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Investigating the Effect of Color Gamut Mapping Quantitatively and Visually

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Investigating the Effect of Color Gamut Mapping Quantitatively and Visually

by Anupam Dhopade

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Certificate of Approval

Investigating the Effect of Color Gamut Mapping Quantitatively and Visually

This is to certify that the Master's Thesis of

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has been approved by the Thesis Committee as satisfactory
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Abstract

With the advent of various color management standards and tools, the print media industry has seen many advancements aimed towards quantitatively and qualitatively acceptable color reproduction. This research attempts to test one of the most fundamental and integral parts of a standard color management workflow, the profile. The gamut mapping techniques implemented by the ICC profiles created using different profiling application programs were tested for their congruity to the theoretical concepts, standards, and definitions documented by International Color Consortium (ICC). Once these profiling software applications were examined, the significance of the possible discrepancies were tested by establishing a visual assessment of pictorial images using these profiles.

In short, this research assessed the implementations of the ICC color rendering intents in a standard or a commonly used color managed workflow, and then described the significance of these discrepancies in terms of interoperability. For this research, interoperability was defined the assessment of different ICC profiles in producing similar results, i.e., quantitatively and visually.

In order to achieve the desired assessment, the two profiling applications were selected and each used to create an output profile using the same characterization data set. The two profiles were then compared for differences in the way they mapped real world colors. The results displayed that even though there were some significant quantitative

color differences, visual subjective evaluation did not reflect any noticeable color differences and therefore concluded that the profiles were interoperable. These findings reveal that even though quantitative color differences may reflect significant color differences, subjective visual comparisons may not always reflect the same or agree with quantitative findings.

Chapter 1

Introduction

Statement of the Problem

The International Color Consortium (ICC) was established in 1993 with an aim to standardize the color management process and promote standardization of cross platform and vendor neutral files used in a color managed workflow. They developed a protocol for color definition between device values and the device-independent color called 'profiles' which allowed linking cross-platform devices in a single workflow and hence increase the efficiency of color management workflows.

Today, ICC color management is practiced almost everywhere and has been adopted by most printing processes. The introduction of profiles and ICC specifications have revolutionized how color reproduction is carried out and follows a standardized process as explained in Figure 1.

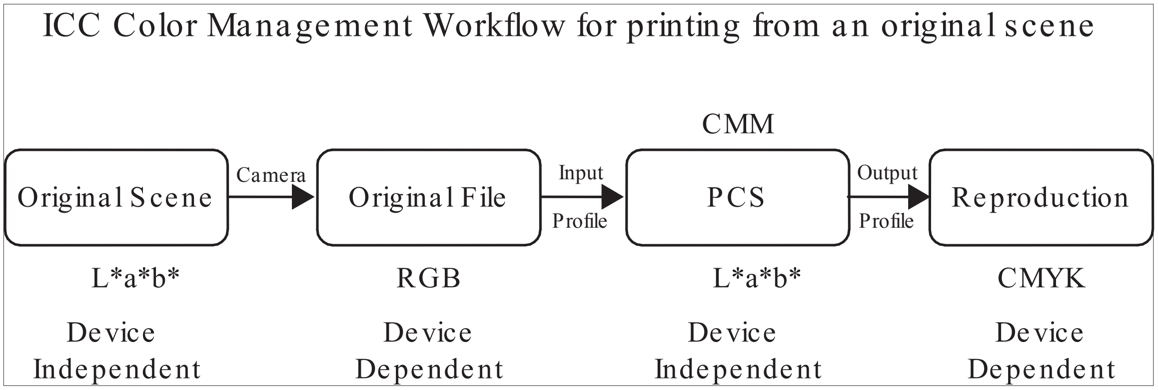


Figure 1: Workflow for color managed printing of an original scene seen by an eye.

As clearly visible from the workflow, the scene is captured by a camera (a scanner is used in cases where the original is a photograph or a tangible flat surface) and converted to 'device digital information' and this device-dependent information is embedded with an input profile that helps the color management module or the 'engine' understand the nature of the color information. In other words, the engine is able to convert the device-dependent color information to device-independent color information in the profile connection space (PCS), which acts as a hub for color transformation.

The L*a*b* color space was introduced as the PCS, as it was larger than any color space that a device could have and was also considered to be visually uniform by the ICC. ICC laid out a simple framework for an open loop color management workflow, which was readily accepted by the print media industry and has been used for the last two decades.

Although ICC's framework for open loop color management was simple, the process of gamut mapping is still complex. When mapping color from a larger gamut

(e.g., RGB) to a smaller gamut (e.g., CMYK), clipping and compressing of the gamut is necessary. This can be done in different ways and is up to the color scientist to design the algorithms for the color mapping program that do these conversions in a way that optimizes a specific color rendering intent between original and reproduction. Recognizing this situation, ICC laid the framework and the general outline of the process, but did not define the specific algorithm thereby allowing individual programmer's creativity in the form of trade secrets. ICC introduced four rendering intents which defined the end results for different image categories. But ICC entirely left it to the profiling application program designer's choice to achieve the required results and what principle to be used. This also means there is not necessarily a correct or an incorrect way of doing gamut mapping.

There are many possible gamut mapping solutions. The user who may be a print operator, or a color expert does not really know what is under the hood and needs to rely on the vendors of the application programs required for creating the ICC profiles. Moreover vendors do not reveal or document the entire logic of their programs. Several interesting questions arise such as:

- What are the different ways of handling the out of gamut colors?
- If the paper base has a color, how is it accounted for in different rendering intents?
- Is the gamut compressed linearly or non- linearly?
- During compression or clipping, is the lightness of the color preserved?
- Does gamut mapping aim at minimum delta E or least possible hue shifts?

So there is no clear and easy method to identify how these differences may impact the quality of the printed products. Any user may want to know the answers to such questions before investing in a profiling application.

Significance of the Topic

A user spends approximate $3,000 to $5,000 for buying a profiling program of his choice, and similarly upgrading these programs costs more money. But he or she may not know if that particular program is better than the others for a given application. Due to all the above mentioned reasons and questions, it would be interesting to understand what really happens in the gamut mapping process.

Reason for Interest in the Topic

Being a student and having access to different profiling programs, it is possible to carry out the tests of interest and do a systematic comparison that the people in the print industry may not be able to do.

Glossary of Terms

This section introduces a few technical terms that are extensively used in documenting the research.

Color Gamut

“Solid in a colour space, consisting of all those colours that are present in a specific scene, artwork, photograph, photomechanical or other reproduction; or are capable of being created using a particular output device and/or medium" (ISO 12640-3, 2005).

Color Gamut Mapping

“The process of converting colors from one color space to another is called as gamut mapping” (Sharma, 2003).

Gamut Mapping Algorithms (GMA)

“An algorithm for assigning colours from the reproduction medium to colours from the original medium or image (Morivic & Luo, 1997).

Color Management Module (CMM)

“The CMM, often called the engine, is the piece of software that performs all the calculations needed to convert the RGB or CMYK values” (Sharma, 2000).

Profile Connection Space (PCS)

“An intermediate representation of the desired colors in a device independent color space is called the profile connection space” (Fraser, 2005).

Profile

"File containing data between device space and PCS in the form of matrix or look up tables (LUT). Profiles are classified as input and output based on the devices, or source and destination based on their roles in the workflow" (Chung, 2010).

Forward device characterization model

A forward transformation that takes device digital counts (e.g. a display's RGB or a printer's CMYK) and transforms it into a colorimetric description for specific viewing conditions (Morovic, 2008). Also known as A2B mapping when mapping to profile connection space.

Inverse device characterization model / Inverse Routine

An inverse transformation takes the colorimetric description for a specific viewing condition and transforms it back into destination device digital counts (Morovic, 2008). Also known as B2A mapping when mapping from profile connection space.

Rendering Intent

The process of gamut mapping is performed by implementing one of the four rendering intent techniques described by the ICC. Each intent defines the way the CMM handles the in-gamut and out-of-gamut colors, according to ICC specifications.

Perceptual Rendering Intent

"This rendering intent is useful for general reproduction of pictorial images, typically includes tone scale adjustments to map the dynamic range of one medium to that of another, and gamut warping to deal with gamut mismatches" (ICC specifications ver.2).

Saturation Rendering Intent

"This rendering intent is useful for images which contain objects such as charts or diagrams, usually involves compromises such as trading off preservation of hue in order to preserve the vividness of pure colours." (ICC specifications ver.2).

Absolute Colorimetric Rendering Intent

"Absolute colorimetric differs from relative colorimetric and maps source white to destination white. Absolute colorimetric rendering from a source with a bluish white to a destination with yellowish-white paper puts cyan ink in the white areas to simulate the white of the original" (ICC specifications ver.2).

Media Relative Colorimetric Rendering Intent

"This intent is based on media-relative colorimetry in which data is normalized relative to the media white point for reflecting and transmitting media. Thus the media white will have the PCS CIELAB values 100,0,0" (ICC specifications ver.2).

Measurement and Perception of Color

A color is usually measured spectrally using a spectrophotometer. This device provides a reading every 5nm or 10nm, generally from 380nm to 730nm and this data can be repurposed to calculate other data. The phenomenon of sensation of color depends on the object, illuminant and observer. The perception of color, on the other hand, heavily depends on various factors such as the spectral distribution of illuminant, the ambient lighting, the surrounding, surface characteristics, psychological and cultural influence etc. Hence a certain color object appears differently under different conditions. This sometimes results in cases where considerable quantitative differences in measurements render just noticeable visual differences, while minute quantitative discrepancies sometimes are perceived as significant visual differences. The relationship between color measurement and perception of color is not linear and cannot simply be represented by a mathematical matrix. Consequently, judgment of color image reproduction quality cannot easily be correlated to the numbers derived from measurement.

Chapter 2

Literature Review

The primary focus of this research was to visualize and illustrate to an average user what the profiling programs actually do in terms of gamut mapping. Therefore it does not involve color scientific discussions but simple language and easy to understand graphics. This literature review summarizes the previous relevant research related to gamut mapping. The issues included in this review were:

1) Conceptual stages of gamut mapping
2) Gamut Mapping Algorithm building blocks / Conditions for gamut mapping
3) Gamut mapping complexities
4) Real world gamut of surface colors. ISO 12640-3

Conceptual Stages of Gamut Mapping

Identifying several problems in the gamut mapping algorithm, the CIE has established a technical committee 'CIE:TC8-03 Gamut Mapping' under the supervision of Jan Morovic (2004). CIE TC08-03 has been established based on the work of Morovic where he surveyed more than 90 gamut mapping algorithms and provided a greater understanding of the intricacies involved in the gamut mapping process. Morovic and his committee members have been pursuing the aim of developing a universal gamut mapping algorithm since 1999. Morovic (2008) explains gamut mapping as an integral

and a critical part of any color management system by stating “Gamut mapping takes place in the context of a color reproduction process that can be implemented by means of a color management system..there are a variety of color management architectures that implement the conceptual stages of color reproduction in different ways, but that all of them need to provide gamut mapping functionality in at least one place” (p.90).

Morovic (2008) described color gamut mapping as having three conceptual stages where the first stage is the prediction of the visual appearance of the original (characterization); the second stage, making changes to the original to compensate for the inevitable changes expected in destination color space (conversion to PCS); and final stage, predicting destination device’s color values (inversion routine).

Morovic’s experiment offers a wide range of areas worth researching. For this thesis, the scope of experiments will be limited to only the second stage mentioned above.

GMA Building Blocks

Fairchild (1998) explains that the entire process of gamut mapping involves prediction, interpolation, and evaluation of the computed values at various stages. An ‘objective function’ is another critical component of this computational process. This function predicts the destination digital counts, or the expected value of color for each input value based on the characterization model and finds the delta E between the input and the output values. It does this repetitively until it can no longer minimize the value of delta E and this value is selected for a particular color. Hence there is no ‘correct’ answer or method to this process and hence the gamut mapping function often optimizes this

process by incorporating an optimized color transformation matrix, and reiterating the objective function a number of times.

Morovic explains that there are several aspects for consideration and complexities involved in decision making while designing a gamut mapping algorithm. He shows how different designers may come up with different solutions while none are right or wrong. According to Morovic (2008: 105), there might be several gamut mapping algorithms available based on different principles and rules, including but not limited to single dimension mapping, mapping towards the point on lightness axis, or off lightness axis, mapping towards predetermined properties, interpolating or morphing, linear mapping, non-linear mapping, tetrahedral or distance weighted morphing, and numerous other considerations.

The argument presented by Nakauchi (1999) is: can the algorithm produce color accurately and pleasantly through all scenarios? The question implies that different algorithms are capable of producing excellent results in some applications while they might not produce the same quality of results for others. Therefore, the profiling program designers must modify or tweak to make it more adaptable by providing different settings. When a user selects one of the given settings in the program he/she might be implementing different rules of mapping.

Sharma's (2003) research attempts testing different profiling software and reveals a wide range of differences in delta E for tests based on printer profiles, scanner profiles and monitor profiles. The article reviews several well-established software products and

ranks them. However, Sharma does not focus on the reasons causing the differences. The author leads the reader to think more about the profiles which are the only variable in the workflows tested.

