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PREVENTIVE CONSERVATION

A reality check for microfade testing: Five examples

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ABSTRACT

This paper describes five instances in which it has been either possible to semi-quantitatively compare microfade lightfastness test results to fading on display, or to place upper limits on the technique's inaccuracy. They include textile dyes, inks, natural fibres, acrylic paints and hand-coloured historic photographs, each displayed under different lighting conditions encompassing typical low-lux museum lighting, direct and indirect UV-filtered indoor sunlight and unknown historical exposures. The paper concludes that, where it can be tested, the accuracy of microfade testing is sufficient to proactively manage the risk of light fading with a great deal less uncertainty than heuristic light exposure guidelines.

INTRODUCTION

For nearly a decade the National Museum of Australia (NMA) has used microfade testing to screen objects for colourfastness prior to long-term exhibition. This has allowed conservators to pinpoint and protect dyes and pigments that may be rapidly damaged on display, even under controlled museum conditions. Microfading also identifies objects which can be confidently exhibited for longer than recommended by heuristic lighting guidelines like CIE 157:2004 (CIE 2004), allowing greater public access with very significant reductions in the object handling, time and expenditure associated with worst case scenarios (Ford and Smith 2010).

Accelerated studies are clearly superior to the guesswork involved in assigning unknown colourants to lightfastness categories; however, there are concerns that the very high light levels involved in microfade testing in particular (millions of lux) might seriously misrepresent lightfastness under ambient conditions if the 'reciprocity principle', upon which all accelerated fading studies depend, were to 'fail'. This principle holds that the same light dose (lux hours) causes the same colour change (ΔE) irrespective of intensity (lux). Crucially, underestimation of real fading rates is plausible for a number of reasons, but cannot be predicted because it is a property of the particular colourant-substrate system, not of the test itself (Whitmore et al. 1999).

It is therefore important to take advantage of opportunities that occur – whether by circumstance or design – to compare actual light fading of colourants on display with accelerated estimates. The Museum's exposure guidelines aim to limit colour change to 1 just-noticeable difference (1 JND = $1.6\Delta E_{00}$) in 50 years, or less than 0.32 ΔE during a typical permanent exhibition (Ford and Smith 2009). Because colourimetric measurement errors are typically of this order (e.g. Figure 2, bottom), it is difficult or impossible to validate microfading 'predictions' without very long measurement campaigns. Nevertheless, collections do present opportunities to semi-quantitatively field-test microfading predictions; for example it should be possible to determine if it systematically and seriously underestimates fading rates by colourimetrically tracking dyes and pigments to identify examples that have faded much faster than expected. Other situations include differentially exposed textiles;

photographs and paintings partly protected from light under frames and mats; exposed and unexposed versions of the same object; and colourants exposed to high light intensities, particularly if exposure histories can be estimated.

Five such examples from the NMA are presented. They include a modern tapestry (*The Crimson Thread of Kinship*, 2001), an acrylic painting (*Martumili Ngurra*, 2009) and a contemporary reconstruction of a traditional Tasmanian paperbark canoe (2012). Each were exposed to unusually high lux levels in UV-filtered day-lit spaces for extended periods, and colourimetrically monitored as a safety check on prior microfading results. Cumulative exposures were extrapolated from intermittent electronic light and UV logging, and ISO Blue Wool Fading Standards (BWs) were used as integrating light dosimeters. The other two objects are a hand-coloured photograph containing a dye that faded completely within four years at 50 lux, and a badly faded CMYK printed poster (the *Coulter Panorama*, 1911), for which an archived pristine copy was available for comparison. In these cases the pre- and post-exposure colours were not measured, however, the differences were visually obvious.

