A Year in the Life of an Inkjet Print – Environmental, Colorimetric, and Visual Assessments

by

Mark H. McCormick-Goodhart

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Figure 1 Framed Print sample # AaI_20071008_DP-01 was first displayed in October, 2007on the second floor of the Hyde House in the main Hall by a west-facing window. It was soon moved in early November, 2007 to the first floor Keeping room (see figure 3). It has recently been hung once again in this original location for ongoing environmental research.

Introduction

Sample # AaI_20071008_DP-01 is an inkjet photographic print made with an Epson Stylus Photo R1800 printer using MIS R800 Equivalent Ink from MIS Associates, Inc. and Red River Ultra Pro Gloss Plus paper from Red River Paper Company. The print was made on August 20, 2007 along with five identical copies and donated to the AaI&A digital print research program by an amateur photographer and printmaker, Gunars Lucans. Gunar's image is entitled "Lake Superior". Sample # AaI_20071008_DP-01 is the first print in the AaI&A digital print research program to be framed with standard acrylic glazing in a picture frame fitted with environmental dataloggers. This work was completed October 10, 2007. The print also contains six sets of color patches with three sets exposed to light (see figures 1, 2 and 3) while the other identical sets are hidden from view and protected from light exposure by the window mat.

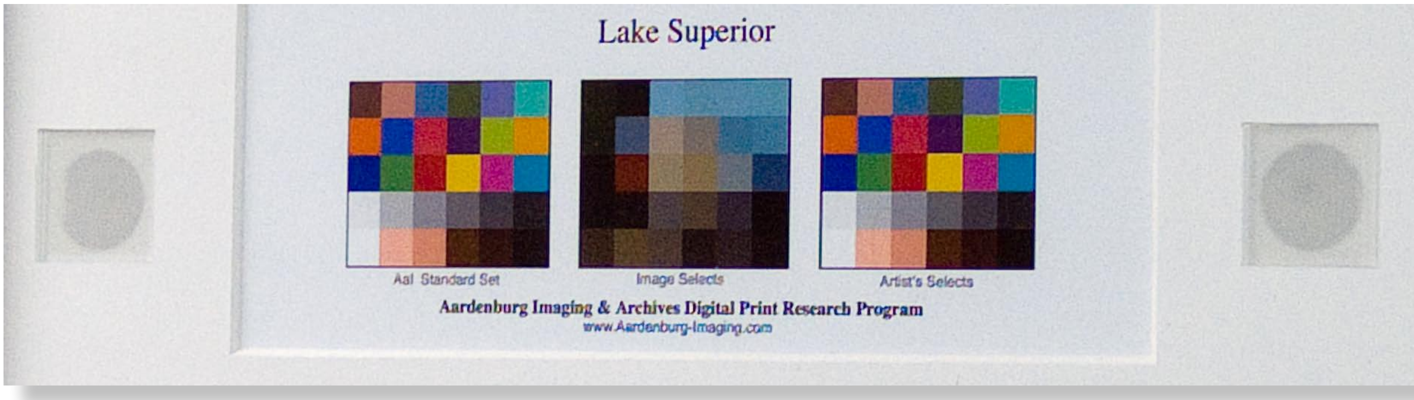

Figure 2. The sets of color control patches consist of the "AaI Standard Set" (also used in AaI&A's standardized accelerated light fade tests and derived largely from the 24 colors of the Macbeth ColorcChecker™ Chart), a center group of colors corresponding directly to the colors in the photographic image, and a group that the printmaker was allowed to customize. No custom colors were chosen, so the "Artist's Selects" group is a replicate of the AaI Standard color set in this case. The two calibrated light sensor ports can be seen in the window mat area to the right and left of the color control patches. Note the cool "blue-white" paper color imparted by optical brightener agents in the ink receptor coating.

The Red River Ultra Pro Gloss Plus inkjet paper is no longer commercially available. It has been replaced by a newer version (Pro Gloss 2). However, the framed print and dark stored copies are representative of many popular resin coated (RC) microporous inkjet media that have a high gloss finish and a bright white paper color. The "bright white" appearance is achieved by the incorporation of optical brightener agents (OBAs) in the ink receptor coating.

The framed print's embedded dataloggers (see figure 4) have been continuously recording temperature, relative humidity,

Figure 3 The print was relocated to a desk surface near a window in the Keeping room of the Hyde House in early November, 2007. The environmental data presented in this report was primarily recorded here.