On the other hand, Sigg (2005) details the differences in how the colors are mapped and leaves it to the reader to observe and conclude based on detailed graphs. For instance, the graph shown in Figure 2 presents a profile from a well-known profiling software implementing 'saturation rendering intent' does almost the opposite than what the theory says.

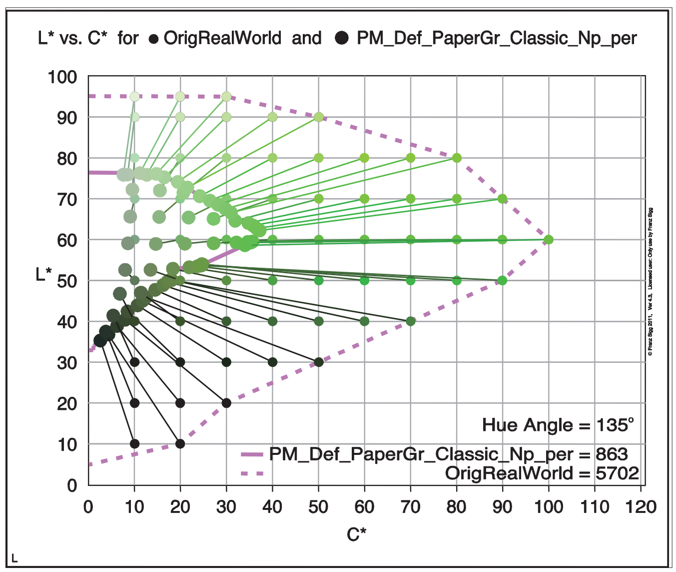


Figure 2: Sigg's graphic test result for one of the hue slices for Saturation Intent

As shown in Figure 2, the source color is denoted by the smaller dots and the destination color is denoted by the larger dots. It can be concluded that (1) the non-reproducible colors are clipped to the gamut boundaries; (2) lightnesses are mapped

nonlinearly; and (3) the reproducible colors are not forced to the gamut boundaries, but darkened and desaturated. In theory, colors outside the gamut must be clipped and the ones inside the gamut must be forced towards the boundary of the gamut. This research identifies such issues and investigates the gamut mapping algorithms using graphs and simple language.

Identifying the need of such research and tests, ISO 12640-3 compiled a set of standard digital images and a list of real world colors that would be useful for:

1. Evaluating the color reproduction of imaging systems
2. Evaluating color image output devices
3. Evaluating the effect of image processing algorithms applied to the images
4. Evaluating the coding technologies necessary for the storage and transmission of high-definition image data

This provides an idea of what the gamut of the original could be and how much compression or clipping would be required and an overview of the original color values. Using the color data list from this ISO 12640-3 standard would provide this research a strong base to start with, and using graphs such as shown in Figure 4, it would be easy to help the reader understand different complexities involved in the gamut mapping process.

Gamut Mapping Complexities

Some of the gamut mapping complexities which are well documented in various projects are of great interest. Studies have revealed that these occurrences are undesirable

and considered as problems as they produce mathematical complexities in the gamut mapping computational process (Rosen, 2009). Some are:

Concavity of the gamut hull confuses the gamut mapping algorithms and often produces wrong values or duplicate values for adjacent numbers. In such case, the matrices are algebraically inflated to compensate for; but this requires a lot of assumptions and is not desirable.

Overlapping of slices/hulls is also undesirable since the same input value is computed for differently and produces two different values. (Usually a gamut is divided into sectors or slices at different hue angles, for making the computations simpler and then merged again).

Method of compression is one of the most challenging issues that needs to be handled. Would a linear compression, be preferable or a bilinear compression, to preserve the saturation levels of most colors? When calculating the compression should L* be preserved or should the hue angle be preserved, to avoid non-linear hue shifts in different regions? Should the whitepoint be preserved or the entire gray axis be preserved? (Kolas, 2008) Several other issues lead to confusion and hence an improved method of testing is essential to understand the problems and then clearly state the problems (Dugay F. et al., 2009).

Such gamut mapping complexities issues lead profiling applications to employ different gamut mapping principles, and hence may lead into different color. Hence, it is of interest to find the differences and the significance of those color differences. Further, it would also be interesting to evaluate if the differences are visually noticeable and therefore significant.

Chapter 3

Research Questions and Limitations of This Research

Research Questions

Usually, a typical press operator using color management techniques seldom understands all the computations executed in a color managed workflow, including under the hood of a profiling application. In addition, since there is no correct or incorrect method of executing the gamut mapping, it becomes not only interesting but also necessary to exemplify different ways being used, explain the logic implemented, and determine if these procedures result in visually noticeable differences in the printed product. This research focused on the following questions:

Q1) How different are the selected profiling application programs in B-to-A mapping for a given CMM under perceptual rendering intent? How different are the profiling applications in B-to-A mapping under absolute, relative and saturation rendering intents?

Existing literature on gamut mapping techniques is either too scientific or too technical to communicate to typical color management practitioners, so it becomes necessary to help convey this knowledge through a simpler method. A method will be developed to display the differences between gamut mapping application programs available commercially that is simple enough to understand by a typical user.

However, quantitative color difference displayed by the method above may not translate to visual color difference. This leads to the second research question:

Q2) Even if there are quantitative color differences due to different color mapping, are the color differences visually noticeable in pictorial samples?

By answering the second research question with the use of SCID images in CIELAB color space, it will be clear to the reader that existence of several different methods of gamut mapping techniques might lead to different visual appearances.

Limitations of this Research

- A single CMM, CHROMiX ColorThink's CMM, is used in the experiment
- The round-trip (B-to-A-to-B) is used to implement the gamut mapping with the assumption that the A-to-B conversion, which takes place after the gamut mapping, is colorimetrically accurate.
- Only the B-to-A conversion from different ICC profiles are used. It means that SCID images in CIELAB color space are used.

Chapter 4

Methodology

Methodology for Research Question 1

Q1) How different are the selected profiling applications in B-to-A mapping for a given CMM under perceptual rendering intent? How different are the profiling applications in B-to-A mapping under absolute, relative and saturation rendering intents?

To obtain a clear explanation for the first research question, the following methodology used a 'Profile Analysis Tool' written in Postscript and MS Excel by Franz Sigg. Franz Sigg has published some results from using this software tool, but the tool itself was not published. This tool generates L*C* graphs and other graphs showing tone reproduction and gray balance relationships on the basis of ICC profiles. Basically, the color space of existing reflection colors is sampled using the test target mentioned in step 2 below. The colors of this chart are defined in the device independent CIELab color space, which is the ICC profile connection space. We now can use a given output profile that we want to test, and convert these colors to CMYK which is the device space of the output device for which the profile was made. The real world colors cover a larger gamut than the CMYK colors which are gamut limited by the output device. Therefore, the profile needs to compress the original L*a*b data. This gamut mapping is different for different rendering intents.

The procedure for testing is as follows:

1) It must be understood that a large amount of gamut compression and clipping is preferable. Since this study is about understanding gamut clipping and compression, the destination gamut selected should be of a smaller size so as to make the effect of gamut compression and clipping more evident. In doing so, this will amplify the effects of gamut mapping, and make it easy for the observer to draw inferences and conclusions. To achieve maximum compression and clipping, the profiling testform could be printed on an uncoated grayish paper with a low whiteness and brightness value, such as newsprint paper. But this introduces several variables such as mottle and poor repeatability of the process. Instead, a standard characterization data set for newsprint paper were used to create the profiles using the profiling software. 'ISOnewspaper26v4.icc' data set will be acquired from 'World Association of Newspapers and News Publishers' website – 'www.wan-ifra.com', for this purpose. This eliminates all the variables related to printing the profiling test target and therefore provides more reliability to the procedure.
2) The downloaded standard data set for ISOnewspaper26v4.icc will be used to make a profile using at least two of the following profiling programs - Monaco Profiler v5, Gretagmacbeth ProfileMaker v.5.0, and Heidelberg Prinect.

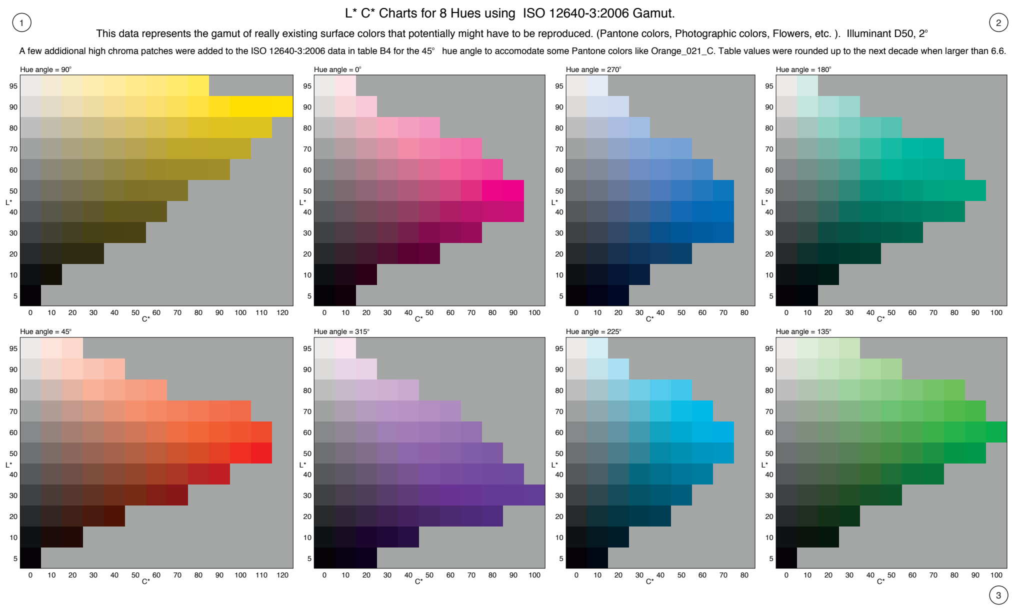


Figure 3: Sample Testform from real world colors for gamut mapping.

3) The testform shown in the Figure 3 with eight hue slices 45° apart, created by Franz Sigg, will be used for testing the profiles. The testform contains only 'real world colors' as stated by ISO 12640-3. The colors in this testform were defined in the CIELab space (PCS) and hence it is device independent color information.

4) The data from this testform was then converted by the profiles which were created using different profiling programs using CHROMiX ColorThink Pro 3.0 with its CMM. The conversion returns in device L*a*b* color values.

5) The obtained device L*a*b* values were then compared with input L*a*b* values from the testform. By the end of step 4, a round-trip conversion was obtained, where the inversion (B-to-A) and the forward (A-to-B) routines were performed with gamut mapping as an integral part of these steps.

6) From the two profiles, the converted data sets for all the four rendering intents were plotted on an L*C* graph, a*b* graph, tone reproduction graph, and gray axis graph as shown in Figure 4, Figure 5, and Figure 6 respectively. These graphs show how the gamut mapping is applied to the eight different hue slices. From the sample graphs shown in Figure 6, and Figure 7, it can be easily seen how the real world colors converge from a larger gamut to a smaller gamut. The L*C* graphs will be generated for eight different hue angles, as mentioned previously, revealing the specifics of the gamut mapping algorithm.

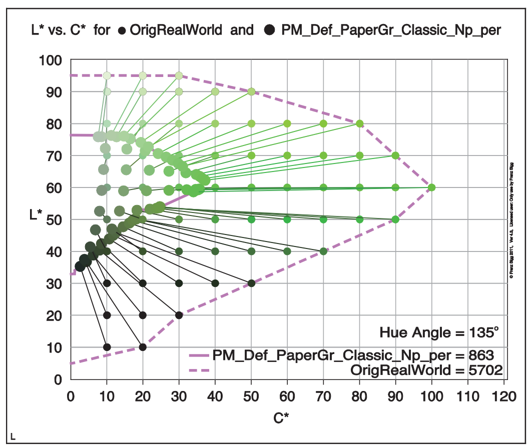


Figure 4: Sample L*C* graph showing gamut mapping.

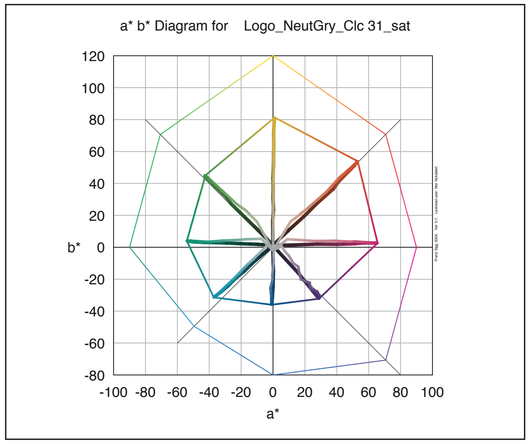


Figure 5: Sample a*b* graph showing gamut mapping.

The a*b* graph in Figure 5, shows the original gamut and the destination gamut and also shows the colors at the eight hue angles, giving a clear idea about the gamut of the saturated colors. This graph also shows that the fully saturated colors, moving from the white point to the black point for each hue angle do not necessarily maintain a constant hue angle. Each color is shown using closest hue and darkness in the graph, therefore darker lines represent colors with low L* values, while lighter lines represent colors with higher L* values.