Figure 1. Microfade testing of the acrylic painting *Martumili Ngurra* (top). In-situ colour measurement (bottom). The location and orientation of the measuring head is photographically recorded for future replication

METHODS

Microfading

The Oriel Microfade Tester (Newport) was substantially as described by Whitmore et al. (1999). A Thorlabs FM02 hot mirror filtered the xenon test illumination to approximately 400–710 nm (< 0.5% below 400 nm). A photometric intensity of approximately 6 Mlux delivered a light dose of approximately 1 Mlux hour to the 300-um-diameter test area over the 10-minute test duration. BWs 1–3 were used as internal calibration standards and approximate lightfastness (Mlux h/JND) was calculated from data for UV-free illumination in CIE 157 (Table 3.3). CIE 157's estimates of BW lightfastness, which are based on a literature survey by Michalski (1987), are approximate with a possible uncertainty as large as 'one blue wool step' (Michalski 2010). Recently, two independent unpublished controlled exposure experiments have found BW 1 to be closer to 0.1 Mlux h/JND than 0.3 Mlux h/JND in CIE 157, and were in reasonable agreement for BWs 2–4 (Druzik 2014, Tse 2016).

Colourimetry

In-situ colour measurements were made using an X-Rite ColorEye XTH handheld spectrometer. Colour change (ΔE_{00}) was calculated from L*a*b* values (D65 illuminant, specular included, 2 degrees observer) according to the CIEDE2000 equation (CIE 2001). The instrument was calibrated using the supplied white tile. The ColorEye XTH has location templates for large (10 mm illuminated/5 mm measured) and small (5 mm/2 mm) diameter test areas. The larger was used for the BWs, tapestry and canoe measurements and the smaller for the acrylic paint dots. The head was relocated using close-up photographs of its position during the initial readings (Figure 1, bottom).

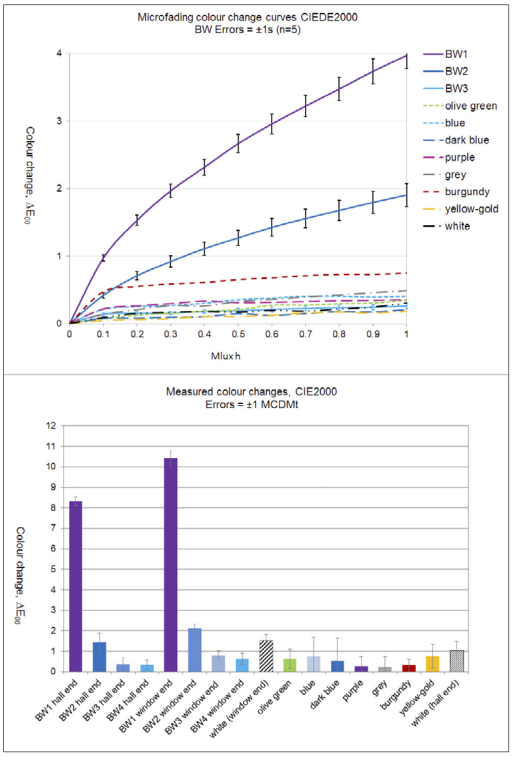

Figure 2. *Crimson Thread of Kinship* microfading results (top). In-situ colourimetry at 0.9 Mlux h (bottom). The reason for the proportionally larger in-situ response of BW 1 compared to microfading is unknown, but likely to be illuminant spectral power and/or BW batch differences

Average L*a*b* values were calculated from 10 independent replicates in which the ColorEye XTH was removed and repositioned each time. A statistical measurement, 'mean colour distance from the mean' (MCDM), was used to assess replicate measurement errors. Only colour differences in which $MCDMt/\Delta E_{00} < 0.5$ were considered significant, where MCDMt is the sum of the before and after measurement errors (Berns 2000).

Light monitoring

Light (Lux) and UV (mW/m^2, µW/lm) were episodically logged at different times of the year using an Elsec 765 environmental monitor placed as close as possible to, and in the same plane as, the objects' exposed surfaces (Table 1, Figure 8). Cumulative annual (Mlux h/year) and total light exposures (Mlux h) were extrapolated from the logging results. Strips of BWs 1–8 were similarly positioned. Half of each strip was covered with a removable light-proof cardboard shield as a reference, and half exposed. Approximate light doses were calculated from colourimetric monitoring of the exposed and unexposed areas using the calibration data for UV-free illumination from CIE 157 (Table 2) and lightfastness estimates (Mlux h/JND) were back-calculated from colour change and electronically logged values.

