The Identification and Light Sensitivity of Japanese Woodblock Print Colorants: The Impact on Art History and Preservation

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Abstract

Eighty-nine eighteenth- and nineteenth-century Japanese woodblock prints from the collections of the Carnegie Museum of Art and the Library of Congress were surveyed to determine their sensitivity to visible light using a micro-fading tester developed at the Research Center on the Materials of the Artist and Conservator. When possible, the reflectance data collected by the micro-fading tester were also used to identify the natural organic colorants used on these objects. Japanese woodblock prints are considered to be light-sensitive objects, but surprisingly wide ranges of fading behavior were found. Yellow areas were created with the most light-sensitive colorants, while blue areas proved to be relatively stable to visible light. Further examination of the data showed that medium values of a colorant will fade faster than their light and dark counterparts and that the prior fading history of a colorant has little affect on its light sensitivity. The reasons for specific colorant/color use by Japanese woodblock printers are also explored.

Introduction

The light sensitivity of many Japanese woodblock print colorants is widely recognized, mainly from witnessing the damage that prolonged exhibition can produce. Despite this understanding, questions still remain about the care of these objects. The light sensitivity of individual prints is not usually known, especially for those in very good states of preservation. It is also difficult to predict how much damage these prints will suffer when displayed in low-intensity, UV-free lighting environments. Many of the sensitive colorants on these objects are natural organic materials, and it is unknown whether variations in the growth, manufacture, or aging history of those materials could affect their current light sensitivity. How much of the apparent fading damage on a print is the result of light damage, or how much may be caused by other aging factors or by intentional printing of dilute colors, is also poorly understood.

In the past few years, similar questions have been addressed for specific artifacts by studying them with a micro-fading tester developed at the Research Center on the Materials of the Artist and Conservator. This device allows the direct determination of light sensitivity and provides information that may sometimes be used to identify the colorants present. While the main use of this instrument has been to determine the preservation needs of particular artifacts, this project is its first use to survey a group of related objects—Japanese woodblock prints from the eighteenth and nineteenth century containing natural organic colorants—in order to explore the trends and variations of light sensitivity for specific colors and colorants. The relative sensitivity of colorants applied at different depths of shade, and whether a colorant’s prior fading may affect its current light sensitivity, have also been explored. Further, the implications of these findings are considered from an art historical perspective by discussing the specific color and colorant choices made throughout the development of this art form.

Scope of survey and analytical methods used

Eighty-nine Japanese woodblock prints were chosen for this survey, sixty-six from the James B. Austin Collection at the Carnegie Museum of Art and twenty-three from the Japanese Print Collection at the Library of Congress. The prints selected range in date from 1726–1863 and provide examples of both well-preserved and poorly-preserved color. Each color on a print was tested for sensitivity to visible light by performing *in situ* micro-fading tests. The instrument used has been described in detail previously (Whitmore, Pan, and Bailie 1999). Tests were performed with high-intensity visible light (400–700 nm) focused to a spot 0.4 mm in diameter. Reflectance spectra of each test spot were collected during a five-minute interval and color differences (CIE ΔE values) were calculated from them using the initial spectrum as the basis for the comparison. Large values of ΔE indicate a greater measured color change in the test area. The ΔE value from each test area was compared to the ΔE values produced in Blue Wool standards exposed under the same conditions. The Blue Wool standards are designed to fade at specific rates, with Blue Wool #1 more sensitive than Blue Wool #2 and Blue Wool #2 more sensitive than Blue Wool #3. For colored materials used to make works of art, fading rates comparable to Blue Wool #1–#3 are considered to be "light-sensitive." All fading tests on the prints were performed so that the resulting color changes never exceeded five ΔE units. Such a small change in the color of the test areas is not visibly perceptible.