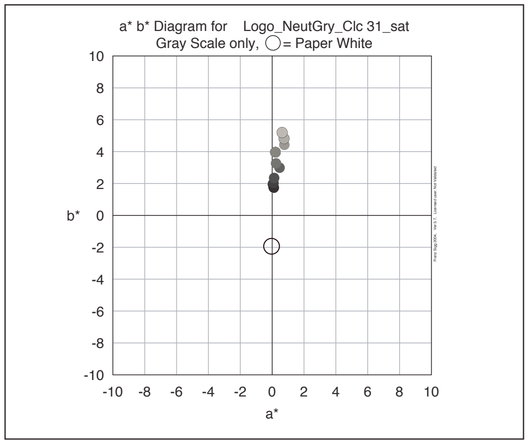


Figure 6: Sample Gray axis plot

In addition to this, the gray axis will also be plotted as shown in Figure 6 which displays the axis shift or the whitepoint shift.

7. To list significant quantitative color differences from the observations off the graphs and the available quantitative data.

Methodology for Research Question 2

Q2) Even if there are quantitative color differences due to different color mapping, are the color differences noticeable when examining the samples visually?

The objective of answering question 2 is to verify if a systematic analysis of subjective responses would substantiate a conclusive finding. Employing simulation at all stages was one of the objectives to not only reduce the cost of this research but also to consistently retain use of printing standards throughout the research and offer more

flexibility. As a part of the preparation for the experiment, the following steps were followed:

1) Three pictorial images from the group of ISO CIELab SCID images were selected which covered most hues and also had intricate details that would be affected due to gamut size. The selected images were 'N3_16_LAB_r', 'N4_16_LAB_r', and 'N7_16_LAB_r', as shown in Figure 7.

Figure 7: CIELab SCID images stacked into a block in Adobe Photoshop

2) The selected CIELab SCID pictorial images were opened in Photoshop and a block of all three images was created as shown in Figure 7 above.

3) Eight duplicate copies were made of this block. Each copy was color managed for both profiling applications, for each rendering intent respectively, and was saved with proper naming convention so as to clearly distinguish between each file. For example: "CIELabSCID_Slab_Mn_Abs.TIF"

4) Each image was converted to Adobe RGB, with absolute rendering intent, in order to produce a common comparing color space but also preserve the gamut compressions and clippings caused by the respective profiles and rendering intents.

Figure 8: CIELab SCID image blocks paired besides each other per rendering intent

5) In MS PowerPoint 2007, a comparison set of two blocks from both the profiling applications for each rendering intent was assembled, resulting in four comparison sets. Each comparison set (as shown in Figure 8) consisted of two blocks of the three CIELab images converted to profiles from Monaco Profiler and Gretagmacbeth ProfileMaker.

6) Such assemblies when displayed on an ISO 12646 compliant monitor, such as an Eizo display, makes it very easy to compare and evaluate the tonality, colorfulness and the neutral gray rendering.

7) In the experiment, the observers were instructed to evaluate visual color differences between the color image pairs. The questions were limited to be very basic and simple to understand so as not to confuse the observer.

8) The observers were shown the paired blocks for all four rendering intents one pair at a time. Each pair was shown to the observer as shown in Figure 8, twice and randomly sequenced without the knowledge of having been repeated or having known that there were only four distinct pairs.

9) All observers were instructed to ***"Pick one, block of images from the pair, that is visually more chromatic/saturated colors than the other***."

10) The questions were conceived in such a way that the answers would help either to corroborate or refute the conclusion from question 1. Any ambiguity in the answers could mislead the research into meaningless information and conclusions.

11) The observer would be considered consistent only when he/she picked the same image block as one with visually more pleasing colors twice. This enabled the data from inconsistent observers to be identified and filtered out.

12) 20 observers were involved in the analysis, where each observer produced four observations, per rendering intent, qualified either as 'consistent' or 'inconsistent.' An observation qualified as consistent, only if the observer would pick the same image both times. Likewise, an observation was treated as inconsistent when an observer picked both blocks of images. This process produced a total of 80 observations.

The results section shows the findings from the above explained methodologies for both the research questions.

Chapter 5

Results

Results for Research Question 1

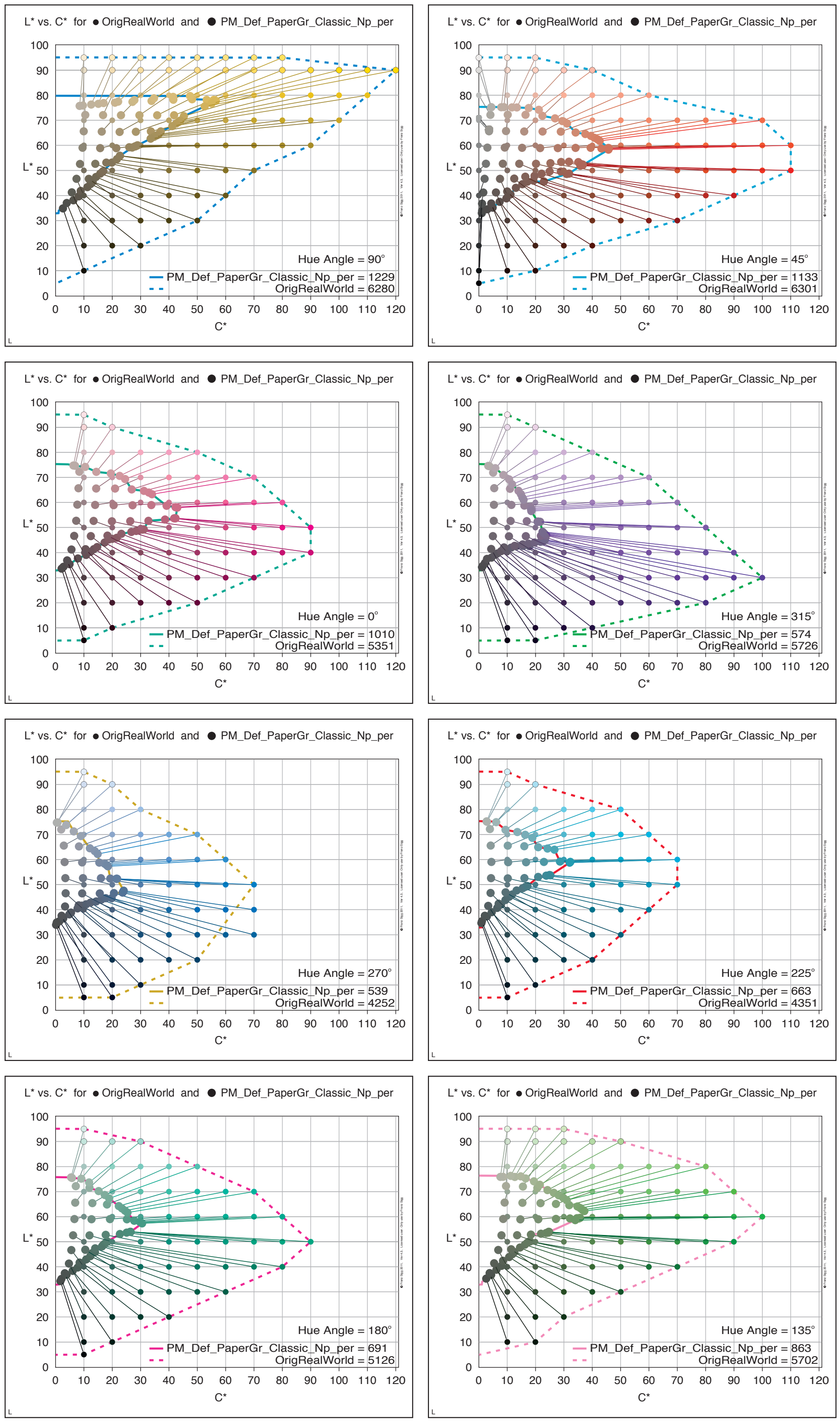
Q1) How different are the selected profiling application programs in B-to-A mapping for a given CMM under perceptual rendering intent? How different are the profiling applications in B-to-A mapping under absolute, relative and saturation rendering intents?

In order to answer ***Q1***, the following quantitative differences can be observed based on the graphs produced by 'Sigg's Profile Analysis Tool version 45.' The differences may not necessarily refer to significantly noticeable color differences, but may refer to observations that show unique rules /methods implemented by the profiling applications that influence the profile's color conversions differently in each application. Before delving into the data, the most notable observations based on the 'summary of profile analysis' from 'Sigg's Profile Analysis Tool version 45' are mentioned.

CHROMiX ColorThink Pro 3's worksheet feature was used for converting the real world colors from ISO 12640-3 to the respective profiles. The following differences in Figure 9 are listed for CHROMiX ColorThink's CMM which was used while obtaining the round-trip L*a*b* data for the real world color test target using the profiles in the research.

CIELAB Data from LC_11U-6.6.EPS chart with ISO-WD 12640-3.4 colors was taken, and the PM_Def_PaperGr_Classic_Np.ICC profile was applied using ColorThink, first converting Lab to CMYK using Perceptual color rendering intent. Then, to simulate printing, this CMYK data file was converted back to Lab, using the same profile back to Lab using the same profile with Absolute rendering. The L*C* charts below show this data compared against the original Lab data from LC_11U-6.6.EPS.

Note: The indicated gamut size numbers are in terms of L*C* CIELAB area units. It is well known that a step difference in yellow is visually less significant than a step difference in blue. Gamut comparisons in CIELAB should therefore be limited to comparing same hue angles only. CIELAB is not visually equidistant.



Perceptual Rendering, PM_Def_PaperGr_Classic_Np.ICC,

Figure 9: Sample L*C* graphs for eight hue angles 45º for

'PM_Def_PaperGr_Classic_Np.ICC' from Gretagmacbeth Profile Maker 5.0

Figure 9 provides a sense of how some of the graphs appeared. Several other graphs were used to deduce observations. The entire quantitative analysis summary of profiles is shown graphically in Figure 10 below. The full set, of these graphs, is shown in the appendix.

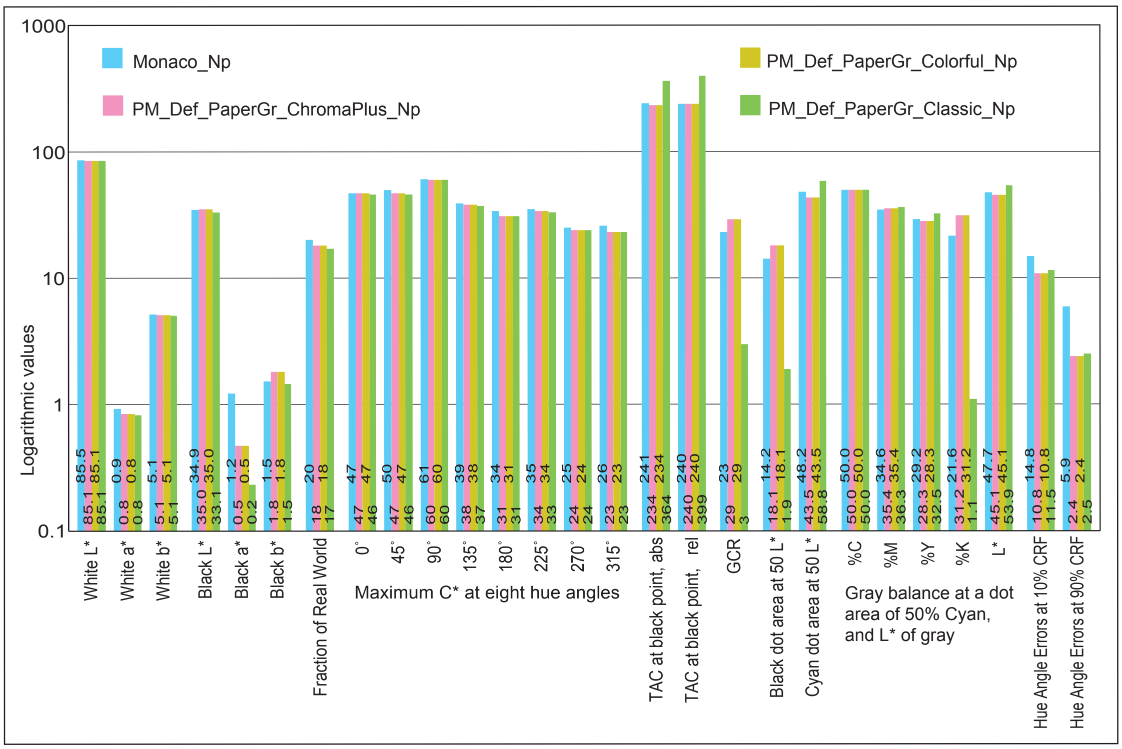


Figure 10: Graphic summary of all three profiles from Gretagmacbeth Profile Maker 5.0, and one profile from Monaco Profiler 5.0

It is known that CIELAB is not visually uniform (Hill et al.; 1997), hence step differences for a certain hue can be visually less significant than step differences for another hue, for ex. yellow and blue. Therefore, gamut comparisons in CIELAB in this research are always limited to comparing same hue angles only.

