the sample and collection of reflected light. Two advantages of this technique are the small diameter of the illuminated spot (~0.4 mm) and a relatively short testing time when compared to other accelerated aging methods. The working distance measured from the external lens of the illuminating probe to the surface of the sample is approximately 1.0 cm. The intensity of the illuminated spot was measured with an ILT 1700 radiometer from International Light Technologies (Massachusetts) using a probe calibrated for point sources. The experimental parameters were chosen based on the assumption that the majority of objects were moderately or highly sensitive to light and also on the lack of information about their exact chemical composition. **Although ethnographic objects are typically associated with a history of use in outdoor environments where UV radiation was present, current museum lighting standards recommend that sensitive artifacts should be exhibited in galleries where the UV light component is completely removed. For this reason, micro-fading tests were performed exclusively using visible light to better simulate the lighting conditions in which these artifacts will be displayed.** The intensity of the illuminated spot was 4000 klx. The times of exposure varied from 8 to 12 min resulting in exposure doses that ranged from 533 to 800 klx·h. The integration time was 6 milliseconds and 10 spectra were averaged. The International Commission on Illumination (Commission Internationale de l'Éclairage [CIE]) illuminant and observer combination used was D_{65} and 2 degree, respectively.

2.2. Calculations

The CIELAB, 1976 color difference equation was used in the survey [18]. The values in the CIE, 1976 color space are L^*, a^*, and b^* used to designate lightness-darkness, redness-greenness, and yellowness-blueness, respectively. CIE $L^*a^*b^*$ values are calculated from measured tristimulus $X\ Y\ Z$ values and the corresponding X_n Y_n Z_n values of the standard illuminant and observer combination used. Reflectance spectra of each test spot were collected and color differences were calculated using the initial spectrum as the basis for comparison. For example, the difference between two color measurements recorded at times t_1 and t_2 ($t_2 > t_1$) is given by Eq. (1):

$$\Delta E* = \sqrt{(L_2^* - L_1^*)^2 + (a_2^* - a_1^*)^2 + (b_2^* - b_1^*)^2} \quad (1)$$

where ΔE^* is the total change in color, which depends on the three color parameters explained above. Total color changes detected with the MFT should be decomposed into their individual CIE $L^*a^*b^*$ parameters since this information is essential for understanding the nature and direction of the overall light-induced color change. Thus, an evaluation of the change in CIE $L^*a^*b^*$ values with time allows determining if a colorant experiences a hue change, a variation in shade, or a combination of both. The CIE $L^*a^*b^*$ color difference equation provides a mathematical way of relating spectroscopic changes to the ones perceived by a human observer. However, some discrepancies in ΔE^* values regarding a just noticeable difference (JND) which may range from 1 to 3 have been observed

[19–21]. A ΔE^* of 5 can be considered a definite change, which is large enough to be detected by most observers [22]. Nevertheless, the light exposures employed in this study did not resulted in color changes which were greater than 5 ΔE^* units.

2.3. *Assessment of color change*

Blue Wool (BW) Standard cards have been adopted as the international method for testing color fastness by the International Organization for Standardization (ISO) and the British Standards Institute as ISO 105 and BS1006, respectively [23]. The scale consists of eight BW reference samples dyed with different types of colorants resulting in different degrees of light-fastness. Each standard exhibits increasing light-fastness by a factor of two, relative to the previous one, with BW 1 being the most light-sensitive dye. Qualitative and quantitative determinations of the degree of fading can be made by examining the color changes produced as a result of exposure of BW standards to light [24]. Materials exhibiting high sensitivity to light will have similar photochemical stability to BW standards 1 to 3 and they should experience noticeable color changes within the first minutes of a micro-fading test. Micro-fading curves of BW standards 1, 2, and 3 were recorded and their final ΔE^* values are indicated in the secondary y-axis where appropriate. **However, since these tests were conducted in the absence of UV light, the fading rates showed some deviation from the normal factor of two described above. After comparing the times required to reach a specific ΔE^*, it was found that BW 1 and BW 2 were related by a factor of three instead.** Nevertheless, the reaction rates of the surveyed areas were compared to those observed for BW standards 1–3 under the same experimental conditions **since they constitute the only feasible references for evaluating the light-fastness of the unknown colors**. Whitmore has successfully applied this methodology when performing micro-fading tests of commercial gouaches and Japanese woodblock prints [25]. Color changes recorded for BW 1, BW 2, and BW 3 after 10 min of exposure to a 4.0 Mlx illuminated spot were 6.8, 3.6, and, 0.26 ΔE^*s, respectively. Fading rates from every location within an object were evaluated in order to divide them into five categories namely high, moderate-high, moderate, moderate-low, or low sensitivity. **This classification system is described in** Table 2.