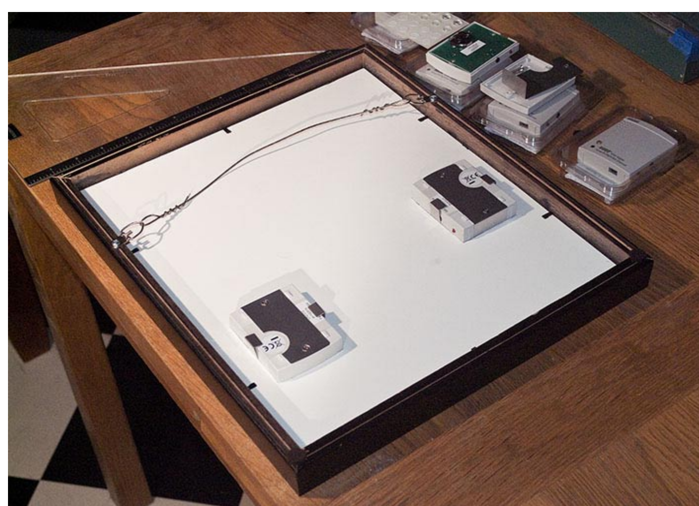

Figure 4 Two Hobo® U12-012 dataloggers made by Onset Computer Corp. are installed in the picture frame assembly so that they detect the temperature, relative humidity, and light levels in the immediate vicinity of the matted print.

and illumination levels at the print surface for approximately 1.5 years to date. The dataloggers have collected 19,275 temperature readings, 19275 relative humidity readings, and almost 60,000 light level readings. The data were exported from the datalogger's software application (Hoboware Pro 2.7.3) as text files and then imported into Microsoft Excel in order to conduct the analyses shown in figures 5-8. Most datalogger software will readily generate graphs like those shown in figures 5 and 6, but the data presented in figures 7 and 8 required more complex filtering and calculations on the raw data than data logger software can typically perform. These analyses were performed efficiently in Excel.

On November 8, 2007, the print shown in figure 1 was relocated to the Keeping Room (see figure 3). There was no particular reason for changing locations other than the fact that this first fully functional environment-monitoring picture frame was routinely being shown to friends, colleagues, and visitors at the Hyde House. The print would be briefly taken off the wall to show the embedded dataloggers, and it simply became easier to leave it on the desk in the Keeping room. Although the former location is a more conventional wall display location situated near three colonial-style windows, the new location on the desk nearby a similar set of windows is comparably illuminated. Both locations have the potential to allow direct sunlight to strike the print, and both are real-world picture display environments (note the other small picture frame on the desk in figure 3).

Temperature and Relative Humidity

The Keeping room at the Hyde house is located in the main structure that was built in 1792. The wooden frame construction of the house cannot be retrofitted with modern insulation in the walls without destroying the architectural details of the home. For reasons of energy conservation and preservation of the collection, the room is only heated to 10˚C (50 ˚F) during the winter months. This low indoor temperature has the positive effect of significantly slowing chemical decomposition rates and also helps the relative humidity to remain above 30% RH rather than plummeting to below 20% during the coldest winter months. The woods and glues used in antique furniture and the paper, paint layers, and other coatings found in prints, paintings, and photographs are hygroscopic. They require some moisture content to be structurally stable and if allowed to dry out too much, large mechanical stresses can develop which in turn lead to cracking, flaking, etc. Attempting to maintain higher temperatures results in greatly decreased relative humidity which then drops below safe limits for many objects in the room. Trying to counter the subsequent drop in relative humidity by the use of a humidifier during the winter months has serious limitations in cold northern U.S. climates and especially in historic buildings that lack the insulation and vapor barrier materials used in more modern construction. Moisture condensation can quickly start to occur in historic buildings within the non insulated walls and on the windows. The low room temperature during the winter months can be readily seen in the graph shown in figure 5. The dataloggers in the picture frame confirm that the thermostat in the room was set to 50 degrees Fahrenheit all winter long. Table I lists maximum, minimum, and average environmental results. The minimum temperature value of 5.9 ˚C (42.4 ˚F) occurred on January 17, 2008 during a power outage. A small emergency generator is maintained on the premises to power the gas-fired boilers in the basement and a select few electrical outlets for emergency lighting when the need arises. It serves as a critical backup to the baseboard hot water heating system that would suffer burst pipes if freezing conditions were allowed to occur indoors. During a power outage under cold outdoor winter temperature conditions, the Hyde house takes several hours to reach the pipe-freezing danger zone, so the manually operated emergency generator is not started immediately. More often than not the utility company has the power outage corrected before the situation becomes serious for homeowners. One of these self-correcting situations caused the minimum recorded temperature during the time period of October 2007 to November 2008.