Architectural sunlight modelling

Light mapping in the hall employed an Ecotect model developed from a 3DS and CAD file. An 'augmented reality' smartphone sun path application, Sun Seeker, was also used to determine the time of year when direct sunlight penetrated the window adjacent to the tapestry.

RESULTS AND DISCUSSION

Crimson Thread of Kinship tapestry

In 2012, the 12-m tapestry was displayed for 8 months adjacent to a UV-filtered (<100 µW/lm) northeast-facing window in a corridor where it was exposed to indirect sunlight reflected from the white painted wall opposite. Because it had been woven for the museum by the Australian Capital Territory Embroiders' Guild for the centenary of the Federation of Australian in 1901, there was strong community interest in seeing it displayed, but few other walls of sufficient length. The tapestry was not available for microfade testing prior to display; however, a selection of the (pristine) woollen yarns from which it was woven, accessioned with the tapestry in 2001, were tested instead.

In the authors' experience, modern textile dyes are usually of 'medium responsivity' (defined in CIE 157 as more lightfast than BW 3); however, exceptions are not uncommon. In this case, the microfading results clustered around BW 3, with the exception of 'burgundy' which initially responded rapidly (less than a JND) and stabilised after the first 0.1 Mlux h (Figure 2, top). This is a common pattern for textile dyes, which Giles et al. (1961) attributed to the rapid fading of residual un-mordanted dye. This should affect the pristine yarns more than the tapestry itself, which had been displayed previously. The other dye fading curves were similar in this respect, but with smaller initial changes. It is arguable that this early response can be discounted and that the dyes belong in a higher lightfastness category than the microfading indicates.

The response of the wool itself is that of the white yarn, which on display darkened (-DL*) and became less yellow (-Db*), more so near the window where light levels were higher. Yellowness also decreased with microfading, but lightness increased (+DL*). Differences may reflect soiling and thermal reactions, both of which are in principle unable to be measured by microfading, which only accelerates photochemical reactions. The underlying wool response (and early rapid fading) may dominate early colour change particularly of light-coloured lightfast dyes in pristine textiles, and estimates based on linear extrapolations of early single-point colour measurements may underestimate their long-term lightfastness.

Martumili Ngurra acrylic painting

This 2.5 × 5m acrylic landscape, painted in 2009 by a group of Martu women from the central Western Australian desert, was displayed in the museum's extensively glazed Main Hall for three years. Direct sunlight penetrates the hall through UV-filtered northeast-facing bay windows, especially in winter when the sun is low, and also through the overhead skylights from mid-spring to mid-autumn (Table 1). It has moderate temperature control and relative humidity (RH) ranges from 15–85%. Although not designed as an exhibition space. the Main Hall has been repurposed to display a diverse array of collection items, and microfade testing is used to screen all potentially light-sensitive items proposed for display there. The painting was exhibited at a location and orientation within the space that, according to the results of architectural sunlight modelling, received only indirect sunlight throughout the year. Nevertheless the annual cumulative exposure of about 1.2Mlx h (Table 1) was many times that of controlled lighting situations in the museum galleries (0.2–0.3Mlx h/year).