3. Results

3.1. *Tlingit Chilkat leggings*

Light-fastness tests were conducted on different areas of a pair of Chilkat leggings manufactured using silk, hide, wool, dyes, cedar bark, and puffin beak. Previous fading of the dyes on wool was evident after comparing the verso and recto side (Fig. 1a and b). Equivalent colored areas of wool were tested to compare the preserved and faded colorants. Fig. 1c shows micro-fading test results obtained for yellow, white, and blue areas on the recto and verso sides. As expected, less faded areas registered greater color changes when compared to the areas that have received higher exposure to light. Exposed white, blue, and yellow areas showed fading rates, which were slightly above, in the vicinity of, and slightly below BW 3, respectively. Equivalent areas of these three dyes on the verso side of the object showed fading rates, which were located between those of BW 2 and BW 3 with greater tendency towards the latter one. Color changes recorded for these three colorants were dominated by reductions in yellowness parameter. Black wool, black silk, and hide fragments located along the edges of these objects showed good light-fastness with color changes that were under 0.3 ΔE^* units, indicative of the greater stability of these materials relative to the blue, yellow, and white zones of wool tested.

Table 2
Classification system developed based on measured fading rates of Blue Wool (BW) standards.

BW standards range	ΔE^* range[a]	Sensitivity
Greater or equal to BW 1	$\times \geq 6.8$	Very high
Between BW 1 and BW 2	$3.6 \leq \times \leq 6.8$	High
Near BW 2	$\times \approx 3.6$	High
Between BW 2 and BW 3 (higher end)	$1.67 \leq \times \leq 3.6$	Moderate-high
Near (BW 2 + BW 3) × 0.5	$\times \approx 1.67$	Moderate
Between BW 2 and BW 3 (lower end)	$0.23 \leq \times \leq 1.67$	Moderate-low
Lower or equal to BW 3	$\times \leq 0.23$	Low

[a] These ΔE^* ranges are based on color changes recorded after a 10-min exposure to an illumination intensity of 4 Mlx.

3.2. *Tlingit baby carrier*

The light-fastness properties of various skin areas of a Tlingit baby carrier were determined. Color differences observed throughout the surface of the object generated an interest for investigating the relative stability of these leather zones. In addition to tanned skin, this object was made using materials such as cloth and beads. Fig. 2a shows examples of dark, medium, and light skin zones, which were identified as areas 1, 2, and 3, respectively. Since these different areas of color were clearly discernible, it was possible to compare their fading rates when exposed to high intensity light from the MFT. Light-fastness tests were conducted at various locations inside the three rectangles indicated in Fig. 2a. In general, these three different areas changed at rates between those of BW 2 and BW 3 with higher tendency towards the latter one

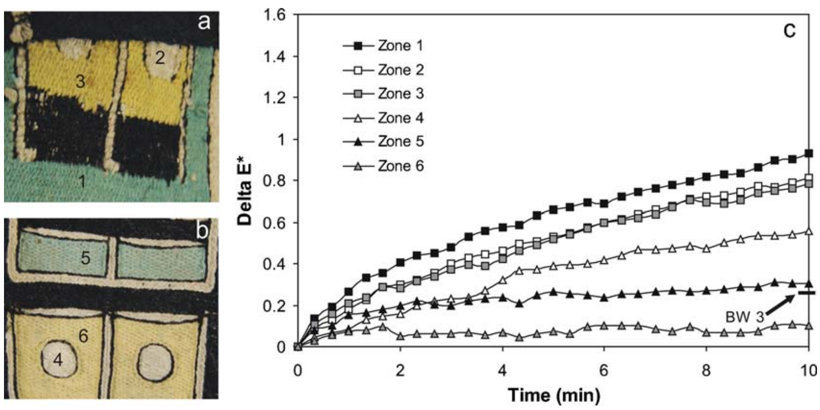

Fig. 1. (a) Detail of an unexposed area on the verso of the Tlingit Chilkat leggings; (b) detail of an area showing evidence of fading on the recto; (c) micro-fading test results for six areas of color indicated in the photographs showing a greater degree of change experienced by the unexposed side.