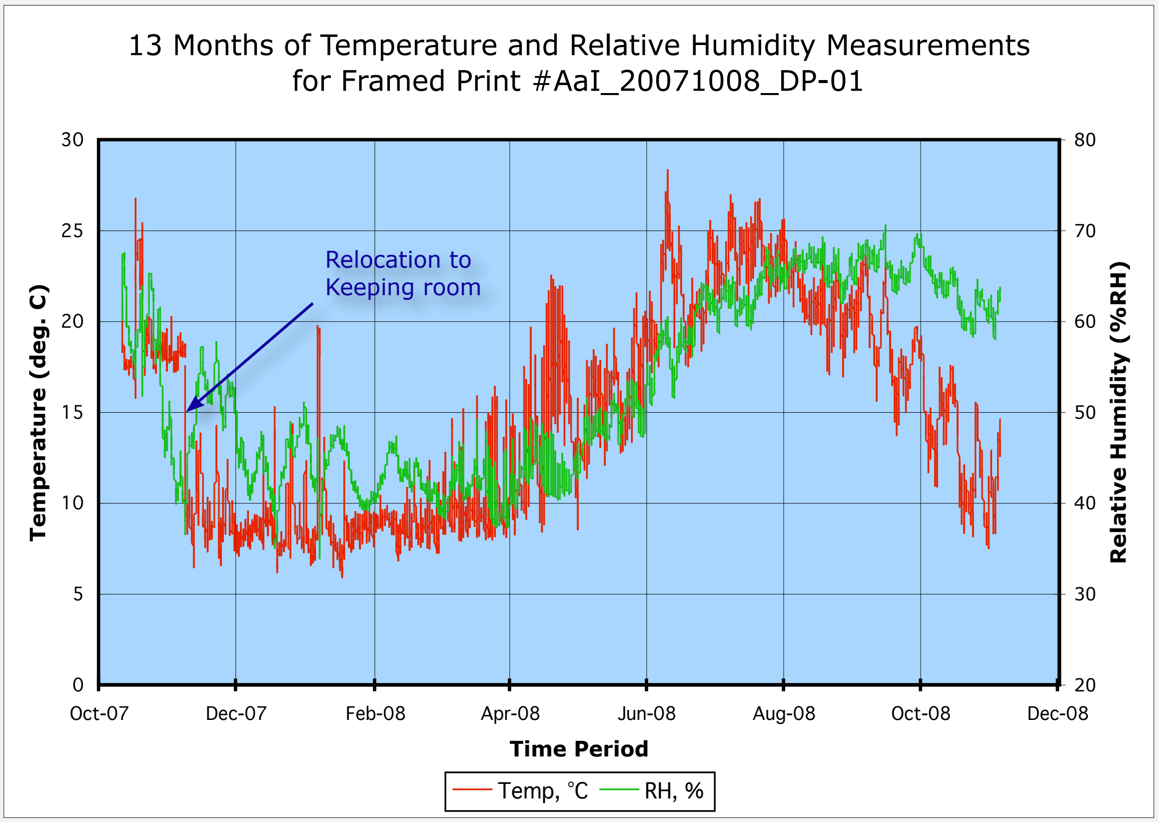

Figure 5 Approximately one month of data collected on the second floor and subsequently after relocation of the print to the first floor, one complete four-season cycle of temperature and relative humidy in the Keeping room at the Hyde House in Lee, Massachusetts.

In the summertime, the Berkshire Mountains in Western Massachusetts stay reasonably comfortable in terms of temperature, but relative humidity is fairly high. Although, modern HVAC would provide superior dehumidification benefits for the home and its contents, summertime temperatures seldom exceed human comfort levels of 25˚C (75 ˚F) on the first two floors of the house. Retrofitting the Hyde house with a modern HVAC system would be very expensive and also challenge the historic architectural integrity of the Hyde house.

During the summer months a portable dehumidifier is used to reduce the peak relative humidity levels in the Keeping room. Figure 5 shows one complete year of temperature and humidity cycling in the Keeping room. Psychometric charts can be used to calculate the effects of heating the air drawn in from cold outdoor wintertime conditions, and these calculations predict indoor relative humidity levels in the 30% RH range when the Keeping room thermostat is kept at 10˚C (50 ˚F) during the winter months. The dataloggers in the picture frame confirmed this indoor seasonal response to cold outdoor temperatures.