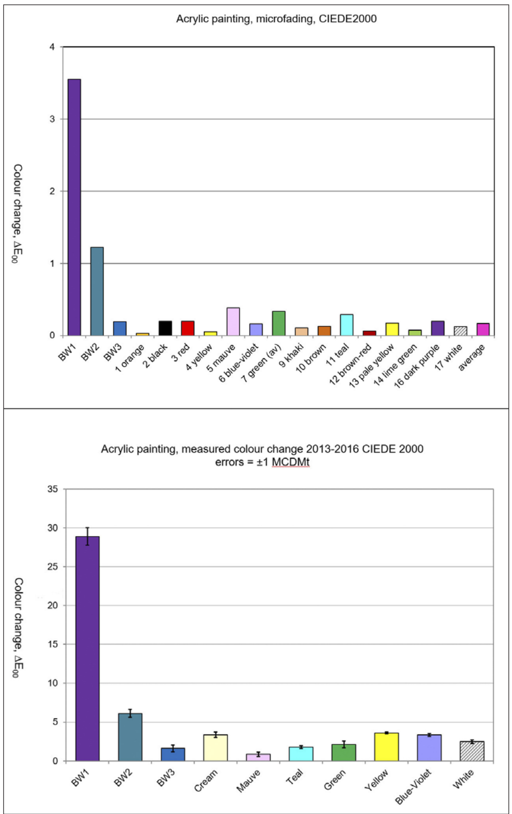

Figure 3. *Martumili Ngurra* acrylic painting microfading results (top). In-situ colourimetry (bottom)

Although CIE 157 states that ASTM compliant modern pigments 'are all in the irresponsive or low responsivity categories of lightfastness' the authors have found examples within the NMA's indigenous collection well within the 'high responsivity' range (Ford and Smith 2011); therefore, the main concern was that this painting might contain them too. Microfading suggested this was unlikely (Figure 3, top), an assessment that was supported by colourimetrically monitoring a subset of paints able to be measured in situ (Figure 3, bottom). Assuming the white pigment is titanium dioxide, its apparent colour change (+ΔL*, -Δb*) under ambient and accelerated conditions represents bleaching of the yellowed medium (Whitmore et al. 2002). The colourimetry may also have been affected by gloss changes, including soiling, which was assessed by measuring the colour of the white paint before and after swabbing with a damp cotton bud. Although lightness increased, the overall colour change was not significant (MCDMt/ΔE>0.5). Particulate matter adheres strongly to dried acrylic emulsions because of the polymer's low glass transition temperature, and therefore the cleaning may not have been effective (Jablonski et al. 2004).

Tasmanian bark canoe

The 4.7-m traditional Tasmanian Aboriginal canoe (based on historic European illustrations) was commissioned by the museum and built in 2012 by the Aboriginal Tasmanian artist Rex Greeno. It was exposed for over four years to direct sunlight and radiant heating very close to one of the northeast-facing windows, where it was acknowledged that its rich brown colour would fade and that it would probably sustain mechanical damage (Figure 4, bottom). The 14-Mlux hr/year exposure (Table 1) is nearly two orders of magnitude greater than normal museum doses; therefore, in this case the ambient and microfading comparison is essentially between two accelerated tests which both placed the bark in the BW 2–3 lightfastness range (Figure 5). Whilst the bark lost chroma and lightened in both cases, the colour change patterns were not exactly the same. As with wool (above) and other natural fibres, differences between microfading and real-time ageing were expected because of the contribution of concurrent thermal reactions to colour change (Hallett and Bradley 2003).

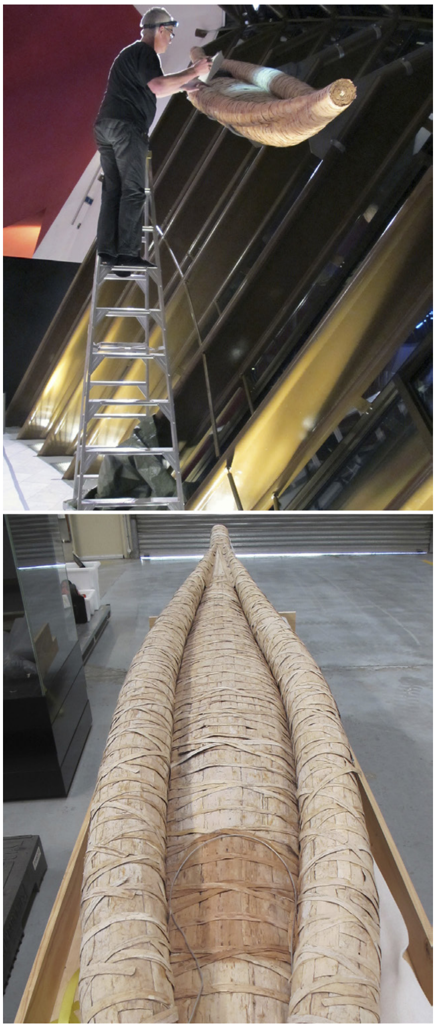

Figure 4. Paperbark Tasmanian canoe suspended against windows (top). Fading apparent where a hearth protected the paperbark from light (bottom)