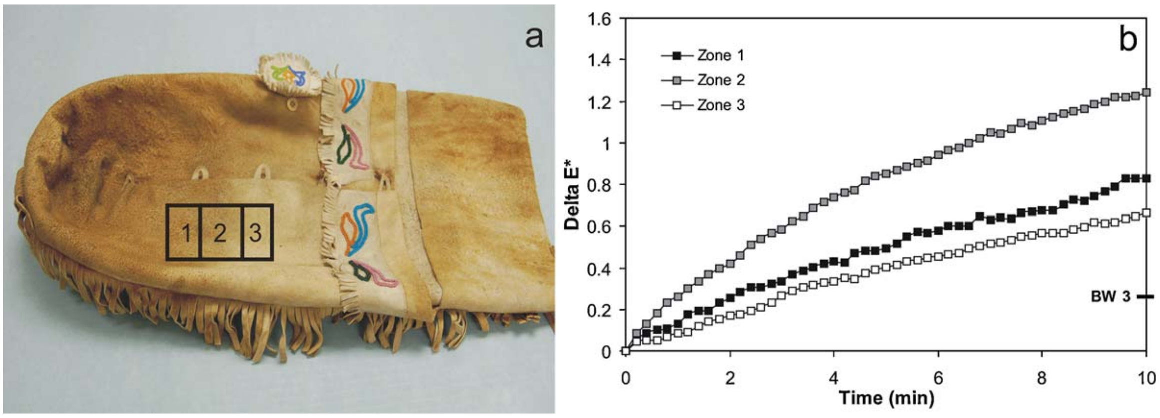

Fig. 2. (a) Tlingit baby carrier showing different saturation degrees of the leather. Areas demarcated by the rectangle from left to right indicate zones described as dark, medium, and light colored; (b) micro-fading curves obtained for three zones described in the photograph showing higher light-sensitivity of the medium-value area.

(Fig. 2b). However, the medium-value skin area showed greater sensitivity when compared to dark and light zones suggesting that a light-induced chemical reaction of greater rate takes place at the interface between dark and light skin when the area is illuminated. Color changes were dominated by a loss of yellow observed in all evaluated areas with a higher change of $-1.17\ b^*$ units observed for the medium-value area relative to its light and dark counterparts. Each area registered a slight increase in lightness, which suggests that the MFT produces a bleaching effect on the material.

3.3. *SLI Yupik pipe*

A SLI Yupik pipe was investigated and its materials included lead, copper alloy, wood, ivory, and semi-tanned leather. A side view of the pipe showing a variety of materials is presented in Fig. 3a. This artifact was initially classified as relatively stable to light since it contains ivory, leather, and wood, identified as zones 3 through 5 in Fig. 3a. However, red and black pigments applied to ivory elements were suspicious of exhibiting high light-sensitivity. Micro-fading test results for various areas of the SLI Yupik pipe are presented in Fig. 3b. The red colorant was the least stable material with a fading rate, which is halfway between the ones recorded for BW 2 and BW 3. This colorant exhibited a linear change in color with time with a ΔE^* of 1.6 recorded after 10 min of exposure, making this pigment a moderately sensitive material. Ivory, leather, wood, and black-painted areas showed reaction rates which were slightly above BW 3 and therefore were considered relatively light-stable materials. It can be seen that although the majority of the materials are relatively stable to light, the red pigment underwent a significant change after such a short exposure.

4. Discussion

Micro-fading results for the three objects described above have confirmed that these artifacts contain materials with moderate to low light-sensitivity. Although it was possible to detect differences in the light-stability of dyes on the recto and verso sides of the Tlingit Chilkat leggings, all color changes experienced after a 667 klx·h exposure dose would not be perceptible to the average human observer ($\Delta E^* < 1$). The preservation of color in the backside along with fading observed in the front part is a known occurrence in these artifacts [26]. The results indicate that these colorants would exhibit fair stability under controlled museum lighting conditions. The color of the surface of the Tlingit baby carrier is not homogeneous probably due to photodegradation reactions, which have resulted in bleaching or darkening of some areas due to exposure to sunlight associated to the history of use of the object. **However, there is no visual or written record of the original condition of the object making it difficult to establish whether or not the object was evenly tanned in the beginning.** Micro-fading test results indicate that the colorant introduced during the tanning process exhibits less stability when present in a zone with intermediate saturation. A similar behavior has been observed for micro-fading tests conducted on paint glazes of various shades where the medium-value paints exhibited higher sensitivity to light than their darker and lighter counterparts [27,28]. A red