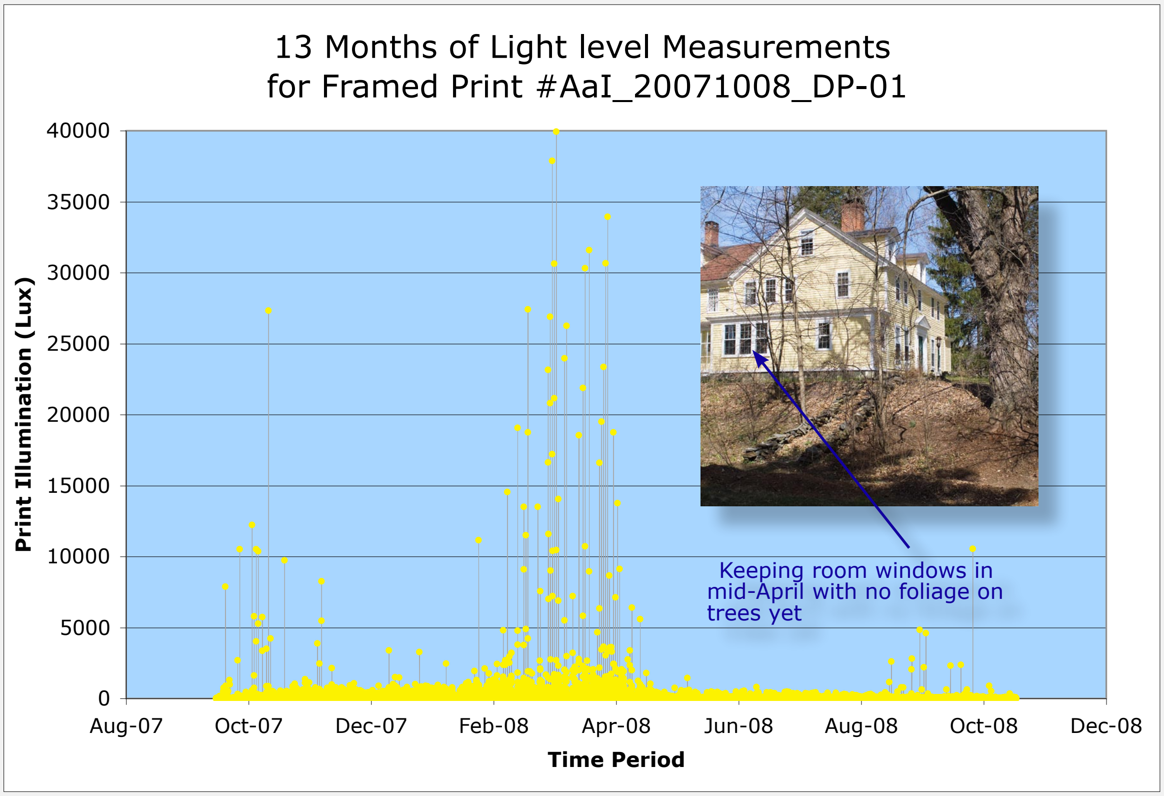

Figure 6 Peak light levels occurred during the late winter and into spring, 2008, and to a lesser extent in the fall of 2007 and 2008. The amount of foliage on the trees on the grounds of the Hyde house plus the lower angles of sun in the winter months compared to summer months account for this pattern of light reaching the desk surface in the Keeping room at the Hyde House.

Light Levels

The average daily illumination level on the displayed print was 163 lux. Expressed in terms of a generalized 12 hour day/night cycle as is common industry practice, the print was thus exposed to 336 Lux for 12 hours per day on average. Perhaps ironically, this result falls right between the 120 lux/12 hr per day value used by the Eastman Kodak Company and the 450 lux/12 hour per day value used by Wilhelm Imaging Research, Inc. to make print display

Table 1	**Environmental Summary** (13 month Period from 2007-10-07 to 2008-11-05)		
	Temperature	Relative Humidity	Illumination
Average Value	14.8 °C (58.6 °F)	52.9% RH	163 Lux (*full 24 hour cycle*)
Maximum (Peak) Value	28.4 °C (83.1 °F)	70.7% RH	39,953 Lux
Minimum Value	5.9 °C (42.4 °F)	33.8% RH	0 Lux (night time)

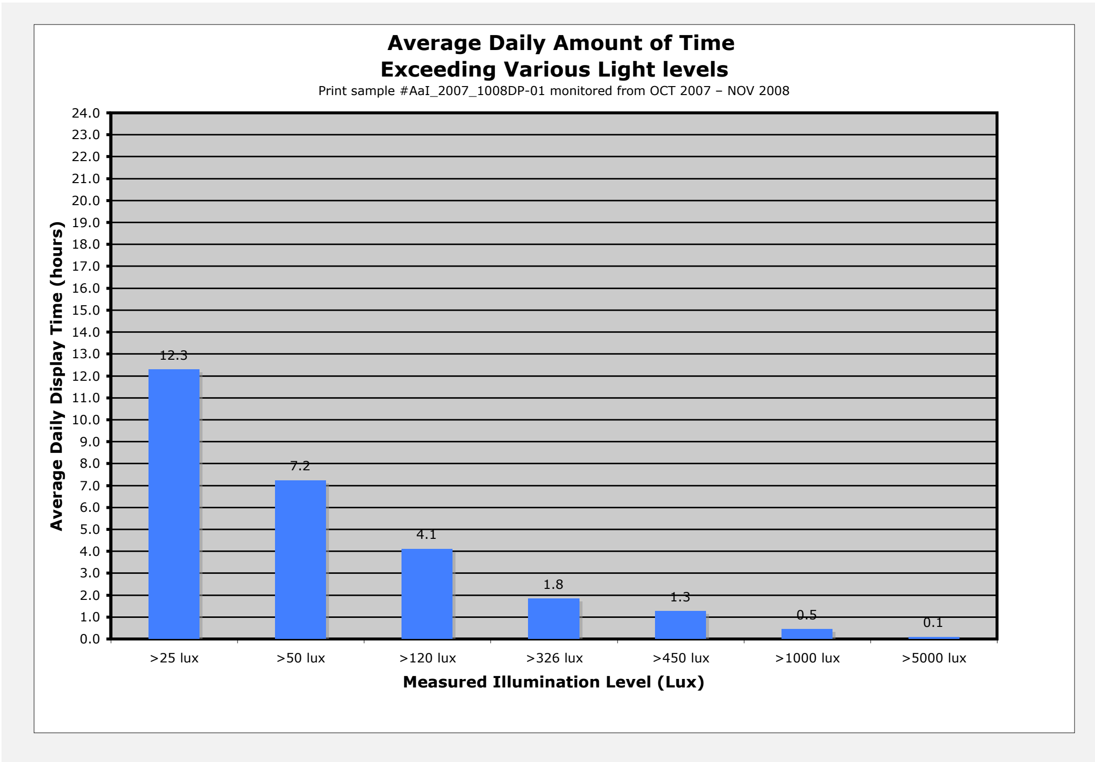

Figure 7 By sorting the recorded time intervals based on measured lux values, the environmental data was used to determine the average amount of time each day that the print was illuminated at or above specified levels.