Hand-coloured photograph

A page from a 1920s album containing the hand-coloured photograph in Figure 6 was accidentally left on display, despite a microfading report which advised that many of the dyes were fugitive and regular page turns were necessary. Unfortunately, they were not implemented and the photograph was exhibited for four years at 50 lux (UV-free), during which time the blue dye faded completely. Hand-coloured photographs are routinely tested at the NMA because, although the AIC's photographic lighting guidelines recommend displaying them as if they were all 'very light-sensitive', many are not fugitive and do not warrant restricting their display to the recommended equivalent of about six months/decade at 50 lux (von Waldthausen 2003). Although aniline dyes of very poor lightfastness were used, so were mostly lightfast watercolour paints (Wagner et al. 2001, Lavédrine et al. 2009).

In this case, Druzik and Tse's (personal communications 2016) revised calibration data for BW 1 (~0.1 Mlux h/JND) suggest exposure for only a few weeks/decade pro rata to remain within the NMA's tolerance for colour change; much more conservative than either the AIC's or the earlier microfading recommendation, both of which would have resulted in serious fading after a very few exhibition cycles.

The *Coulter Panorama*

The National Australian Archives (NAA) contracted the NMA in 2012 to microfade test two examples of the *Coulter Panorama* (1911; Figure 7), a 2.3-m-long commercial CMYK print of a cycloramic painting of the site upon which the new capital of Australia, Canberra, was to be built. One print was pristine and the other, which had reportedly hung in a government office, contained no trace of magenta and very little cyan, while yellow was largely unfaded. It was microfade tested because the condition of the faded version prompted concerns that its pristine counterpart might fade unacceptably when it was exhibited during Canberra's centenary year.

Had the commemorative panorama been microfade tested in 1910, both the extent and order of the inks' fading after 100 years of intermittent display would have been predicted. Magenta and cyan are both fugitive; however, the cyan fading curve begins to flatten out at ~1 Mlux h, suggesting that it is more lightfast than magenta in the long term. Yellow, at BW 3, is probably 20–30 times more lightfast than magenta. Consistent with the shape of its microfading curve, faded cyan fades more slowly than unfaded.

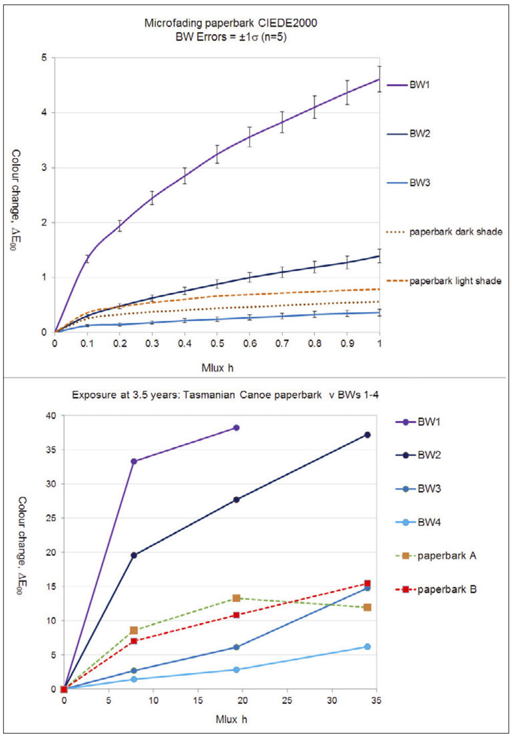

Figure 5. Tasmanian canoe microfading (top). Colourimetry (bottom)