The reflectance spectra recorded at the start of each fading test were also used to identify those natural organic colorants having characteristic spectral profiles. These included dayflower blue (*tsuyukusa*, or *aigami*), indigo (*ai*), safflower red, and cochineal (*enji*), lac or madder lakes (the latter three having reflectance spectra that are nearly indistinguishable). The method for identification of these colorants using reflectance data is described elsewhere (Feller, Curran, and Bailie 1984; Leona and Winter 2001; Schweppe and Roosen-Runge 1986; Schweppe and Winter 1997). Prussian blue, a colorant used in the nineteenth century, does not have a distinctive visible reflectance spectrum, but it was identified by the absence of spectral features indicating either dayflower blue or indigo (Leona and Winter 2001).

Fading test results: variations in light sensitivity among all prints

Blue colorants

Of the 112 blue areas tested, all but nine (which could not be identified by their reflectance spectra) were found to be one of the three blue colorants mentioned above (dayflower blue, indigo, and Prussian blue). Dayflower blue was found in one-third of the areas tested, and figure 1 shows the fading changes produced in all areas of dayflower blue, with the final ΔE values for the Blue Wool standards #1–#3 indicated on the right axis for reference. Dayflower blue showed fairly uniform light sensitivity, with fading rates similar to that of Blue Wool #3, making it one of the most light-stable organic colorants tested on these prints. Interestingly, the very slight color change produced during these fading tests resulted more from a loss of yellow (reflectance increase between 400–500 nm) than from a loss of blue color. Figure 2 shows the reflectance spectra for dayflower blue on a print entitled *View of Ochanomizu* by Hokuju in the collection of the Carnegie Museum of Art, before and after the fading test. Longer fading tests on laboratory samples showed that dayflower blue begins fading by this bleaching of yellow color, followed by a gradual reflectance increase at all wavelengths, including those at the absorbance peaks associated with the blue color (unpublished results).

Indigo was found in fewer than one-quarter of the blue areas tested and produced similar results to those found with dayflower blue. Figure 3 shows the fading results for all areas of indigo tested. The final ΔE values are grouped around that produced from the fading of Blue Wool #3, making this colorant another relatively light-stable material. Similar to dayflower blue, indigo experienced a reflectance increase in the 400–500 nm region during the fading test, rather than in the 660–700 nm region of the main indigo absorption band.

The fading tests of Prussian blue areas produced ΔE values from 0.5 to 5.4 after five minutes of exposure, which is equivalent to a range in lightfastness from Blue Wool #3 to Blue Wool #1. This result is seemingly at odds with the known light stability of this colorant (ASTM D5067-98). However, an earlier study of Prussian blue on cyanotypes (Whitmore, Bailie, and Connors 2000) showed that these fading tests cause Prussian blue (ferric ferrocyanide) to undergo the well known reversible conversion to a white compound (ferrous ferrocyanide), which converts back to the blue once the light exposure has ended. If these applications of Prussian blue behave in this typical way, then the micro-fading tests have overestimated the light sensitivity of those areas. The confirmation that these fading changes are reversible would further support the identification of these passages as Prussian blue, the only available pigment known to display such behavior.

Red colorants

Most of the 139 red areas tested faded very slightly, showing an increase in reflectance between 400–600 nm, the main absorbance region for most red colorants. Figure 4 shows the fading test results for all red areas studied. Most of the red areas faded at rates between those of Blue Wool #2 and Blue Wool #3 and should therefore be considered moderately sensitive to visible light.

Safflower red was identified on a number of prints, so the light sensitivity of these passages can be examined separately. The fading results of all the safflower red passages lie in a range only slightly narrower than that of all the red areas combined (see figure 5), with fading rates between Blue Wool #3 and halfway between Blue Wool #2 and Blue Wool #3.

The three-peak absorbance pattern typical of cochineal, lac and madder lakes was found on two of the prints studied. The fading rates in these areas were found to be comparable to that of Blue Wool #3.

Purple colorants

Figure 6 shows the fading results for all purple areas tested. A relatively narrow range of fading behavior centered around Blue Wool #3 was found, with the exception of two purple areas showing faster fading rates (around Blue Wool #2).