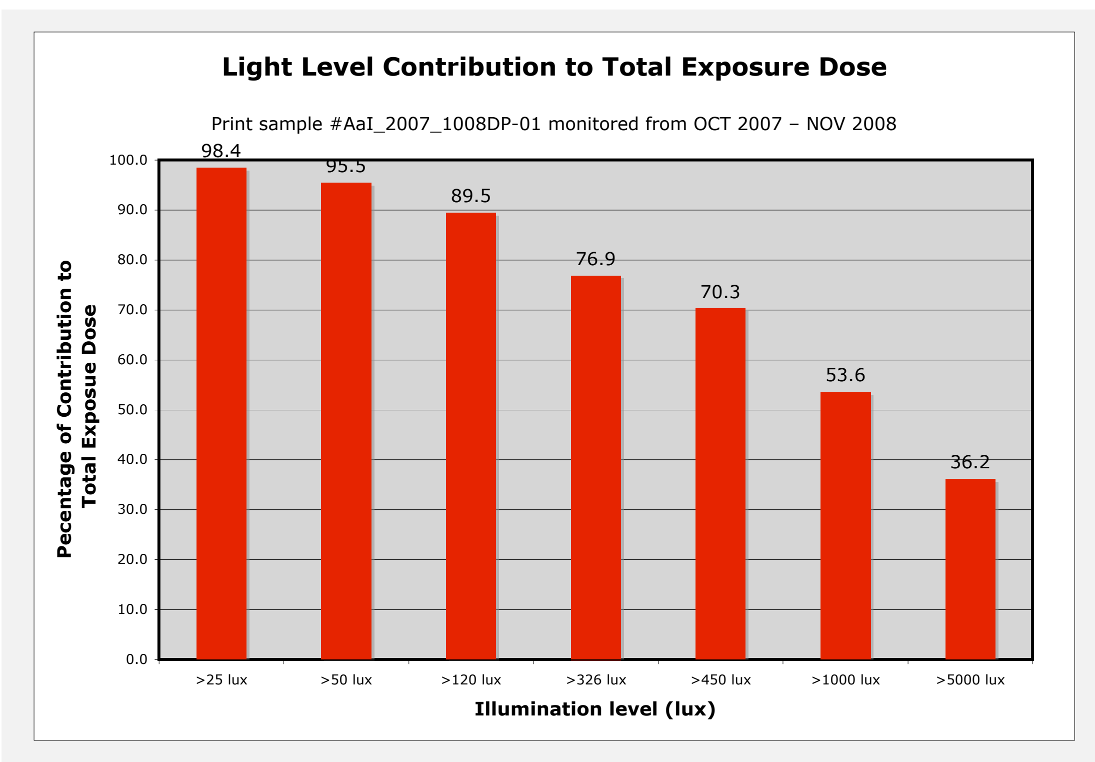

Figure 8 Peak light levels in natural daylight display environments, even when lasting for brief time periods, can contribute significantly to the accumulation of total exposure dose that leads to light-induced deterioration.

life predictions for light-induced deterioration. Yet figures 7 and 8 reveal a more complex and interesting story than simple average illumination level summaries. The print on display experienced a full 12 hour illumination period only by counting all light measurements above 25 lux. When we examine the average 326 lux/12 hour per day level, the graph in figure 7 shows that the light exposed print experienced an average daily display time of only 1.8 hours at light levels equal to or greater than the average 326 lux. The graph also shows that direct sunlight on the print which caused illumination levels to exceed 5000 lux only occurred an average of 0.1 hours per day. In other words, the print was exposed to direct sunlight entering through the windows for only about 6 minutes per day on average. Such brief periods of direct sunlight on the print may lull collectors into a false sense that typical light levels on the print are very low, and indeed they are. The displayed print in this study has spent approximately 17 hours every day in lighting conditions at or below 50 lux (a commonly recommended museum illumination level for light sensitive objects). However, figure 8 reveals the significant environmental impact of those six minutes of average daily direct sunlight. Illumination levels above 5000 lux produced nearly 40 percent of the total accumulated exposure (36.2%). Illumination levels above 1000 lux occurred only ½ hour per day on average (0.5 hours as per figure 7) but accounted for over 50% of the accumulated light exposure to date (53.6% as per figure 8). Important conclusions to be drawn from figures 6-8 is that simple steps like removing the print from display at this location during the months of March through May, or adding some curtains or blinds on the window can easily double the "display life" of the print.