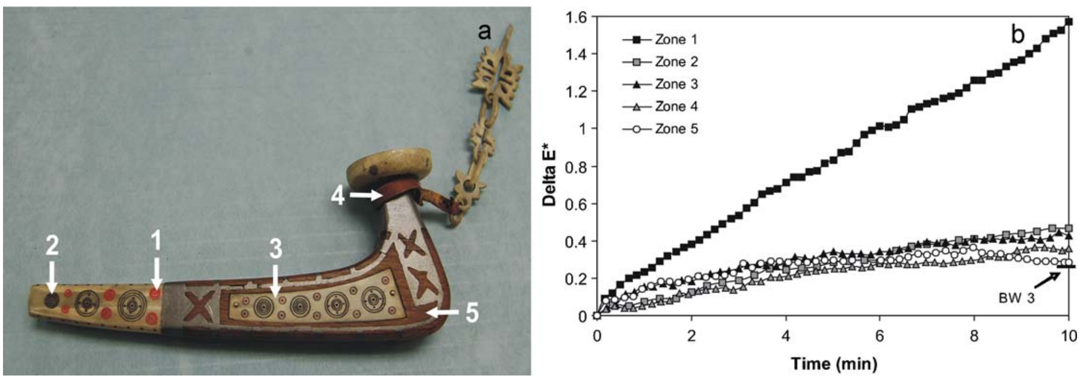

Fig. 3. (a) Saint Lawrence Island (SLI) Yupik pipe showing various areas evaluated with the micro-fading tester (MFT); (b) micro-fading curves obtained for five zones indicated in the photograph.

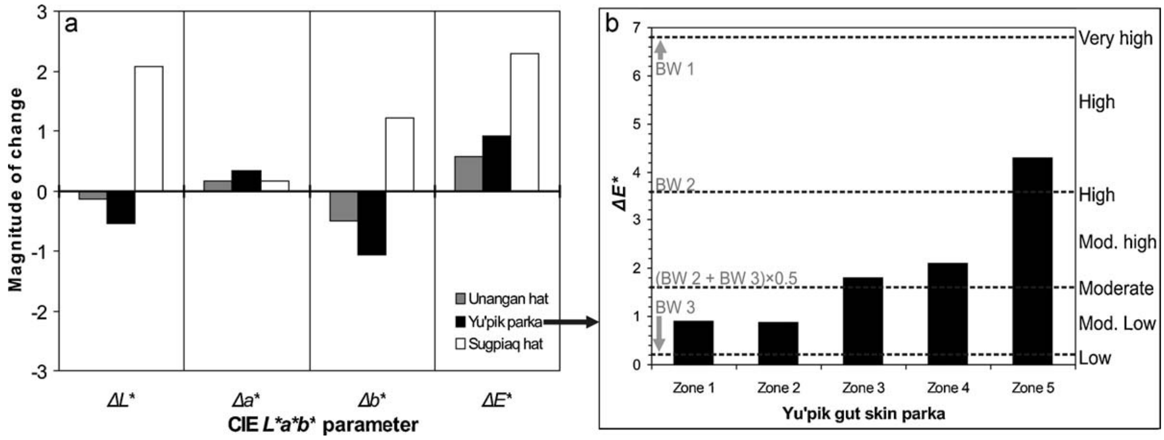

Fig. 4. (a) Summary of micro-fading test results for various areas of gut skin from three objects surveyed; (b) magnitude of color changes observed for five areas of a Yup'ik gut skin parka.

colorant applied to ivory surfaces of a SLI Yupik pipe exhibited moderate to low light-fastness relative to other tested areas. The higher sensitivity of this red pigment relative to the other components of the pipe shows the necessity of performing micro-fading tests on several areas of each artifact.