The literature describes overprinting or mixtures of blue and red colorants being used to create purple areas of color (Keyes 1988; Feller, Curran, and Bailie 1984). Just under half of the sixty-six purple areas studied showed spectral features typical of dayflower blue and safflower red, while only six areas showed the spectral characteristics of indigo and safflower red. The composition of the remaining purple passages could not be determined from their reflectance spectra. In the mixtures of safflower red and dayflower blue, the more fugitive colorant seems to be safflower red. This is consistent with the observed greater light sensitivity of safflower red compared to dayflower blue measured in the passages of unmixed color. Figure 7 shows a difference spectrum describing the spectral changes produced during the fading of the purple area on *Actor as Kintoki Hanhyôe* by Kunisada, in the collection at the Carnegie Museum of Art. The greatest increase in reflectance occurred around 540 nm, the absorbance peak for safflower red, indicating that the light exposure caused predominantly the destruction of the safflower red in the purple mixture.

The two purple areas showing the remarkably fast fading were also mixtures of safflower red and dayflower blue on two prints from an untitled set of *Eight Views of Edo* by Hidemaro, in the collection at the Carnegie Museum of Art. Like the typical safflower–dayflower purple mixtures described in figure 7, these also faded mainly by loss of the safflower red from the mixture. On these two prints, however, the safflower red faded more rapidly from the purple mixture than was observed in the fading tests of the unmixed safflower red areas on these prints. The reason for this finding is not known, but it suggests that a different safflower red could have been used for the purple mixture than was used for the applications of unmixed colorant in the red passages. It should also be noted that there were only a few eighteenth-century prints in this study that included well preserved purple areas. Early methods of preparing safflower red or of printing purple may have resulted in these unusually light sensitive mixtures.

Green colorants

Various green passages were studied, ranging in hue from yellow-green to blue-green. Figure 8 shows the fading results from all eighty-two green areas tested. The range of fading behavior is wider than that seen for either red or blue colorants, with ΔE values between 0.1 and 4.4 after five minutes of exposure. The majority of green areas showed fading rates near Blue Wool #3, but some areas faded at rates near Blue Wool #2, indicating their greater light-sensitivity. The color change that occurred during the fading of most of these green passages was a loss of yellow. Figure 9 shows the difference spectrum after the fading of a green area on *Actor as Oguri Hangan* by Kunisada, in the Collection at the Carnegie Museum of Art. The greatest change was produced between 400–500 nm, indicating fading of a yellow component in a mixture. While dayflower blue and indigo also showed a reflectance increase between 400–500 nm during the fading tests, the increase experienced by a mixture of yellow with either of these blue colorants was greater than that experienced by the blue colorant alone.

Green passages were typically created using yellow-blue colorant mixtures, by overprinting yellow and blue colorants, or by using the green mineral pigment malachite (Keyes 1988; Feller, Curran, and Bailie 1984). Half of the green areas studied showed reflectance spectra indicating the presence of indigo, while only one print contained green passages created from a mixture of dayflower blue and a yellow colorant. The composition of the remaining green passages could not be identified because of the lack of distinctive features in their reflectance spectra.

Yellow colorants

The yellow areas studied showed the widest range of fading behavior of any color category. Figure 10 shows the fading results observed in all yellow areas studied. The light sensitivity of these colorants ranged from relatively light-stable areas, with fading rates less than that of Blue Wool #3, to very fugitive areas, with fading rates greater than that of Blue Wool #2. The yellows were frequently the most light-sensitive colors on a given print.

A variety of organic and inorganic yellow colorants was available for use on Japanese woodblock prints (Keyes 1988; Feller, Curran, and Bailie 1984), and distinction between these colorants is difficult because of the lack of characteristic features in their visible reflectance spectra. However, several of the yellow areas tested showed unusual fading behavior that could be distinctive. For example, some areas darkened (experienced a decrease in reflectance) as a result of light exposure. Exploring whether such a light reaction can be used to identify yellow colorants is an area for future research.