The most notable observations inferred from the two applications (Monaco Profiler 5.0 and Gretagmacbeth ProfileMaker 5.0) obtained from the graphical summary of profiles as shown in Figure 10 are:

a. White points for all the profiles were virtually the same.

b. Monaco Profiler had a slightly more red, but very negligibly different, black point as compared to that of ProfileMaker.

c. Even though the same data set was used to create the two profiles which result in the same gamut size for both profiles as per CHROMiX ColorThink Pro, Sigg's Profile Analysis Tool showed that Monaco Profiler had slightly greater reproducible percentage of real world colors. It was determined that the gamut size differences arise because the data set used to make the profiles (IT8-7.3) and the data set used for Sigg's Profile Analysis Tool are different, and therefore the gamut mapping algorithms have to interpolate, which they do differently.

d. For the same reason, Monaco Profiler showed an equal or slightly greater saturation (C*) of maximum saturated colors for all hue angles as compared to ProfileMaker profiles.

e. GCR (Gray Component Replacement) is a user-specified parameter, and its value may not be one of the inherent characteristics of the profiling algorithm. Although, the GCR settings applied in each profile are the

defaults from the application. GCR in ProfileMaker's Classic workflow is comparatively lower. It also uses a higher TAC.

f. Similarly, K component in GCR and K dot area at 50L* are significantly lower in the ProfileMaker Classic workflow.

g. With these observations, it is clear that the two profiling applications are different in various areas, although the three profiling workflows from ProfileMaker were similar to each other in most areas, except for GCR. Some of the L*C* graphs show some abrupt changes at the gamut boundary which are assumed to be rounding problems due to the fact that the sampling steps for the L* and C* axes are relatively high at 10 units. They are not investigated any deeper, hence it is not conclusive whether there are complexities such as concavity, overlapping of colors (arising due to overlapping of gamut slices/hulls), and other erratic unexplainable behaviors.

h. On the basis of these observations, it was decided to pick the ProfileMaker 'Classic' workflow for comparisons with Monaco Profiler to answer both the parts of question Q1. Moreover, the remaining two profiling workflows from ProfileMaker were quite similar, and hence would not add much to the understanding of the differences between the profiles.

i. Considering the small magnitude of the differences in the two profiles, it is possible to say that the two profiles can ***interoperate*** to produce the same results.

The following differences are listed for CHROMiX ColorThink's CMM, which was used while obtaining the round-trip L*a*b* data for the real world color test target using the profiles in the research.

The most notable observations inferred for the two applications (Monaco Profiler vs. ProfileMaker) for B-to-A mapping with respect to how the color conversions differ for perceptual rendering intent, were:

Table 1: Most notable observations for differences in perceptual rendering intent for the two profiling applications

Factors in comparison	Monaco Profiler	ProfileMaker Classic
a. Chroma	All eight hues have more chromaticity. Greens, yellows, oranges, and violets are significantly more saturated.	Lighter hues in highlights in blues, oranges, violets, cyan and green have more chromaticity. Hence, lighter colors will appear cleaner and more vivid.
b. Gamut Compression and clipping with respect to L*	Lesser gamut compression. All colors at 60<L*<70 retain same L* post clipping.	More gamut compression is notable. Gamut clipping for all hues above the cusp is smooth. Severe concavity (gamut complexity) is apparent in all the hues for colors below the cusp. (See Figure 9 or appendix.)
c. Similarities within application to other rendering intents.	Perceptual rendering intent is unique but relative colorimetric is same as saturation, which defies the definitions of the rendering intents as per the ICC specifications.	Perceptual is same as saturation, which defies the definitions of the rendering intents as per the ICC specifications.
d. Hue angle faithfulness	Hues deviate more from ideal angles. Violets are	Hues are less deviating comparatively and appear

	most deviating and scattered. CRF curve of hue angle accuracy shows +/- 20 degrees deviation at 80% of real world colors. See Figure 10.	to be better retained. No considerable scattering is visible in any hues. High hue angle faithfulness is apparent. Up to 80% of real world colors only deviate by +/- 10 degrees, in the CRF curve.
e. Gray Reproduction	Grays appear to be approximately equidistant in a line.	Grays appear to show slight hooking at extreme low L* values, which may not contribute to any notable differences.
f. Other observations	Several colors are group-forced to same notable points with same L* values on the gamut boundary (resulting in no color difference). This occurs even when the uncompressed colors have greater L* differences as compared to other colors that are mapped to discrete points on the gamut boundary.	

In summation, the Monaco Profiler appears to sacrifice hue angle accuracy but preserves chromaticity, whereas ProfileMaker sacrifices chromaticity and retains maximum hue angle accuracy. Monaco Profiler produces a larger reproducible gamut than ProfileMaker, but it is difficult to state if hue angle accuracy is inversely proportional to chromaticity. Therefore, it may be inferred that Monaco Profiler prioritizes more saturated colors over accurate colors whereas ProfileMaker prioritizes accuracy of colors over other gamut mapping parameters.

Next, the profiles for Monaco Profiler vs. ProfileMaker Classic will be discussed. The most notable observations from the two applications for B-to-A mapping are presented below in Table 2 with respect to how the color conversions differ for absolute colorimetric and relative colorimetric rendering intents.

Table 2: Most notable observations for differences in colorimetric rendering intents for the two profiling applications

Comparison for Absolute and Relative Colorimetric	Monaco Profiler	ProfileMaker Classic
a. Chroma	All eight hues have greater chromaticity.	Hues have slightly lesser chromaticity.
b. Hue Angle accuracy	Hues at each angle deviate in a random wavy pattern, which is of concern. Such an instant would be approvable only in cases where the profiling measurements used were randomly deviating (which they are not). Hue angle errors: at 10% CRF = -14.8 90% CRF = 5.9	Hues at each angle consistently show minimum deviation from the ideal angle. Hue angle errors: at 10% CRF = -11.5 90% CRF = 2.5
c. Gamut complexities in boundaries	More abrupt stepping is visible in the colors above the cusp, in all gamut slices	Concavities (an undesired gamut surface complexity) is consistently visible above the cusp, in all gamut slices
d. Profile settings (Black Point, TAC, GCR)	Slightly redder black point. TAC's limited to 241%. GCR% used is 23%.	Darkest black point (33.1 L*). TAC's sum up all the way to 399% for relative, and maximum GCR% used is only 3%.

Interestingly, the default ProfileMaker Classic black settings are similar to older conventional offset printing practices, which may be the reason why it is named "Classic" workflow. Monaco has greater gamut in darker areas.

All conclusions previously mentioned for perceptual rendering intent related to hue angle, chromaticity and gamut size are applicable for colorimetric rendering intent as well.

Table 3 presents the comparative analysis for saturation rendering intent. Interestingly, both profiling applications for saturation rendering intent appear to deviate from the definition as per ICC Specification Version 2 and have gamut mapping algorithms implemented based on customized definitions.

Table 3: Most notable observations for differences in saturation rendering intent for the two profiling applications

Comparison for Saturation Intent	Monaco Profiler	ProfileMaker Classic
Unique observations and conclusion	Saturation intent is the same as relative colorimetric rendering intent. Hence, it does not increase the saturation of within-gamut colors.	Saturation intent is the same as perceptual rendering intent. Hence, it does not increase the saturation of within-gamut colors, but preserves the inter-relationship of all the colors.

In conclusion for research question Q1 the Monaco Profiler appeared to produce larger gamut that slightly sacrificed the hue accuracy, based on the fact that it had definite hue angle deviations from the nominal hue angle. On the other hand, ProfileMaker sacrificed gamut size but there was not enough evidence to conclude if it prioritized hue accuracy more than any other parameter. Next, the results for research question Q2 will be presented.

Results for Research Question 2

Q2) Even if there are quantitative color differences due to different color mapping, are the color differences noticeable when examining the samples visually?

Based on quantitative findings, the graphical data for the profile from Monaco Profiler displayed slightly more saturation than ProfileMaker. Whether a set of subjective responses produced a similar evaluation was of paramount interest. The results are presented in Table 4. The observations deliberately were not categorized per rendering intent, to avoid complex classifications and inability to draw meaningful conclusions.

Table 4: Total 80 observations from 20 observers twice for 4 rendering intents

<table>
<tr><td rowspan="2">Consistent Observations</td><td>Monaco Profiler 5.0</td><td>Observers to consistently pick Monaco Profiler 5.0 image block, out of 4 image blocks, as one with 'visually more chromatic/saturated colors'</td><td>12</td></tr>
<tr><td>Gretagmacbeth ProfileMaker 5.0</td><td>Observers to consistently pick Gretagmacbeth ProfileMaker 5.0 image block, out of 4 image blocks, as one with 'visually more chromatic/saturated colors'</td><td>09</td></tr>
<tr><td colspan="2">Inconsistent Observations</td><td>Inconsistent observers to pick both ProfileMaker and Gretagmacbeth ProfileMaker 5.0 image blocks as ones with 'visually more pleasing colors' for the same images, when the same images were shown twice</td><td>59</td></tr>
</table>

With these findings, the outcome of the visual comparisons failed to substantiate any differences between the two. Almost 75% of observers were unable to choose one block of images over the other and hence were categorized as 'inconsistent'. From the remaining approximate 25% of the observations, it was not conclusive if the observers favored either Monaco Profiler or ProfileMaker. Since most color-aware observers could not discern the color difference consistently in the psychometric experiment, we conclude that there is no real visual differences among the samples represented by different gamut mapping and profiling software packages. With such findings, it was deemed unnecessary to conduct a formal paired comparison study or use statistical parameters to produce a more systematic visual analysis.

Chapter 6

Summary and Conclusions

The quantitative data revealed that Monaco Profiler produces slightly more saturated colors than Profile Maker. However, the question of interest is whether this could be confirmed by an analysis of subjective visual responses. The answer was no. The subjective responses revealed that the observations were not conclusive enough to corroborate the finding that the images color managed by Monaco Profiler were more chromatic or more saturated. The observers were not able to consistently pick the same images, which may be due to the fact, that visually, there were no significant color differences between the samples.

Readers may well wish to have a conclusion where either of the profiling applications clearly triumphs over the other in a certain aspect. The data revealed that there are several approaches towards implementing a gamut mapping algorithm and creating an output profile. The analysis to identify the quantitative differences between the two profiling applications for perceptual rendering intent and the other rendering intents, resulted in a large amount of data. It should be noted that well established comparative parameters were absent which made it difficult to identify various gamut mapping complexities.

The answer to question Q1 indicates that there are small measurable differences in gamut sizes, inter-relationship between L* and hue angles for input colors and compressed colors, default total ink limits, and default GCR settings. However, the answer to question Q2 suggests that those differences were visually insignificant. The two profiles are interoperable when evaluated visually.

Readers should benefit from this research as it displays how a seemingly impenetrable topic can be investigated without delving too much into the cores of physics and mathematics. The graphical representation of the data is quite detailed and informative, and may help readers to use these graphing techniques in their research. Lastly, readers will benefit by having the insight of where this research was able to evaluate differences between profiles, and where there were shortcomings.

Future Research

The fact that only a limited amount of the entire quantitative data provided by Sigg's Profile Analysis Tool was analyzed while drawing conclusions, implies that there is an opportunity for further research. It would be highly recommended to narrow the scope of the research to something more specific such as perceptual rendering intent and how the rendering intent should be implemented since it is not specified in the ICC specifications. How interpolations and rounding of values in the data sets can affect the gamut size is an area which could be investigated further, possibly with a test target specifically designed to evaluate gamut size as a function of the data set used. Another aspect that may simplify the research is the selection of those profiling applications,

which employ similar gamut mapping algorithms, based on objective evaluation. This may narrow down the differences in the quantitative data and simplify the quantitative evaluation process. Finally, the psychometric visual analysis may be improved by employing images that the observers have never come across, but have some memory colors in them.

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Appendix A: Monaco Profiler 5.0 Analysis

CIELAB Data from LC_11U-6.6.EPS chart with ISO-WD 12640-3.4 colors was taken, and the Monaco_Np.ICC profile was applied using ColorThink, first converting Lab to CMYK using Relative color rendering intent. Then, to simulate printing, this CMYK data file was converted back to Lab, using the same profile back to Lab using the same profile with Absolute rendering. The L*C* charts below show this data compared against the original Lab data from LC_11U-6.6.EPS.