Micro-fading data of objects containing comparable materials can be used to examine their relative sensitivities to light. For example, CIE $L^*a^*b^*$ parameters from various gut skin areas of a Unangan hat, a Yup'ik parka, and a Sugpiaq hat are compared in Fig. 4a. All gut skin areas experienced slight increases in redness values. The headband of the Sugpiaq hat recorded an increase in lightness and yellowness while the Yup'ik parka and **the Unangan hat** experienced a decrease in these two parameters. **Further examination of several areas of the Yup'ik gut skin parka revealed that the object was composed of materials showing different light-sensitivities. Color changes measured on five different zones are compared in** Fig. 4b. **Fading rates with ΔE^* values of 0.91 and 0.89 were observed for zones 1 and 2 which corresponded to the gut skin and a blue cotton fiber, respectively. Zones 3 and 4 consisted of a light orange grass fiber and a purple colored cotton fiber used to sew the seams. These two zones showed moderate sensitivity to light. Hood seams were sewn with a yellow grass fiber similar to the orange one defined as zone 3. This yellow fiber exhibited a fading rate, which was greater than that of BW 2 and was therefore classified as a highly sensitive material. It can be seen that although the gut skin area (zone 1) alone made possible to classify the object initially as one with moderate-low sensitivity, additional tests demonstrated that there were areas of moderate and high light-sensitivity**. **As a result of this data analysis, the Yup'ik gut skin parka was classified as a highly sensitive object.** Similarly, every artifact was classified into a specific sensitivity group based on the micro-fading data (Table 3). The highest ΔE^* values obtained for particular areas of an object were indicative of its overall stability and was used as the main classification criterion, as explained in the analysis of the Yup'ik parka. Every object studied contained areas of moderate light-sensitivity with fading rates between those of BW 2 and BW 3. The Tlingit Chilkat leggings and the Unangan grass matt contained areas with fading rates smaller than the one recorded for BW 3 suggesting that they are stable objects. However, the Unangan grass matt also contained fugitive dyes, which placed this artifact in a much lower stability category. This emphasizes the necessity of measuring enough areas before making a final decision about the stability of an object. The Athabaskan basket exhibited moderate sensitivity while the Chukchee woman's boots, the Sugpiaq hat, and Athabaskan hat contained red colorants which experienced color changes with final ΔE^*s of 2.8, 2.8, and 2.6, respectively. For this reason, these objects were placed in the moderate-high sensitivity group. The medium-value hide, red pigment applied to ivory, and the bleached hide were the most sensitive areas on the Tlingit baby carrier, SLI Yupik pipe, and Eskimo man's boots, respectively. These areas exhibited final ΔE^*s of 1.5, placing these objects in the moderate-low sensitivity group. The Athabaskan mittens, Tlingit Chilkat leggings, Athabaskan tobacco bag, Chukchee hood, and Tlingit tunic exhibited low sensitivity to light.

Micro-fading data have been used as an initial point for establishing adequate exhibition conditions for objects in the Arctic Studies Center. Light level measurements have been recorded in most exhibition areas of the museum at different times of the day and at various times of the year. This information has permitted to estimate the annual exposures for several display areas on the second floor of the museum where these artifacts will be displayed. Estimated light exposures were obtained from photometric measurements, number of hours of museum lighting, computer modeling of daylight, and meteorological information obtained for the specific geographical location of the building. Maximum illuminance levels obtained via natural light occur during the March and September equinoxes at approximately 16:00 h. Approximated annual exposures were in the 135 to 150 klx·h range depending on the location and orientation of the objects towards the windows on the west wall of the gallery. Therefore, if all evaluated materials obey the reciprocity principle of light exposures then the

Table 3
Classification of artifacts based on their light-sensitivities.

Object	Sensitivity	Minimum exposure capable of inducing a noticeable change (klx·h)
Yup'ik gut skin parka	High	220
Unangan grass matt	High	330
Chukchee woman's boots	Moderate-high	420
Unangan hat	Moderate high	422
Sugpiaq hat	Moderate-high	422
Athabaskan basket	Moderate	≈667
SLI Yupik pipe	Moderate-low	–
Tlingit baby carrier	Moderate-low	–
Eskimo man's boots	Moderate-low	–
Athabaskan tobacco bag	Low	–
Athabaskan mittens	Low	–
Tlingit Chilkat leggings	Low	–
Chukchee hood	Low	–
Tlingit tunic	Low	–

SLI: Saint Lawrence Island.

total light dose reached at the end of a micro-fading test would be approximately equal to a 4-year museum exposure.