Light sensitivity for different concentrations of the same colorant

In order to produce a variety of shades for a particular color, colorants were often used in different concentrations, were overprinted, or were applied as gradations of color during the printing. *The Great Bridge at Senju* by Hiroshige, in the collection at the Library of Congress, exhibits a gradation from medium to light shades of safflower red along the horizon, and a dark shade of safflower red was used for the cartouche in the upper right corner of the print. When tested, each of these areas showed different light sensitivities. Figure 11 shows the fading results for dark, medium, and light applications of safflower red on *The Great Bridge at Senju*. Greater fading was observed for the medium-value safflower red area compared to either the very light or very dark areas. This is consistent with the fading behavior observed in light, medium, and dark paint glazes, where the greater sensitivity of the medium-value paints is well known (Whitmore and Bailie 1997).

Fading behavior of well preserved and poorly preserved prints

These results can also be examined to determine whether prior fading of a print has any effect on the current light sensitivity of its colorants. Equivalent shades (reflectance minimum around forty percent) of safflower red were compared from *The Courtesan Miyoharu with Child Attendants* by Kiyomine (a print with well preserved color) and *The Actors Sanogawa Ichimatsu and Ôtani Oniji* by Masanobu (a print with poorly preserved color), both in the collection at the Carnegie Museum of Art. The fading results for the areas tested are seen in figure 12, where it can be seen that the well preserved and previously faded areas of safflower red have essentially the same light sensitivity. This suggests that safflower red is probably not composed of a mixture of components of varying lightfastness. This finding may also explain why the various safflower red passages on all the prints had reasonably similar light sensitivity. While this behavior has not been tested with other colorants because of a lack of suitable prints for comparison, one may reasonably expect that the other colorants found in this survey are similarly homogeneous because they also tended to have relatively constant light sensitivity among the prints in this group.

Art historical implications

Let us now consider this data from a historical perspective. The earliest print in this study is a hand-colored picture of kabuki actors by Toshinobu that was published in the 1720s (see figure 13). Print artists often combined colors in characteristic ways to produce particular effects. The colorist here emphasized the three primary colors, red, yellow, and blue, to produce a lively effect by contrast of hue. When Japanese craftsmen developed techniques of color printing in the middle of the eighteenth century many favored the same palette of three primary colors that predominate the earlier print, as in the Kiyomitsu actor portrait from the early 1760s seen in figure 14. One important result of this study is the discovery that *beni*, or safflower, produces most of the common reds in eighteenth- and early nineteenth-century prints and that dayflower, or *tsuyukusa,* produces nearly all the blue and gray-blue colors in these prints. This is a surprising limitation considering that other red and blue colorants were available and occasionally used on prints. All three primary colors are moderately light sensitive, but we should not assume that light hues of organic colorants on Japanese prints are always the result of fading because printers often diluted the colorants. This was typical of inexpensive color prints of the period, and may have been a cost-cutting measure.

Later artists continued to produce prints using this same color contrast. Figure 15 shows the unfaded courtesan portrait by Kiyomine, which was published in 1805 or 1806. The printer has added some green, but the main colors are still red, blue, and yellow, a combination now associated with inexpensive color prints. Patronage allowed artists to experiment with color and encouraged printers to introduce new colorants. Suzuki Harunobu's *Night Rain on the Kettle* (figure 16) published in 1766 is clearly much more colorful and complex than Kiyomitsu's simple three-color print.

Commercial two-color printing developed in the city of Edo in the mid-1740s, and for over a decade the two colors of choice were green and red, as in the actor portrait by Okumura Masanobu in figure 17. This palette achieved its effect by the contrast of the cool green with the warm red. Another of the surprising results of this study is the discovery that virtually all the greens in eighteenth-century prints are mixtures of indigo blue with yellow. Many hues of green appear on the prints, as in the picture by Shunchô from the late 1780s (see figure 18). It seems likely that this variation results from mixing the indigo blue with different yellows that could not be identified in this study. It is all the more surprising that indigo was so rarely used as a print colorant in its own right during this period. The study found indigo as blue on only one eighteenth-century print. By contrast, the print in figure 19 by Shunshô of around 1780 contains an uncommon yellowish green produced by mixing dayflower blue with yellow.

The unfaded 1798 actor portrait by Toyokuni, in figure 20, is an excellent example of dayflower blue, safflower red, and one of the purples that is produced by mixing them. Dayflower was a versatile color, and the dilute blue here looks like a warm gray, in deliberate contrast to the cooler dilute *sumi* gray of the background.