Visual Assessment and Colorimetric Analyses

Table II – Color Patch Measurements
Color and Tonal Accuracy Scores (I* metric) and Color Difference (delta E) Results

		I* Color	I* tone	ΔE
AaI Standard Set exposed to light	Average of all colors in set	99.2%	98.7%	0.7
	Worst 10% of colors in set	94.1%	97.4%	1.3
AaI Standard Set unexposed under mat	Average of all colors in set	98.7%	98.8%	0.8
	Worst 10% of colors in set	94.7%	97.3%	1.2
Artist's selects Set exposed to light	Average of all colors in set	99.3%	98.4%	0.7
	Worst 10% of colors in set	94.8%	96.4%	1.2
Artist's selects Set unexposed under mat	Average of all colors in set	98.2%	98.9%	0.8
	Worst 10% of colors in set	92.8%	97.9%	1.2
Image Selects Set exposed to light	Average of all colors in set	100%	98.8%	0.5
	Worst 10% of colors in set	99.9%	97.4%	0.8
Image Selects Set unexposed under mat	Average of all colors in set	98.9%	98.6%	0.7
	Worst 10% of colors in set	96.4%	97.3%	1.1

Note: The "Artist's Selects" Color Set was not customized. Therefore, the Artist's Selects Set is a replicate score of the AaI Standard Color Set results. See references for additional information on the I* metric.

AaI&A accelerated light fading tests on this printer/ink/paper combination produced a ***Conservation Display Rating*** (CDR) of 10-18 Megalux hours. The CDR is a measure of how much light exposure the print should be able to withstand and still remain in excellent condition. Little or no noticeable deterioration should be observed. The lower exposure limit of the

CDR (e.g., the 10 megalux hour score) estimates the exposure that would cause the most light-sensitive 10 percent of colors in the print to become just noticeably changed when viewed critically in a side-by-side comparison to a duplicate print in perfect original condition. The upper exposure limit (e,g., the 18 megalux hour score) represents the exposure dose required to produce "just noticeable" changes on average to all colors in the print. Without a duplicate print in perfect original conditions for comparison, these just noticeable changes are often not suspected at all by the viewer.

For the R1800/MIS ink/Red River paper combination, the accelerated test results indicated that the most sensitive 10 percent of the colors in this print are the extreme highlight values, and the principal cause is loss of optical brightener activity which shifts the paper white color and other highlight colors to a slightly more yellow appearance. The image itself does have some highlight color areas in the hull of the boat washed up on shore and some specular highlights on the tree branches as well, but there are no broad image areas of extreme highlights. Therefore, the area of this specific print that is most vulnerable to first showing subtle signs of change is the liberal area of paper white color surrounding the image rather than the image itself. The CDR predicts 10 megalux hours of exposure to reach subtle yellowing in paper color, whereas a typical image is predicted to withstand up to 18 megalux hours of exposure and remain in excellent overall condition. This specific image qualifies conservatively for that upper exposure limit rating. At 336 average Lux for 12 hours per day as determined by the dataloggers, this print has to date received 1.47 megalux hours per year and will reach the 10 megalux hour exposure accumulation in 6.8 years. At 1.5 years into this study, the print should appear to be in excellent condition and we should not be able to visually detect a change, even in the whiteness of the paper. Indeed, when examining this print in good indoor illumination, it appears to be in outstanding condition, even comparing directly to a duplicate print that has remained in dark storage. The colorimetric measurements listed in Table II also verify that at this point in time there is no statistical difference between the light exposed and non-exposed colors in the print. Color and tonal accuracy scores remain very high and ΔE values remain very close to within instrumental meassurement accuracy. The visual assessments and colorimetric measurements are thus consistent to date with the CDR predictions derived from accelerated aging tests of this printer/ink/paper system.