Micro-fading results have been contrasted with various scales used for estimating the times and exposures required to produce a noticeable fade in sensitive artifacts under equivalent museum lighting exposures. The majority of ethnographic artifacts surveyed fall within BW 2 and BW 3 with the exception of the Yup'ik gut skin parka, which contained areas that exhibited fading rates slightly above that of BW 2. According to Tétreault, the objects evaluated fit into a high-sensitivity category (BW 1–3) in which a lowest observed adverse effect dose can be reached after a 1 Mlx·h exposure [29]. Materials falling into the BW 1–3 category are rated as highly responsive (R3) in a similar scale proposed by the CIE in 2004 [30]. Highly responsive materials are subdivided into three groups namely ISO 1, 2, and 3 with corresponding number of years to noticeable fade of 2, 7, and 20, respectively. More recent lighting policies include the ones developed at the National Museum of Ethnology in Leiden and the National Museum of Australia [31,32]. After comparing the micro-fading results with these two scales, it was observed that the objects fall into the sensitive 2 (ISO 2–3) and about BW 2–3 classifications. These two systems propose similar exhibition recommendations of 2 years per decade in order to reach an acceptable noticeable change over a 50-year period. The lighting framework developed by Ford and Smith makes an important distinction between exposure of high significance (high use objects) and exposure of average significance (lower use objects) [32]. In a 10-year period, higher use and lower use objects belonging to the about BW 2–3 class are allowed to be exhibited for 2 and 5 years, respectively.

In the present study, a ΔE^* of 2 was considered a JND. Minimum exposure doses obtained with the MFT capable of inducing a 2 ΔE^* in one or more areas of each artifact are reported in Table 3. These data allowed estimating the number of years of museum lighting required to induce a perceptible change based on the current lighting schedule of about 3000 hours per year and an average illuminance of 50 lx. For example, objects in the high and moderate-high categories would be expected to show a noticeable color change after approximately 2 to 4 years of continuous museum exposure. The Athabaskan basket exhibited moderate sensitivity and could potentially show a noticeable color change after 7 years of museum exposure. After a 10 min test, it was not possible to reach an exposure dose capable of inducing a noticeable color change in any of the eight objects belonging to the moderate-low and low sensitivity classes. These results may be correlated with the data from the CIE report. For example, a 2-year exhibition limit recommended by the CIE for an ISO 1 object could be compared to micro-fading exposures equivalent to 2–4 years of exhibition obtained for high and moderate-high sensitive objects. An object with moderate sensitivity within the R3 category would require approximately 7 years in a museum to experience a noticeable color change. This correlates with the exposure time required to induce a noticeable change on the Athabaskan basket (~6.7 years), which was identified as a moderately sensitive object. Finally, the CIE establishes that materials exhibiting higher light-stability would show a significant change after approximately 20 years of museum exposure. Although micro-fading tests were not able to induce a 2 ΔE^* in eight of the artifacts after 10 min, the data indicates that artifacts belonging to the moderate-low and low sensitivity may experience a noticeable change around that time period depending on their rating. After considering all four systems, it is recommended that objects falling into the high and moderate-high sensitivity class are exhibited for 0.5 and 1 year per decade, respectively. Objects exhibiting moderate and moderate-low sensitivity should be exhibited for 2 years per decade while artifacts in the low sensitivity class may be displayed for 5 years every decade.

Although color stability measurements made with the MFT should be essential before exhibiting light-sensitive artifacts, it should be noted that these evaluations form part of complex collections preservation decisions covering many aspects such as intensity of illumination, duration of exhibition, rotation of exhibits, temperature and relative humidity levels, and presence of atmospheric pollutants, among others. It must be emphasized that an average illuminance of 50 lx is a relatively low value after considering daylight contributions during the summer months and direct light sources. Moreover, the lighting schedules in the galleries must also be verified since evening events and gallery maintenance tasks may result in a larger exposure than anticipated. All these variables could significantly reduce the time required to reach a noticeable change.

5. Conclusions

A MFT has been employed to evaluate the light-fastness of a series of Alaska Native heritage objects that will be on exhibit at the Smithsonian Institution Arctic Studies Center. The light-fastness of 14 representative objects, which contain typical materials found throughout the collection, was investigated in order to identify the materials having higher sensitivity to light with the purpose of establishing gallery lighting and duration of exhibition protocols. BW standards offered an adequate reference scale to evaluate the fading rates of these complex multi-material artifacts since the light-sensitivity of unknown and reference materials was comparable. The majority of the objects surveyed contained areas with sensitivities that were between those of BW 2 and BW 3. Three important aspects have been revealed from this research. First, it is not always possible to make generalizations in terms of the stability of a particular material found in different objects due to the inherent properties of individual materials. This has been the case of artifacts with either leather or gut skin components, which have shown diverging fading rates. The second aspect was the detection of zones exhibiting various light-sensitivities, which could range from stable to fugitive after evaluating multiple materials within the same object. For this reason, it is essential to carry out an exhaustive testing program since preliminary results may indicate that the artifact under investigation is relatively light-stable when opposite circumstances may be encountered after considering a larger number of areas. Third, caution must be exercised when interpreting micro-fading test results since a material that exhibits a small change in ΔE^* might behave this way due to a previous loss of colorant indicating that it has already reached maximum fading. This has been the case for the majority of colorants found in a variety of textile substrates.