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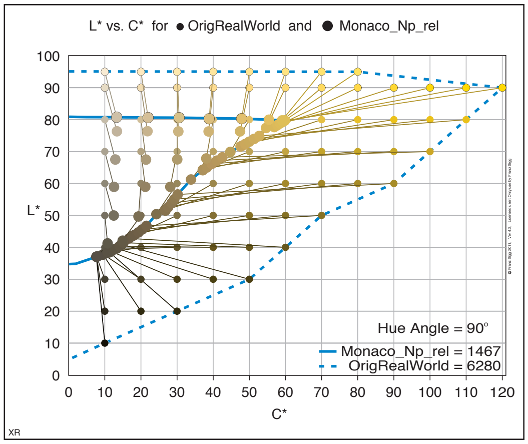

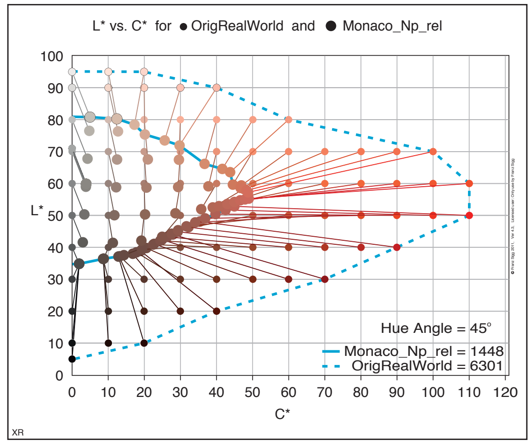

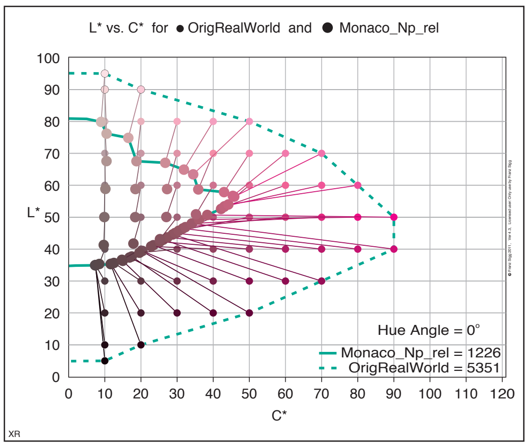

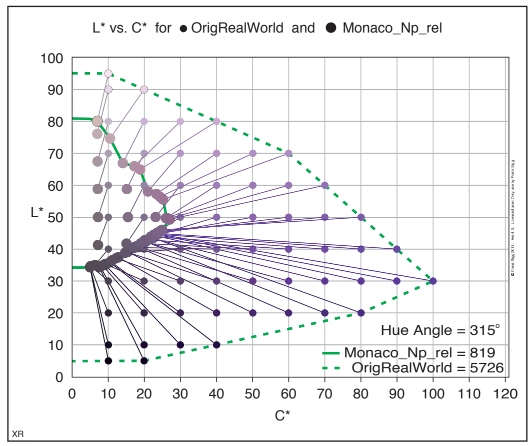

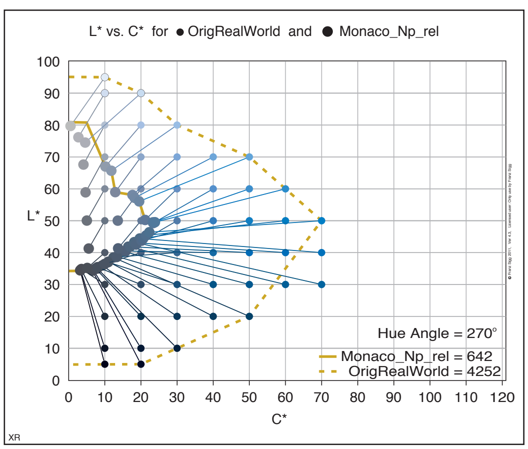

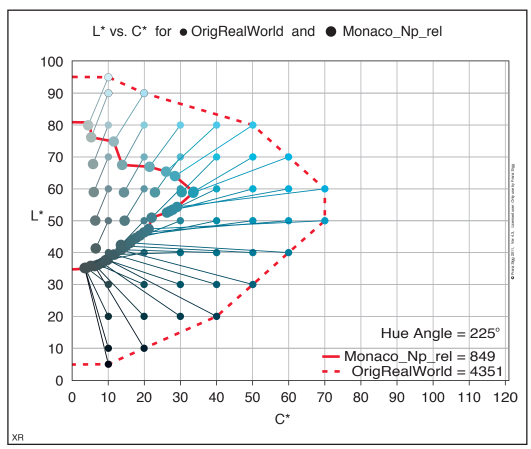

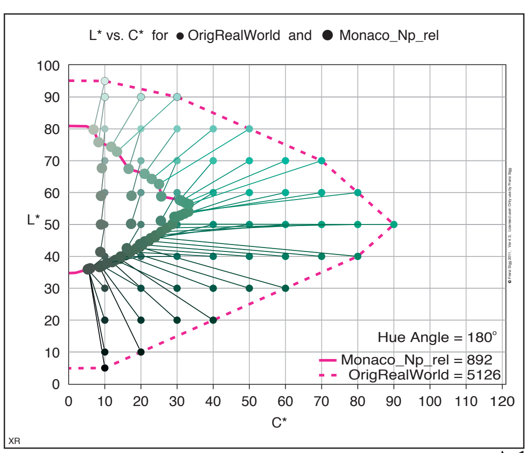

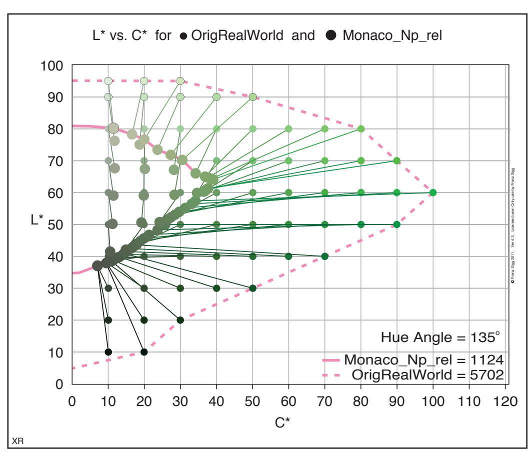

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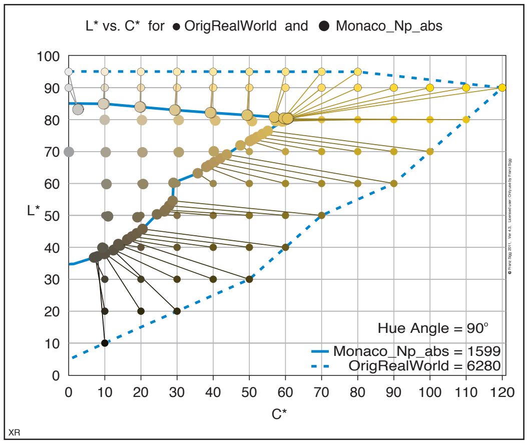