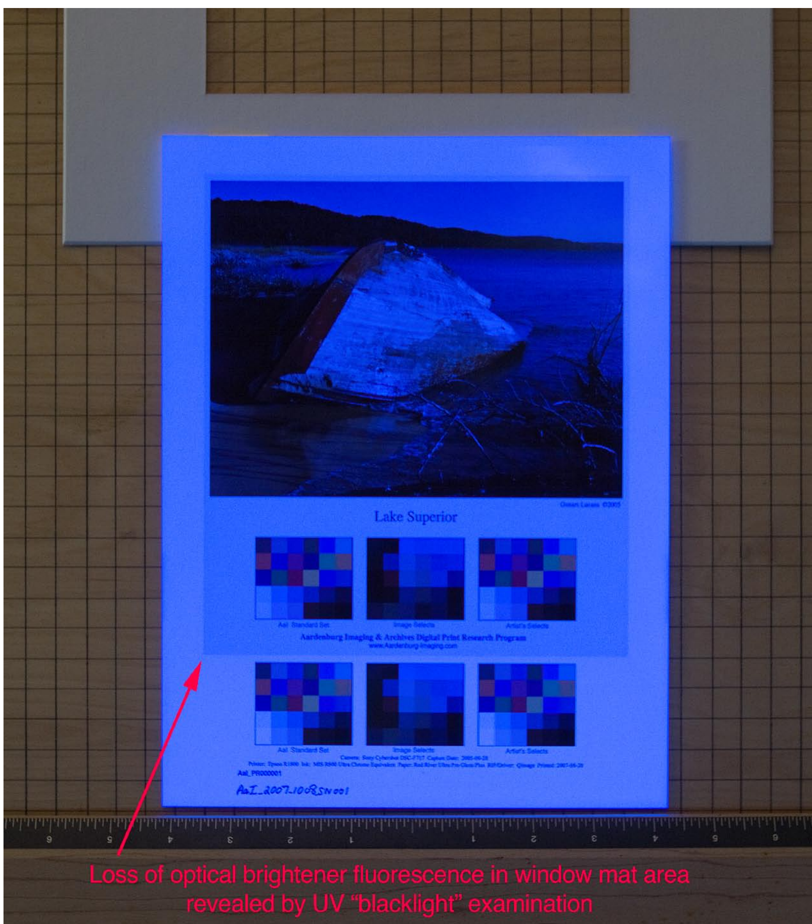

Figure 9 The loss in OBA activity in the area of the print that was not protected from light exposure by the window mat cannot be seen under normal daylight viewing conditions, but it is easily detected by blacklight examination. Blacklights produce 370 nm Ultraviolet radiation that is ideal for exciting the fluorescence of the OBAs.

Light Fading of the Optical Brighteners

An inspection of the print with an ultraviolet emitting "black light" source excites the OBA fluorescence which then appears as a visually distinct bluish-white glow. It turns out this evaluation technique is not only good for evaluating the relative concentrations and location of OBAs in papers. As can be seen in Figure 9, it also revealed the early-stage degradation of the OBAs in the light exposed area of the print ***before*** the human eye can easily detect a color appearance change in the paper. Colorimetric measurements of the light exposed paper compared to the unexposed paper right at the line of demarcation between the paper underneath the mat and the paper just within the window mat opening yielded a ΔE value of about 1.0 using a non UV-cut Gretag/Macbeth Spectrolino spectrophotometer. $\Delta E=1$ is the often cited "just noticeable" detection limit in basic CIELAB color theory. However, to see the line of demarcation with the overmat removed, the print had to be taken outdoors under very bright UV-rich natural daylight. In typical indoor lighting and under standard acrylic glazing this line of demarcation was below the visual detection limit. Hence, even though the blacklight evaluation confirms OBA deterioration has already occurred in under 2 megalux hours of total accumulated light exposure, it simply isn't noticeable yet under typical viewing conditions, especially with the overmat in place that hides the distinct line of demarcation between the exposed and unexposed paper surfaces.

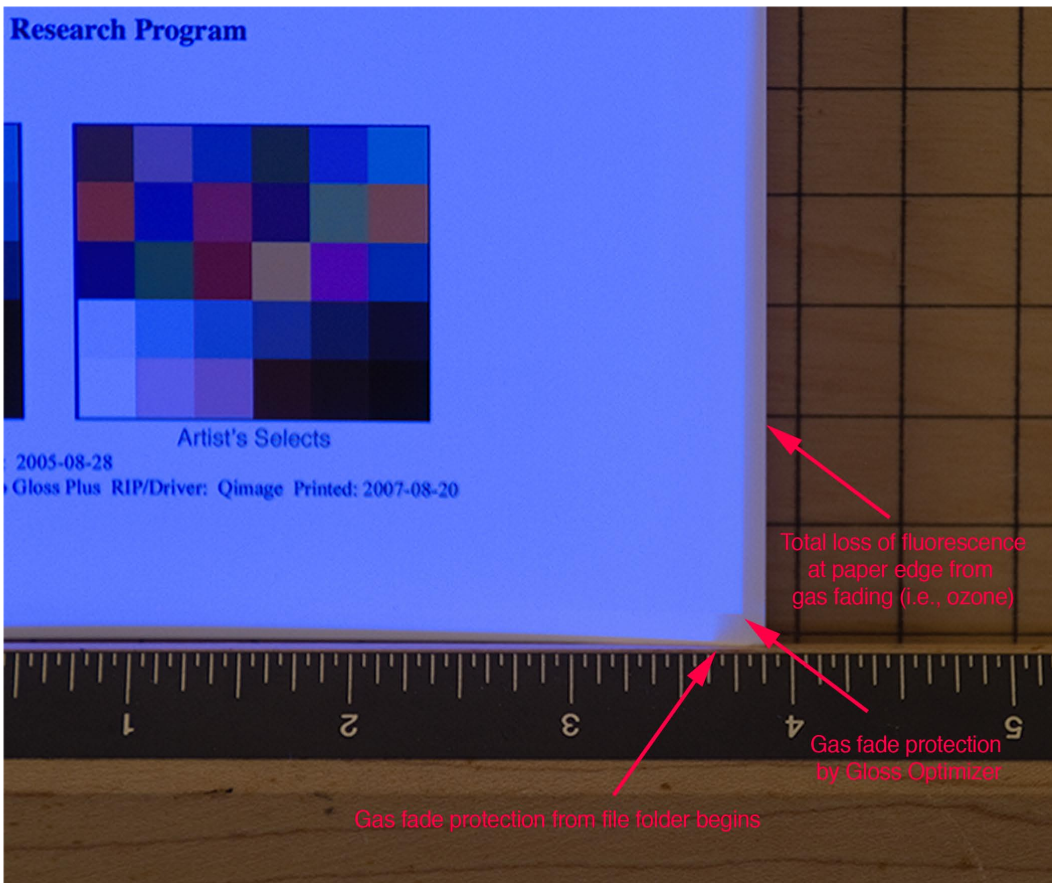

Figure 10 Total degradation of OBAs at the edges of a print kept in dark storage in the Keeping room. The likely cause is ozone generated by the electric motor in a dehumidifier that was located nearby the print folder stack. Note that the clear gloss optimizer ink laid down to nearly the edge of the paper by the R1800 printer provided partial but not complete protection for the OBAs embedded in the ink receptor coating