There is a considerable amount of research published on the effects of light on sensitive museum materials. However, most of these studies have been devoted to evaluate the amount of damage produced by a high intensity light source using traditional accelerated aging methods. Although laboratory samples usually contain comparable materials to the ones found in ethnographic objects, most heritage objects have had longer exposure to various types of radiation including UV light since they are associated to a history of use. The MFT provides a more accurate way of evaluating color alterations since measurements are carried out over the surface of actual artifacts. The experimental parameters used during a micro-fading test are evidently different from the ones encountered in museum display conditions. **Micro-fading experiments only take into account the effect of light under typical laboratory conditions. However, it must be emphasized that in a museum environment other external factors such as temperature, relative humidity, and atmospheric pollutants may act in conjunction with light to affect the fading rate of a colorant.**

For these reasons, the results from this investigation should be employed as an indication of the potential color change that an object may undergo after an equivalent exposure to museum lights, rather than as a prediction of a future degree of color alteration resulting from exhibition lighting. The MFT is a very promising tool for conducting light-fastness surveys of artifacts prior to their exhibition and it can be employed in conjunction with other museum conservation strategies such as color measurements taken directly from the artifacts, light dosimeters, and a systematic light levels monitoring program. **Future research includes characterization studies of light-sensitive materials found in the collection with the aim of determining which chromophores are present and proposing possible degradation routes.** Micro-fading tests have revealed an overall greater light-stability than expected for these ethnographic materials. Hence, this technique offers a unique way of verifying the sensitivity of an object rather than just relying on experience and visual assessments.