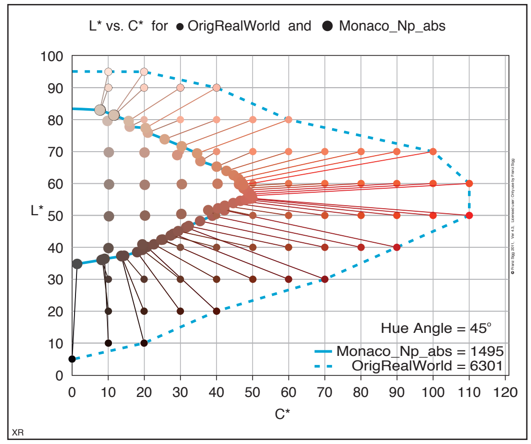

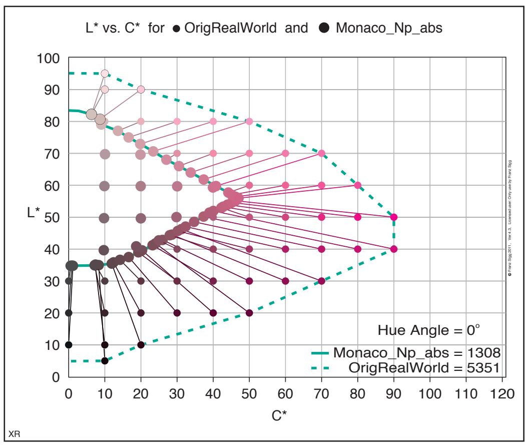

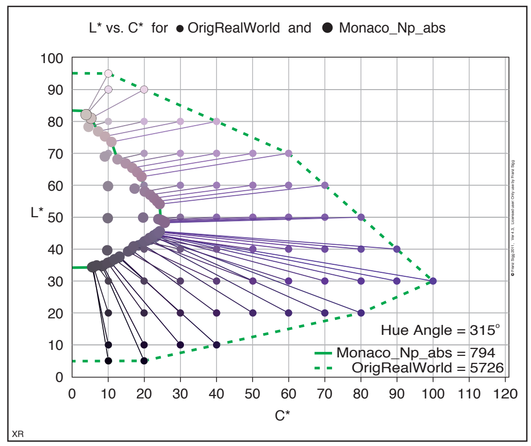

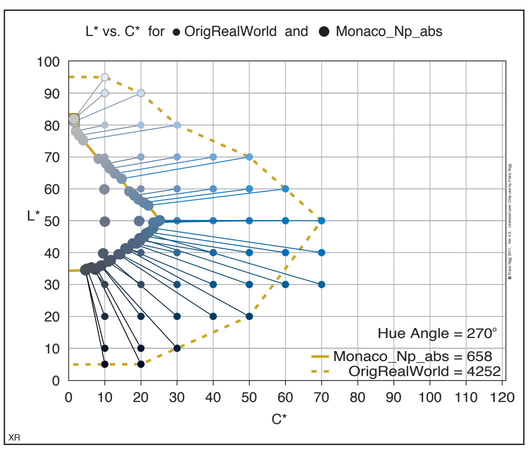

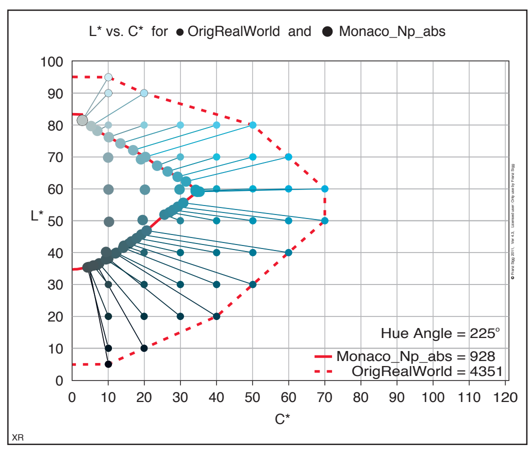

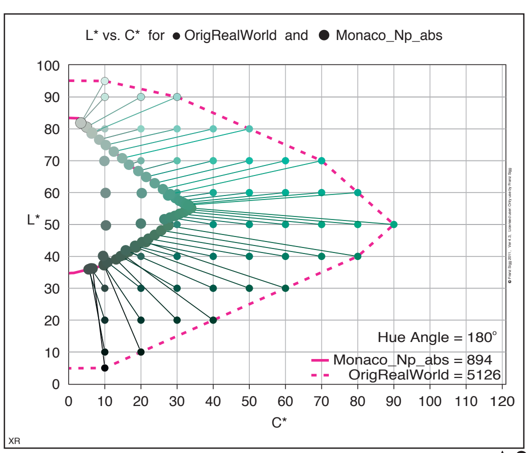

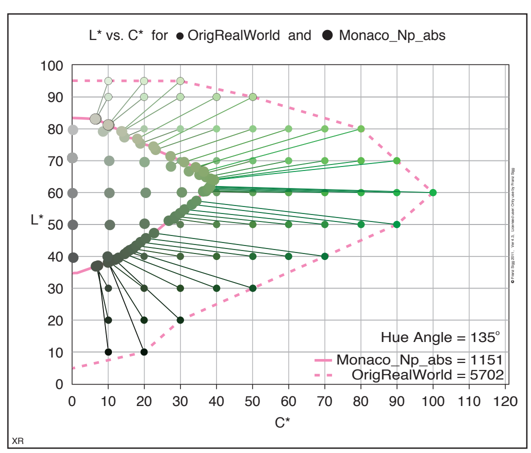

Absolute Rendering, Monaco_Np.ICC,

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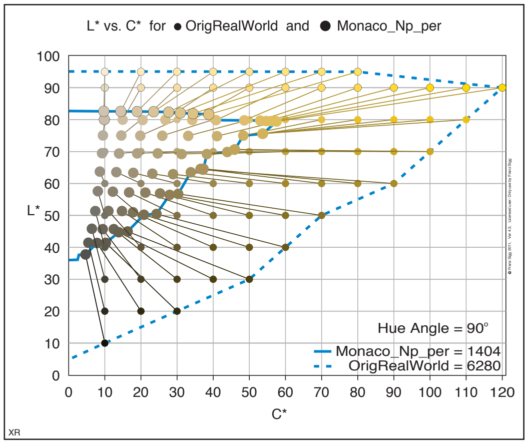
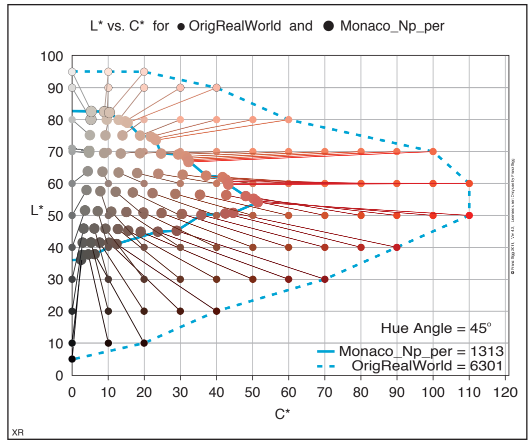
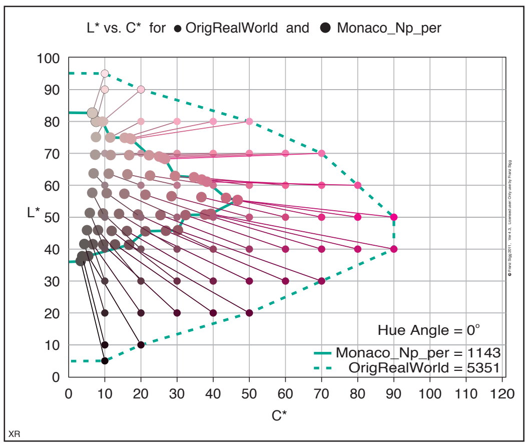
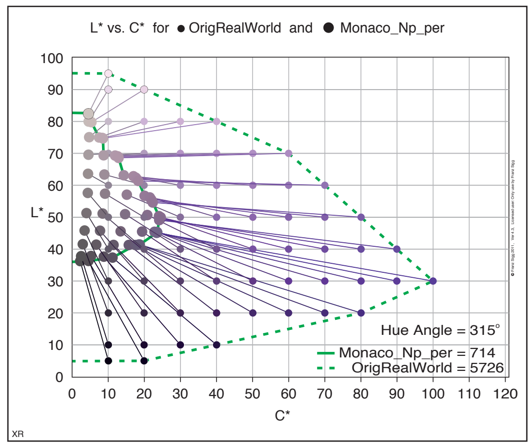
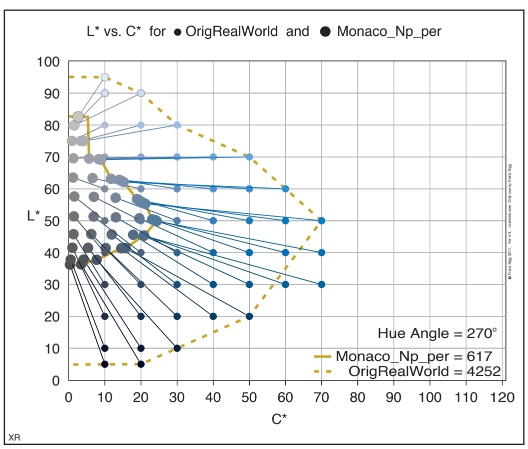
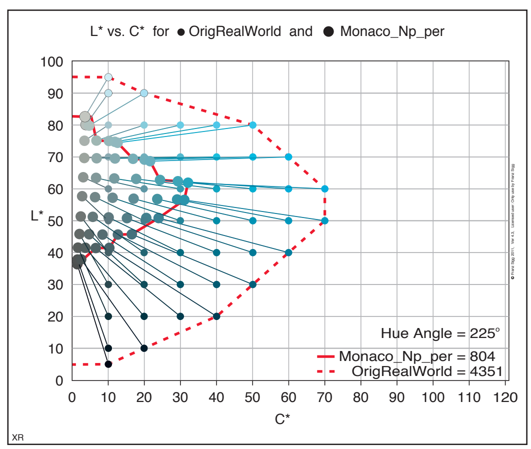


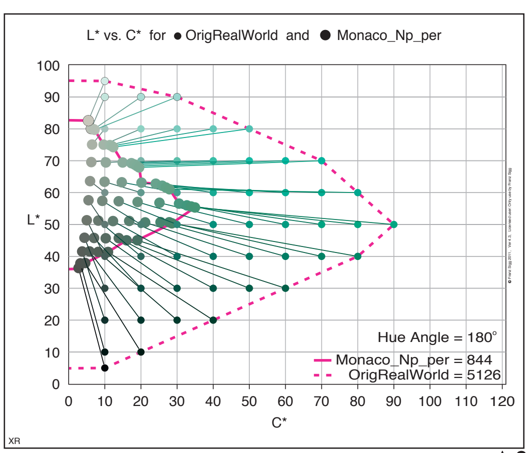


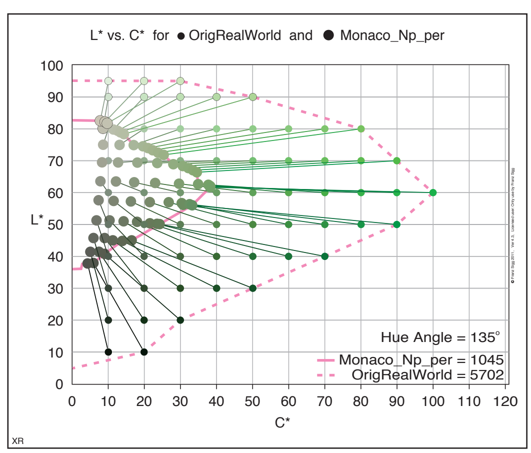






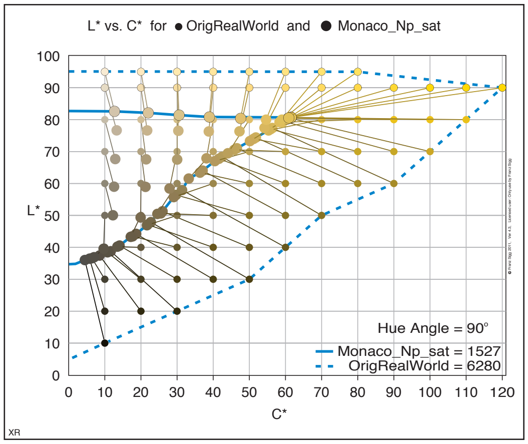


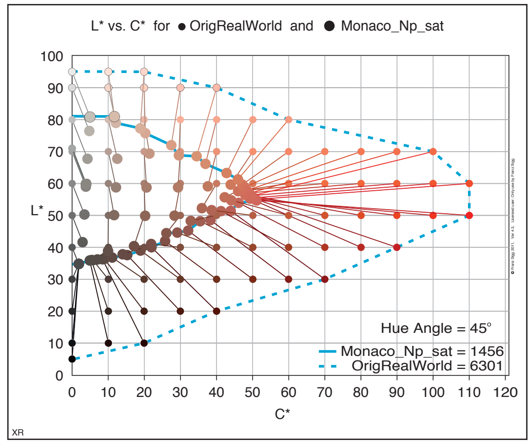


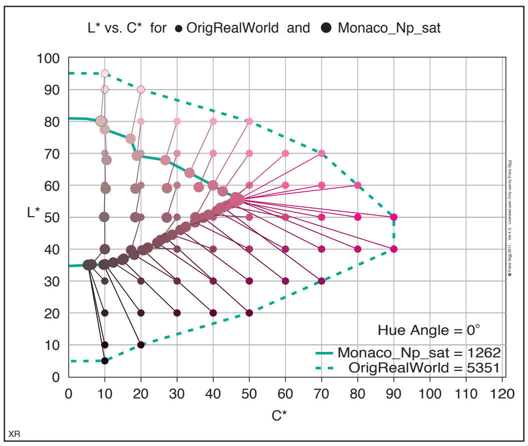


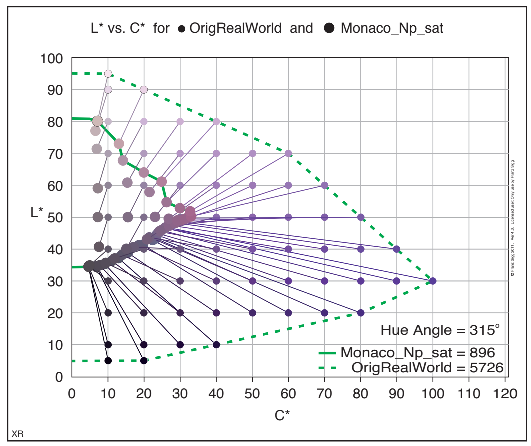
CIELAB Data from LC_11U-6.6.EPS chart with ISO-WD 12640-3.4 colors was taken, and the Monaco_Np.ICC profile was applied using ColorThink, first converting Lab to CMYK using Saturation color rendering intent. Then, to simulate printing, this CMYK data file was converted back to Lab, using the same profile back to Lab using the same profile with Absolute rendering. The L*C* charts below show this data compared against the original Lab data from LC_11U-6.6.EPS.

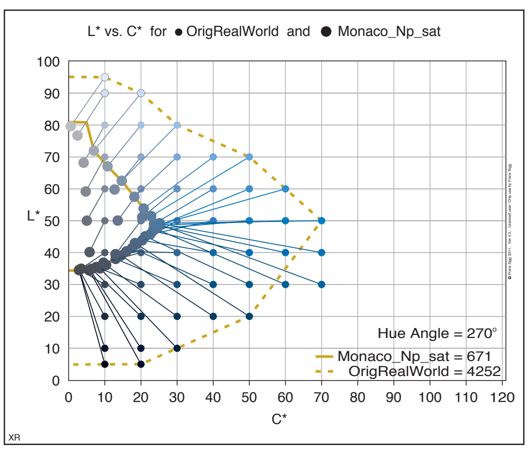
Note: The indicated gamut size numbers are in terms of L*C* CIELAB area units. It is well known that a step difference in yellow is visually less significant than a step difference in blue. Gamut comparisons in CIELAB should therefore be limited to comparing same hue angles only. CIELAB is not visually equidistant.

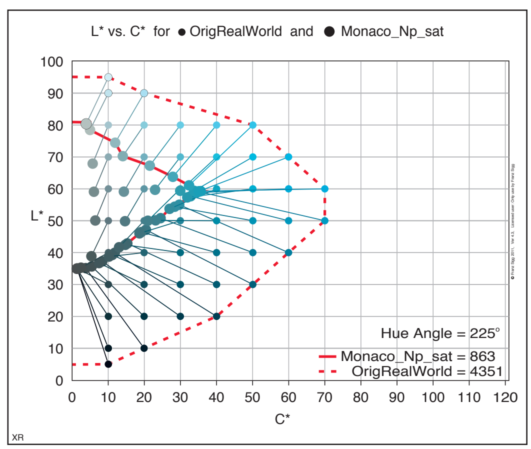


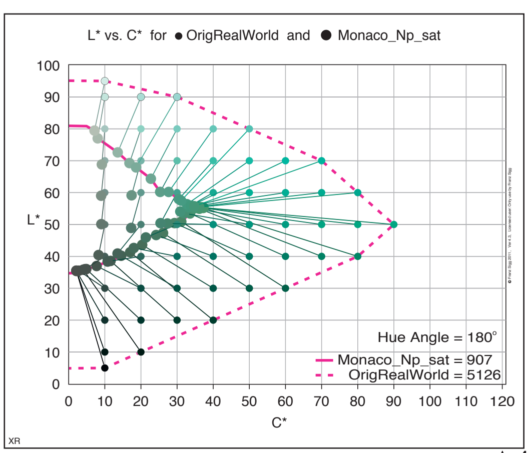


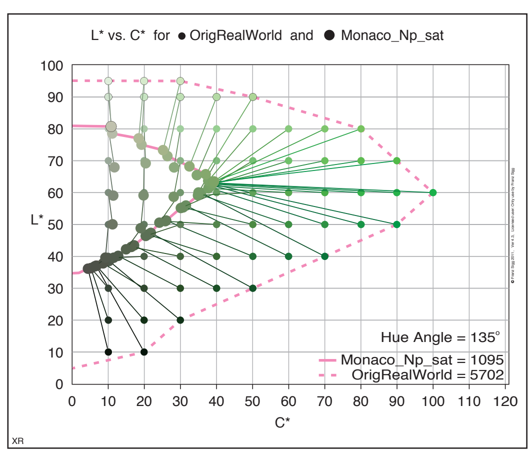








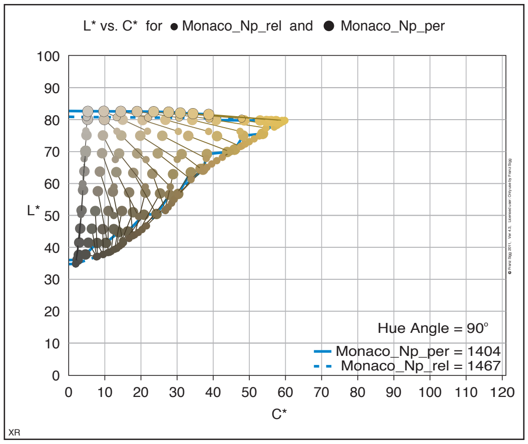


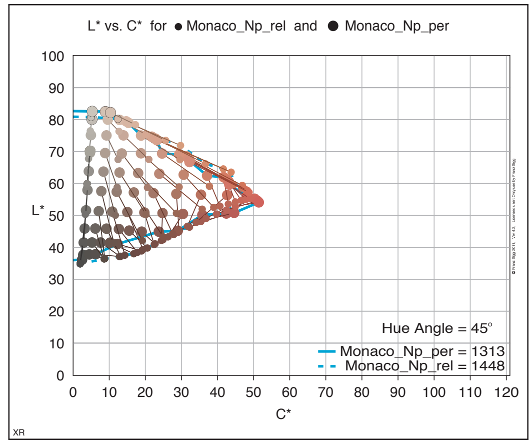


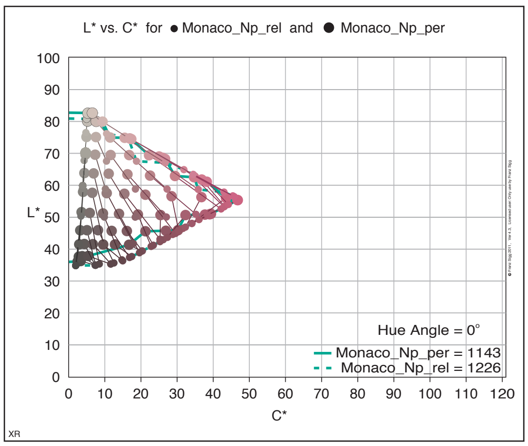
Saturation Rendering, Monaco_Np.ICC,

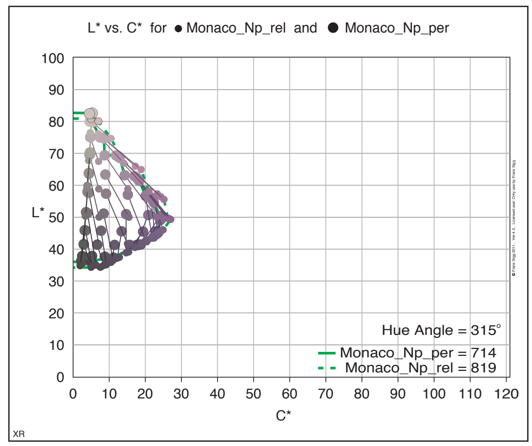
CIELAB Data from LC_11U-6.6.EPS chart with ISO-WD 12640-3.4 colors was taken, and the Monaco_Np.ICC profile was applied using ColorThink, first converting Lab to CMYK using Relative color rendering intent. Then, to simulate printing, this CMYK data file was converted back to Lab, using the same profile with Absolute color rendering. The same was done for Perceptual rendering and the two data sets are compared below.