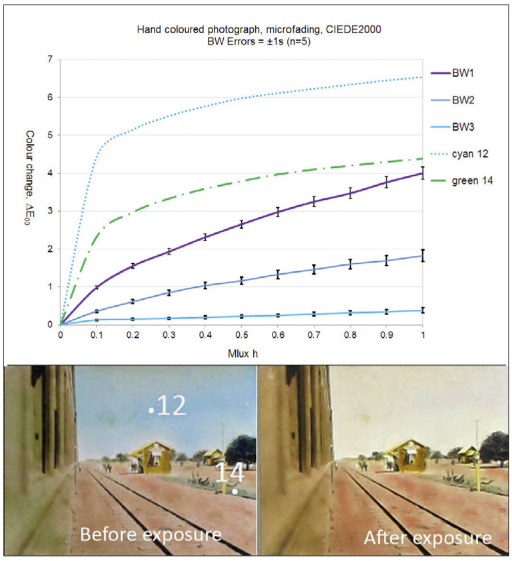

Figure 6. Microfade test results for an early 20th-century hand-coloured photograph (top). Before and after four years on display at 50 lux (~0.8 Mlux h) (bottom)

Blue Wools

Swatches of ISO Blue Wool Fading Standards were mounted alongside the tapestry, acrylic painting and paperbark canoe to assess their usefulness as integrating light dosimeters. Colour change (ΔE_{00}) was calculated from $\Delta(L^*a^*b^*)$ for masked and uncovered swatches (Figure 8, bottom). The calculated lightfastness (Mlux h/JND) of BWs 1–4 is summarised with CIE 157 estimates for UV-free exposure in Table 2. BWs 2–4 are close to those in CIE 157, and the two estimates for BW 1 (0.1 and 0.2 Mlx h/JND) are lower than the CIE 157 value of 0.3 Mlux h/JND. This is consistent with Druzik and Tse's unpublished lightfastness results. Single-figure lightfastness estimates are based on averages or (usually unstated) cumulative exposure endpoints, and because the fading rates of BWs 1–3 decline exponentially, endpoint lightfastness appears to rise with exposure, a pattern apparent in Table 2. In our case, the BWs proved to be reasonably good dosimeters, providing colour change is between about 3 and 10ΔE over the exposure period.

Table 1. Visible light exposures and UV data extrapolated from episodic light logging intervals (Figure 8). Cumulative exposure errors (9.8%) are the standard deviation of six annual dose estimates from separate logging intervals for the acrylic

	Light			UV	
	Mlux h tot (σ)	Mlux h/year (σ)	Lux max	Av mW/m² (σ)	Av µW/lm (σ)
Tapestry	0.9 (0.1)	1.3 (0.1)	1,596	17 (10)	52 (15)
Acrylic	4.1 (0.4)	1.2 (0.1)	7403	8 (10)	25 (6)
Paperbark canoe	46.2 (4.5)	13.6 (1.4)	19,359	109 (140)	56 (19)

Table 2. BW lightfastnesses (Mlx h/JND) calculated from exposures in Table 1, and measured BW colour change (ΔE_{00}). Values omitted where MCDMt / ΔE_{00} >0.5 or colour substantially bleached. Errors are MCDMt plus the light logging uncertainty in Table 1. * max ±1 BW step (Michalski 2010)

	CIE 157	Tapestry location		Acrylic painting location		Paperbark canoe location	
	Mlux h/JND*	ΔE_{00} (σ)	Mlux h/JND (σ)	ΔE_{00}(σ)	Mlux h/JND (σ)	ΔE_{00} (σ)	Mlux h/JND (σ)
BW 1	0.3	9.4 (0.4)	0.1 (0.1)	28.9 (1.1)	0.2 (0.1)	bleached	-
BW 2	1	1.8 (0.7)	0.8 (0.2)	6.1 (0.5)	1.1 (0.2)	37.2 (0.4)	2.9 (0.2)
BW 3	3	-	-	1.6 (0.4)	4.1 (1.5)	14.8 (0.7)	5.0 (0.6)
BW 4	10	-	-	-	-	6.3 (0.5)	11.8 (1.8)