Gas Fading of the Optical Brighteners

During the preparation of this article and the blacklight examination of the light exposed print, a dark stored copy was pulled from the file to use as a visual comparison under the blacklight evaluation conditions. An unexpected outcome occurred. The stored print had completely lost OBA activity along two edges of the paper. The optical brightener fluorescence had been destroyed along the edges of the print because the edges were not completely protected from air movement by the file folder in storage. The edges of all affected prints were noticeably discolored more yellow compared to more central regions of their respective paper surface area. Tracing back along the pathway that could have caused this result, a few critical storage parameters become obvious. The stored prints did not make it into full cabinet storage for about a month. The file folders they had been placed in were allowed to sit on top of a small polyethylene storage container protected from all but very low intensity light (less than 10 lux) but well within nearby reach of the airflow generated from the fan of the portable dehumidifier in the room. As noted previously, the dehumidifer is used in the summer months to reduce the overall humidity in the Keeping room, and as can be seen in the environmental data graphed in figure 5, serves a useful conservation purpose in the summertime in the Berkshire mountains of Massachussets. The unintended consequence of the required air flow from the dehumidifier is that the edges of the prints sitting loosely in their folders experience more air movement which in turn exposed them preferentially to low levels of air pollutants. Although further research is necessary to fully determine the exact cause of the problem, the likely explanation is ozone generation from the electric motor of the dehumidifier and subsequent spreading of this ozone contaminant to nearby objects by the fan motor necessary to circulate the air and reduce the humidity. Since discovering the problem in this study, examination of other edges of bright white inkjet papers that contain high concentrations of OBAs in the microporous ink receptor coatings, confirms that this sensitivity to gas induced fading of the OBA fluorescence along edges of the paper in a stack is apparently quite common.

Conclusions

An inkjet print on display for about one and a half years has been carefully monitored in this study. The print is mounted in a contemporary picture frame with acid-free conservation mat board, foam core backing, and standard acrylic glazing. In that time, the study has logged real-world environmental data that helps us to better understand predictions of print life based on idealized “steady state” temperature, light, and humidity conditions which rarely if ever exist in real-life storage and display environments. In particular, the study has shown that even very brief periods of direct sunlight reaching a home or office-displayed print can contribute substantially to the total accumulated light exposure dose which in turn dramatically shortens the time on display before noticeable fade begins to occur. That said, despite the radical swings in natural light levels for the home display environment recorded in this study, the colorimetric analyses of the color patches after about 2 megalux hours of total accumulated light exposure are indeed tracking well so far with the light fastness estimate of the chosen printer/ink/paper combination as predicted by the steady-state AaI&A accelerated light fade test of this product.

In hindsight, the sensitivity of optical brightener agents to deterioration caused by increased airflow over the surface of the microporous ink receptor coatings should have been anticipated and should be easily predicted in accelerated ozone tests conducted on inkjet print media. Were it not for the fact that current industry criteria for allowable change in the paper white color deemed acceptable to consumers are probably too liberal to be exceeded merely by OBA degradation, the hyper sensitivity of OBAs to gas pollutants would more than likely have already been more widely reported. The gas fading behavior in the literature for the dyes used in dye-based inkjet printers on microporous inkje papers clearly applies to one other type of dye molecule that may be residing even in a pigment-based inkjet print, namely, the optical brightener. Non-uniform loss of fluorescence in OBAs caused by impeded air flow over the full surface of a print raises the noticeability and objectionable nature of the discoloration. Although many printmakers rationalize OBA activity loss as a relatively benign issue bounded merely by the paper gently returning to a more "natural" paper white color, the merits of this argument should be re-considered in light of the noticeably non-uniform paper color appearance that can be caused by gas fading of OBAs. Finally, the empirical evidence found in this study for the gas fading of optical brighteners used in the microporous coatings is far from an exhaustive study of the subject, but it does suggest that inkjet prints in storage or on display should probably be protected from direct airflow whether they contain OBAs or not. In storage this protection can be reasonably achieved by fully enclosed storage boxes that prevent air flow directly over the surface of the prints, and on display standard glazing or encapsulation methods using polyethylene, polypropylene, or mylar slip covers should work.

References

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2) Mark H. McCormick-Goodhart, "An Introduction to the I* Metric", ©Aardenburg Imaging & Archives, February 7, 2007 (available in PDF format at Aardenburg-Imaging.com).