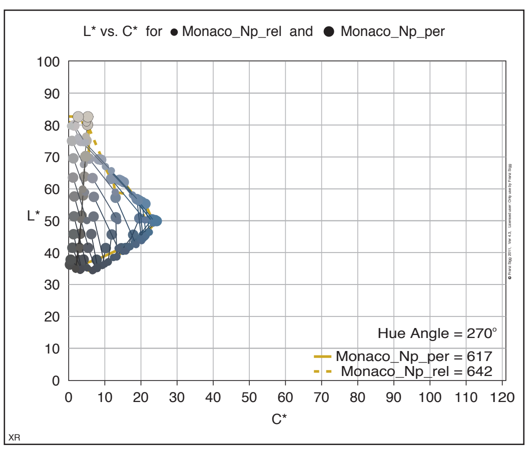
Note: The indicated gamut size numbers are in terms of L*C* CIELAB area units. It is well known that a step difference in yellow is visually less significant than a step difference in blue. Gamut comparisons in CIELAB should therefore be limited to comparing same hue angles only. CIELAB is not visually equidistant.

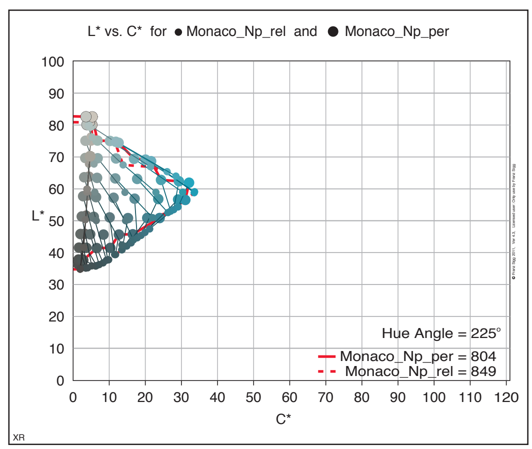


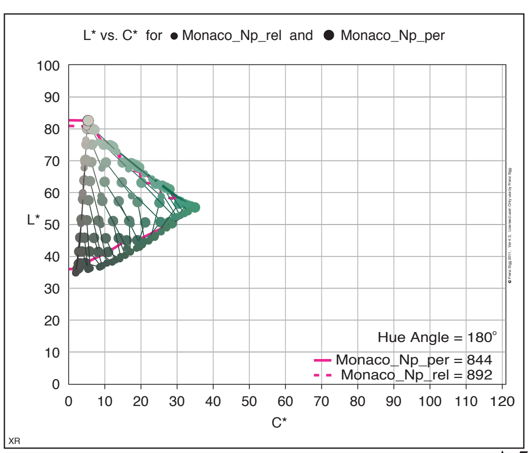


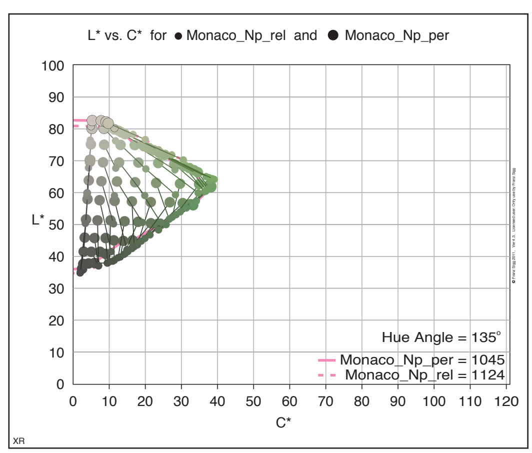








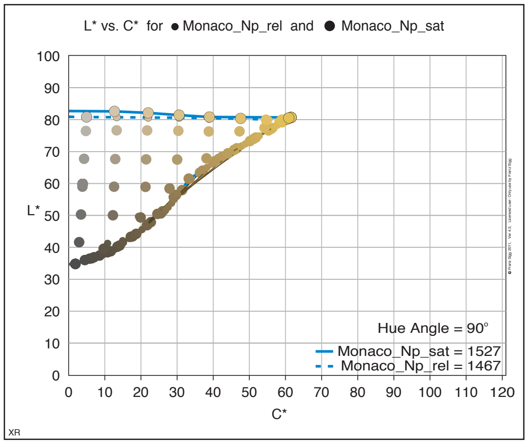


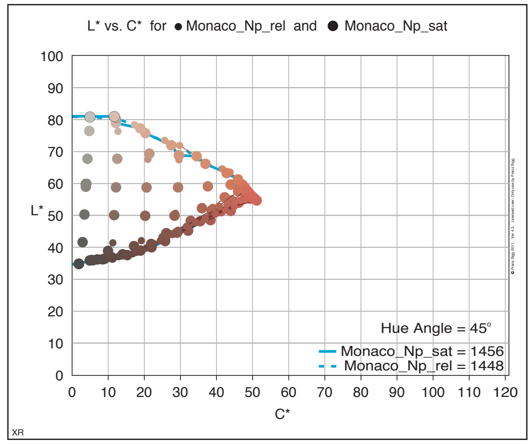


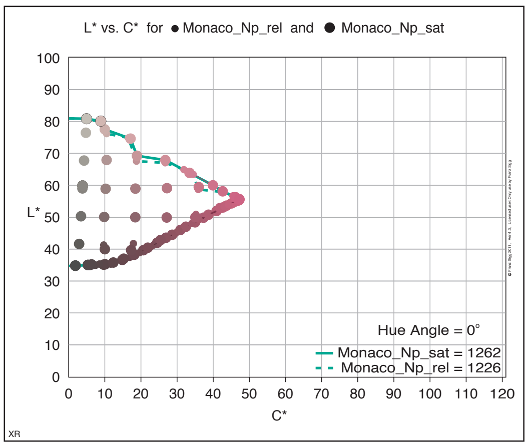
Relative vs. Perceptual Rendering, Monaco_Np.ICC,

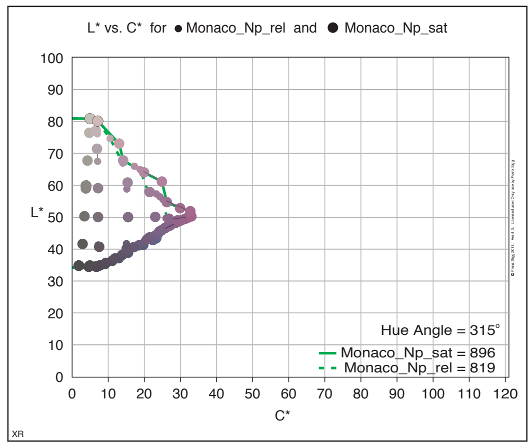
CIELAB Data from LC_11U-6.6.EPS chart with ISO-WD 12640-3.4 colors was taken, and the Monaco_Np.ICC profile was applied using ColorThink, first converting Lab to CMYK using Relative color rendering intent. Then, to simulate printing, this CMYK data file was converted back to Lab, using the same profile with Absolute color rendering. The same was done for Saturation rendering and the two data sets are compared below.

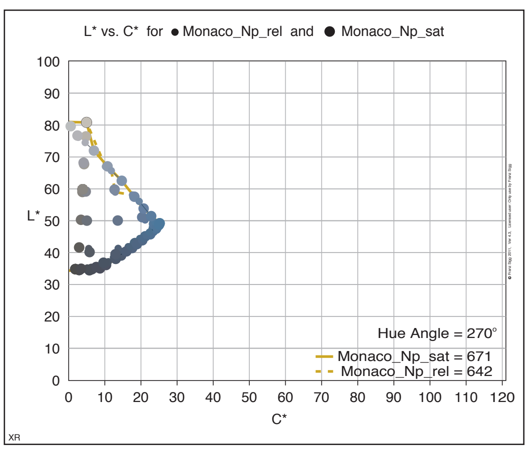
Note: The indicated gamut size numbers are in terms of L*C* CIELAB area units. It is well known that a step difference in yellow is visually less significant than a step difference in blue. Gamut comparisons in CIELAB should therefore be limited to comparing same hue angles only. CIELAB is not visually equidistant.

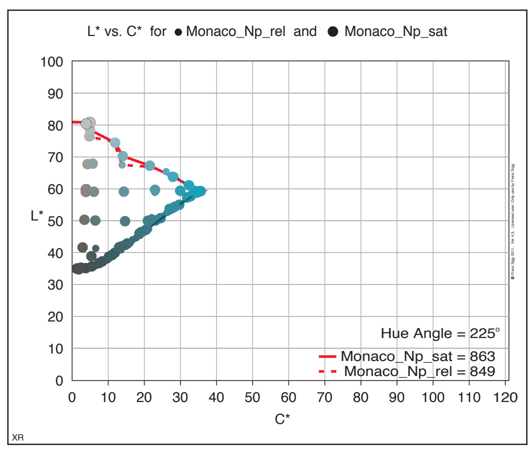


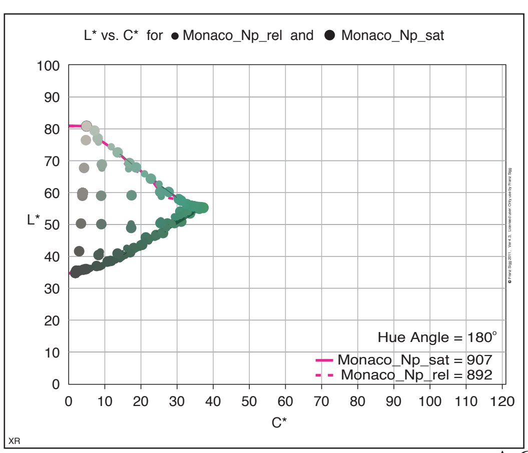


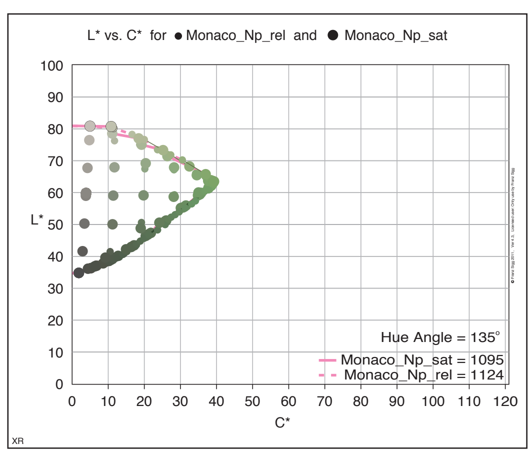








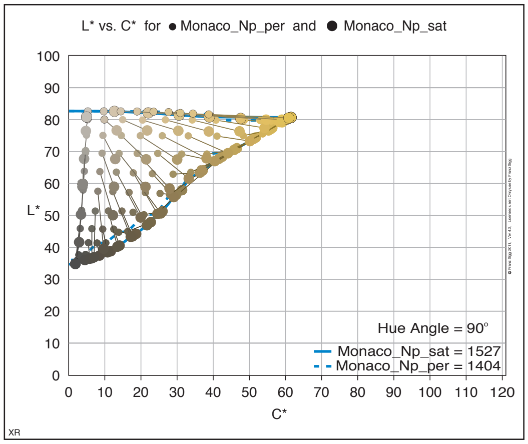


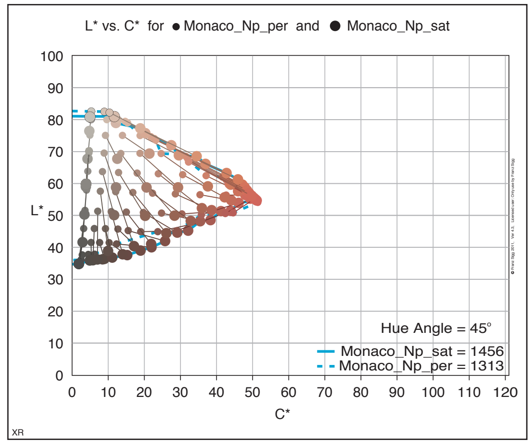


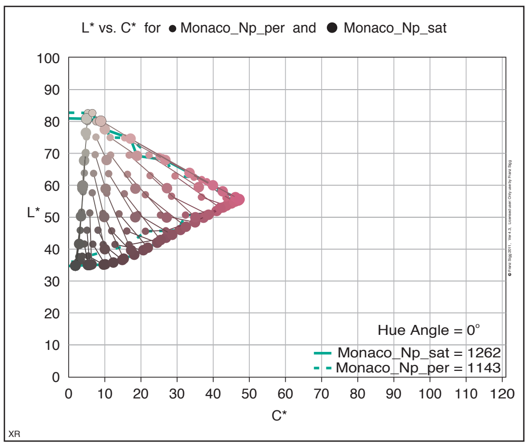
Relative vs. Saturation Rendering, Monaco_Np.ICC,