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References

[1] G. Thomson, The Museum Environment, Butterworth-Heinemann, London, 1986.
[2] B.L. Ford, Monitoring color change in textiles on display, Studies in Conservation 37 (1) (1992) 1–11.
[3] S. Michalski, Damage to museum objects by visible radiation (light) and ultraviolet radiation (UV), in: Lighting in Museums Galleries and Historic Houses, Bristol, April 9–10, The Museums Association, London, 1987, pp. 3–16.
[4] R.L. Feller, Control of deteriorating effects of light upon museum objects, Museum 17 (2) (1964) 57–98.
[5] T. Padfield, S. Landi, The light-fastness of the natural dyes, Studies in Conservation 11 (4) (1966) 181–196.
[6] K. Yoshizumi, P. Cox-Crews, Characteristics of fading of wool cloth dyed with selected natural dyestuffs on the basis of solar radiant energy, Dyes and Pigments 58 (2003) 197–204.
[7] L.G. Salmon, G.R. Cass, The fading of artists' colorants by exposure to atmospheric nitric acid, Studies in Conservation 38 (1993) 73–91.
[8] H. Kühn, The effect of oxygen, relative humidity and temperature on the fading rate of watercolours: reduced light damage in a nitrogen atmosphere, in: G. Thomson (Ed.), Contributions to the London Conference on Museum Climatology, London, September 18–23, International Institute for Conservation of Historic and Artistic Works, London, 1968, pp. 79–85.
[9] D. Saunders, J. Kirby, A comparison of light-accelerated ageing regimes in some galleries and museums, The Conservator 25 (2001) 95–104.
[10] E.A. Moffatt, P.J. Sirois, J. Miller, Analysis of the paints on a selection of Naskapi artifacts in ethnographic collections, Studies in Conservation 42 (1997) 65–73.
[11] A. Fox, C. Heron, M.Q. Sutton, Characterization of natural products on Native American archaeological and ethnographic materials from the Great Basin Region, USA: a preliminary study, Archaeometry 37 (1995) 363–375.
[12] E. Schaffer, Fiber identification in ethnological textile artifacts, Studies in Conservation 26 (1981) 119–129.
[13] K. Hallett, S. Bradley, Ultraviolet-filtered lighting and cellulose degradation: evaluating the effect of light exposure on ethnographic collections, The Conservator 27 (2003) 3–12.
[14] H. Ozgunay, Lightfastness properties of leathers tanned with various vegetable tannins, Journal of the American Leather Chemists Association 103 (2008) 345–351.
[15] N. Herascu, M. Simileanu, R. Radvan, Color changes in the artwork materials aged by UV radiation, Romanian Reports in Physics 60 (2008) 95–103.
[16] Smithsonian Institution, Alaska Native collections sharing knowledge, Smithsonian Institution, Alaska, 2007. http://alaska.si.edu/.
[17] P.M. Whitmore, X. Pan, C. Bailie, Predicting the fading of objects: identification of fugitive colorants through direct nondestructive light-fastness measurements, Journal of the American Institute for Conservation 38 (1999) 395–409.
[18] CIELAB, 1976, Official recommendations on uniform color spaces, color difference equations, and metric color terms, Commission International de l'Éclairage, Vienna, 1978.
[19] R. Johnston-Feller, Color Science in the Examination of Museum Objects: Non Destructive Procedures, The Getty Conservation Institute, Los Angeles, 2001.
[20] G. Sharma, Color fundamentals for digital imaging, in: G. Sharma (Ed.), Digital Color Imaging Handbook, CRC, Florida, 2002, pp. 1–114.
[21] A. Berger-Schunn, Practical Color Measurement a Primer for the Beginner a Reminder for the Expert, John Wiley and Sons, New York, 1994.
[22] P.M. Whitmore, Pursuing the fugitive: direct measurement of light sensitivity with micro-fading tests, in: H.K. Stratis, B. Salvesen (Eds.), The Broad Spectrum: Studies in the Materials, Techniques and Conservation of Color on Paper, Chicago, 5–9 October 1999, Archetype, London, 2002, pp. 241–244.
[23] British Standards Institution BS 1006, Methods of Test for Colour Fastness of Textiles and Leather, British Standards Institution, London, 1990.
[24] M. Bacci, C. Cucci, A.A. Mencaglia, A.G. Mignani, S. Porcinai, Calibration and use of photosensitive materials for light monitoring in museums blue wool standard 1 as a case study, Studies in Conservation 49 (2004) 85–98.
[25] P.M. Whitmore, The Scientific Examination of Works of Art on Paper, in: A.M. Sackler (Ed.), Colloquium on Scientific Examination of Art: Modern Techniques in Conservation and Analysis, Washington DC, 19–21 March 2003, National Academy Press, Washington DC, 2005, pp. 27–39.
[26] C. Samuel, The Chilkat Dancing Blanket, Pacific Search, Seattle, 1982.
[27] P.M. Whitmore, C. Bailie, Further studies on transparent glaze fading: chemical and appearance kinetics, Journal of the American Institute for Conservation 36 (1997) 207–230.
[28] S.A. Connors, P.M. Whitmore, R.S. Keyes, E.I. Coombs, The identification and light sensitivity of Japanese woodblock print colorants: the impact on art history and preservation, in: P. Jett, J. Winter, B. McCarthy (Eds.), Scientific Research on the Pictorial Arts of Asia, Proceedings of the Second Forbes Symposium at the Freer Gallery of Art, Washington DC, 18–20 September 2003, Archetype, Washington DC, 2005, pp. 35–47.
[29] J. Tétreault, Airborne Pollutants in Museums, Galleries and Archives: Risk Assessment, Control Strategies, and Preservation Management, Canadian Conservation Institute, Ottawa, 2003.
[30] CIE 157:2004, Control of damage to museum objects by optical radiation, Commission internationale de l'éclairage, Austria, 2004.
[31] A.W. Brokerhof, M. Reuss, F. MacKinnon, F. Ligterink, H. Neevel, F. Fekrsanati, S. Graeme, Optimum access at minimum risk: the dilemma of displaying Japanese woodblock prints, in: D. Saunders, J.H. Townsend, S. Woodcock (Eds.), Conservation and Access: Contributions to the London Congress, 15–19 September 2008, International Institute for Conservation of Historic and Artistic Works, London, 2008, pp. 82–87.
[32] B. Ford, N. Smith, The development of a significance and risk based lighting framework at the National Museum of Australia, in: Conserving Public and Private Collections: AICCM National Conference, Fremantle, 21–25 September 2009, National Museum of Australia, Canberra, in press.