CONCLUSION

Routine microfade lightfastness testing of museum collections offers valuable opportunities to validate the technique as exemplified by these five examples, which were selected from among many others. In theory, periodically monitoring colour change on exhibition is the only definitive indication of lightfastness; however, while this is sometimes possible, it is time consuming, retrospective and usually unrealistic in a museum setting. By contrast, microfade testing is simple, rapid and does not rely on chemical identification or guesswork to place colourants into exposure guidelines' assumed lightfastness categories. Where independent validation has been possible, the indications are that the accuracy of microfade testing is sufficient to proactively manage the risk of light fading with less uncertainty, and far more cost effectively, than any of the generalised lighting guidelines in common use. It is particularly valuable for institutions with significant post mid-19th-century collections in which the majority of colourants are not the relatively well-known and characterised traditional dyes and pigments.

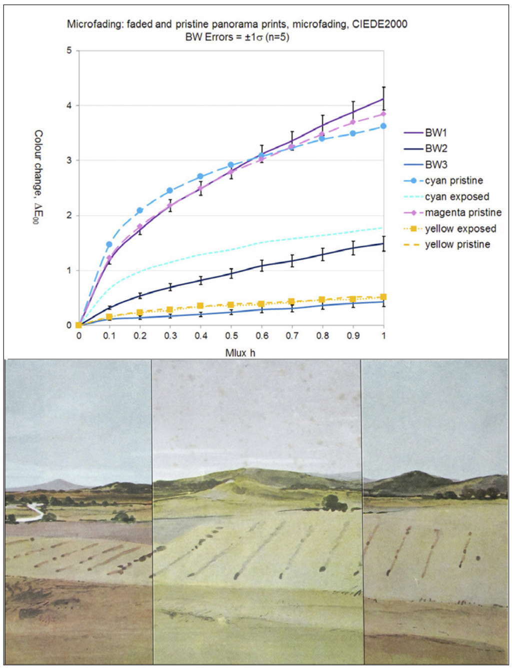

Figure 7. Microfade test results (top). Faded poster (central section) superimposed on pristine version (bottom). Magenta is gone, cyan badly damaged and yellow relatively unaffected

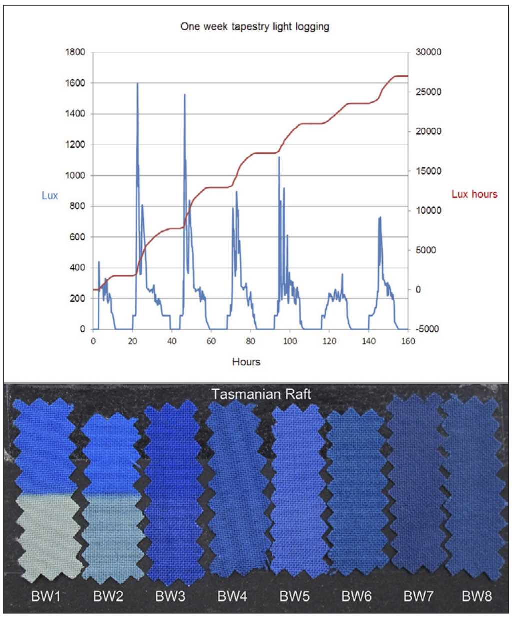

Figure 8. One-week light logging of the tapestry (top). BWs 1–8 placed on the Tasmanian canoe (bottom) after one year's exposure

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MATERIALS LIST

Oriel Fading Test System, Model 80190 (discontinued)
Newport Corporation

Blue Wool Fading Standards
WM Jackson & Company Pty. Ltd
Collingwood VIC, Australia

Sun Seeker augmented reality solar path application
Android and IOS App stores
Developer: OzPDA

X-Rite ColorEye XTH handheld spectrophotometer (discontinued)

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