A dramatic change occurred in the late 1820s when imported Prussian blue became more readily available to printers. The vivid, intense blues in this Yoshitoshi print published in 1863 (see figure 21) are Prussian blue, and it is easy to understand its appeal and to understand why it swiftly replaced both dayflower and indigo. Unlike dayflower, it was also stable in the presence of moisture. The current study was not able to confirm the presence of Prussian blue in mixtures because of its lack of characteristic spectral features, but Prussian blue easily mixed with available reds and yellows and may be responsible for a variety of greens and purples on mid and late nineteenth-century prints. This is an area that must be explored in future research.

This study shows that many Japanese print artists, like Eishi in the 1790s (figure 22) and Hokusai in the 1830s (figure 23), often used a very limited range of familiar colorants. No doubt publishers had an economic incentive to minimize their capital outlay by limiting the number of blocks in a given print and restricting the colorants. Audiences during certain periods also seem to have been conservative in their taste, preferring familiar color combinations. The artists satisfied both groups by producing both extremely bold and extremely subtle effects with a very limited range of colorants. Of course, tastes changed, and private patronage was one force behind these changes. In 1822, Hokusai designed a privately commissioned series of thirty prints including this one for a group of poets, utilizing indigo as blue and metallic powders (figure 24). The designers of *surimono*, as these prints are called, pioneered the use of highly saturated colors and other printing effects that became prevalent in commercial prints of the mid-1840s, like the fan print by Sadahide (figure 25). This study indicates, however, that commercial publishers at the end of this long tradition of color printing still encouraged artists to limit their palettes to readily available colorants, although the printers' increasing skills produced an ever-widening range of color mixtures, color contrasts and special visual effects.

Conclusions

This study successfully used a micro-fading tester to evaluate eighty-nine Japanese woodblock prints. The results give a good prediction of visible light sensitivity when compared to the Blue Wool standards used for reference and will therefore be useful for the future exhibition of these prints. The light source used for these tests, however, is not likely to be the same light source used for museum exhibition conditions. To further understand how such prints will react to specific lighting conditions the Blue Wool reference strips can be used.

The natural organic colorants on these prints exhibited a range of light sensitivity. The fading rates of most of the areas tested were between Blue Wool #3 and Blue Wool #2. For the five color categories tested, the colors ranked from relatively stable (fading rates slower than Blue Wool #3) to fugitive (fading rates faster than Blue Wool #2) in the following way: blue < red < purple < green < yellow. The result that blue colorants are the most stable is somewhat surprising because at least one blue colorant, dayflower blue, was previously thought to be extremely light-sensitive, a perception arising from the observation of apparent fading damage to dayflower areas. The findings of this study suggest that the "damage" to dayflower blue passages may not have been caused by visible light exposure. Exposure to ultraviolet light (which will be limited in future museum exhibition) or other aging processes besides light fading may be to blame. Exploration into some of these factors is an area for future research.

Further examination of the data showed that medium shades of a colorant had faster rates of fading compared to light and dark areas of the same colorant. It is important to note that dark shades may experience an increase in their rate of appearance change over time as they fade towards these medium shades. Therefore, the results of light-sensitivity testing should be considered an evaluation of a dark color's current stability and should not be extrapolated to light exposure doses greater than those used in the test.

It was also shown that the prior fading history of a print does not seem to affect the light sensitivity of safflower red. This suggests that safflower red (or the natural organic materials that make up safflower red) is not a mixture of materials with different light sensitivities. Instead, the color is produced by a single colorant or colorants with very similar light sensitivities. Therefore, faded areas of color will not achieve greater light stability from loss of a light sensitive component.

The tests performed during this study do give a good prediction of a color's light sensitivity; however, they do not indicate how much color change has already occurred. Curators, conservators, and scholars should be cautious in their assessment of color on traditional Japanese prints. Many colors become paler as they fade, but some printers intentionally dilute colors, so pale prints are not necessarily faded, although this is often the case.

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