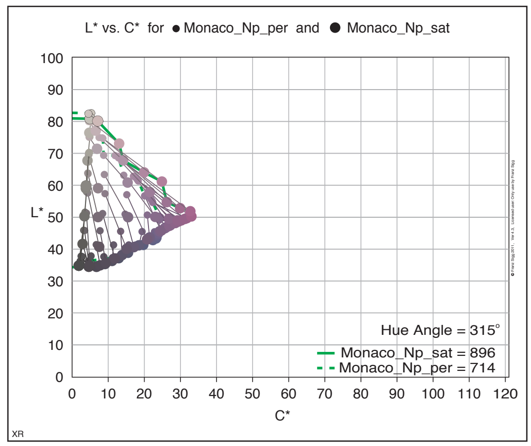
CIELAB Data from LC_11U-6.6.EPS chart with ISO-WD 12640-3.4 colors was taken, and the Monaco_Np.ICC profile was applied using ColorThink, first converting Lab to CMYK using Perceptual color rendering intent. Then, to simulate printing, this CMYK data file was converted back to Lab, using the same profile with Absolute color rendering. The same was done for Saturation rendering and the two data sets are compared below.

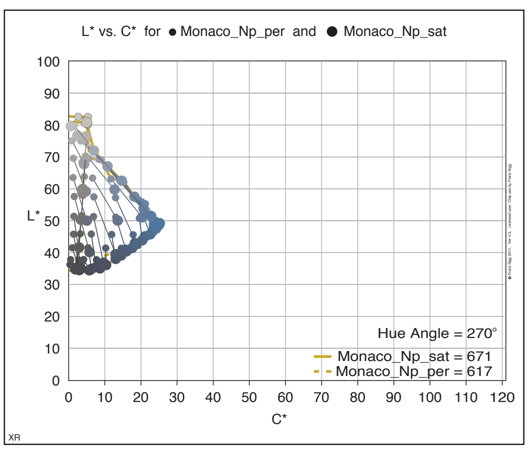
Note: The indicated gamut size numbers are in terms of L*C* CIELAB area units. It is well known that a step difference in yellow is visually less significant than a step difference in blue. Gamut comparisons in CIELAB should therefore be limited to comparing same hue angles only. CIELAB is not visually equidistant.

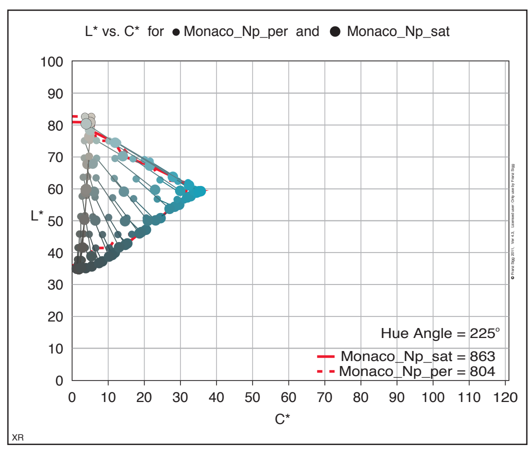


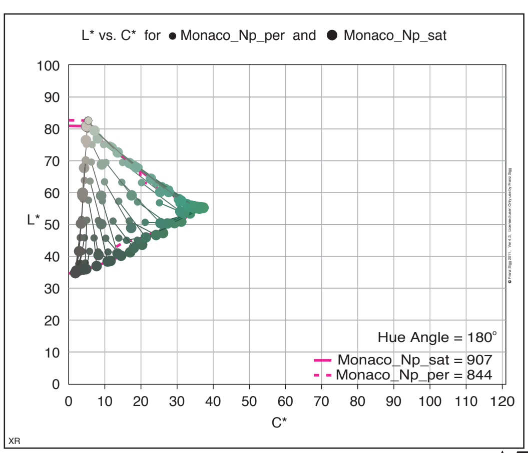


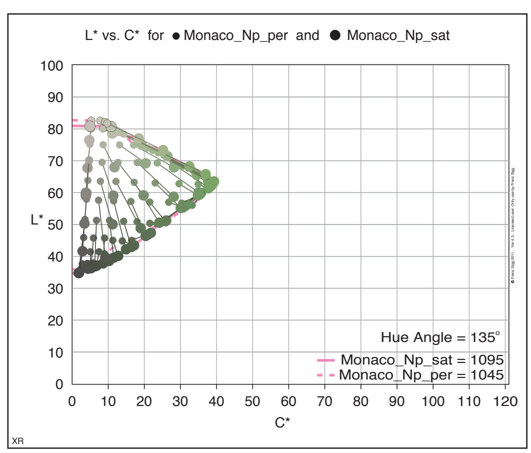






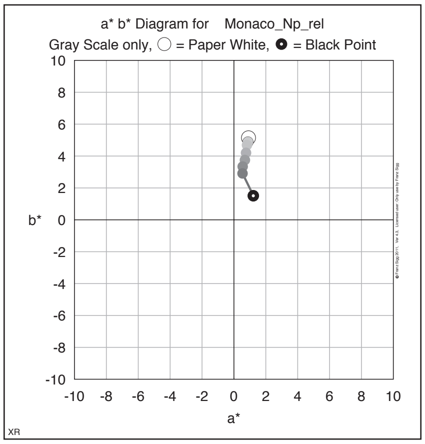


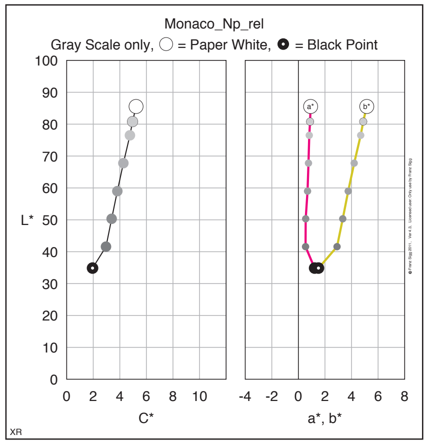


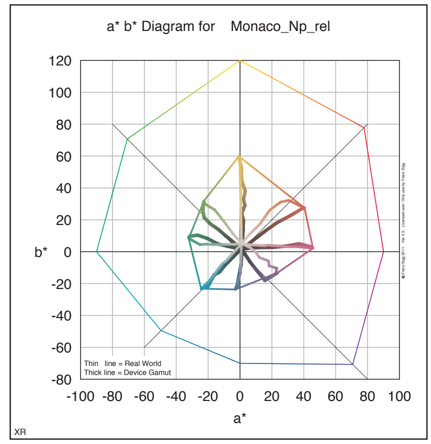


Perceptual vs. Saturation Rendering, Monaco_Np.ICC,

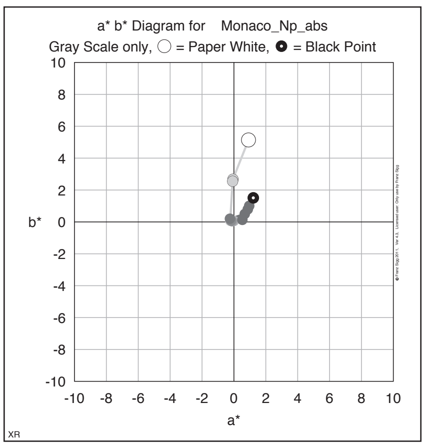
Analysis of Gray Scale Reproduction for Monaco_Np.ICC

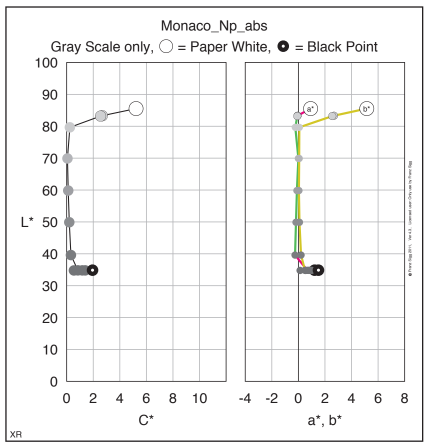


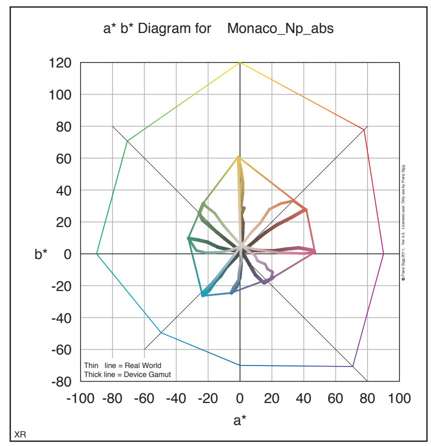




Relative







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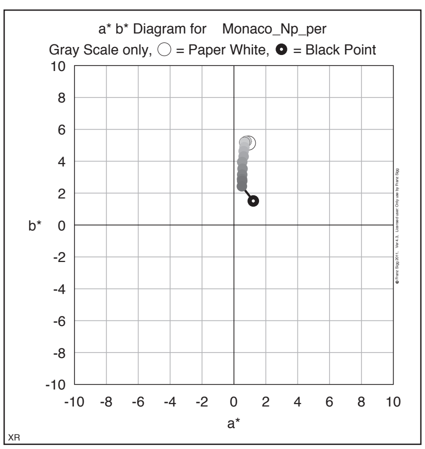
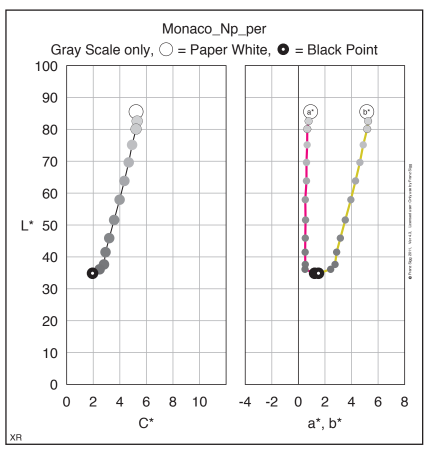
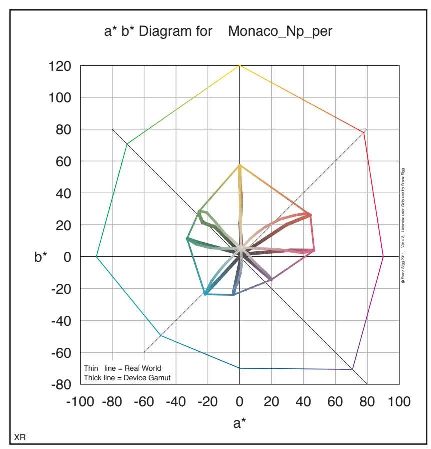
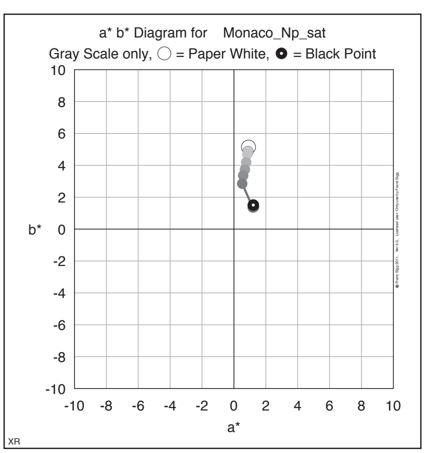
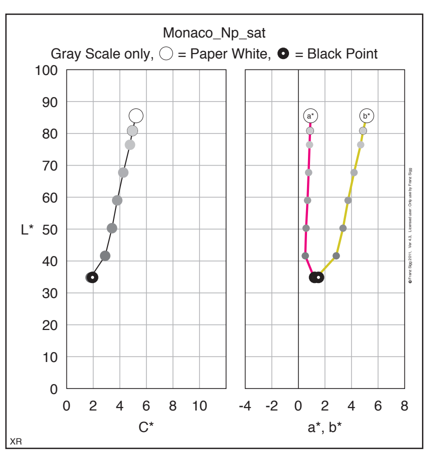


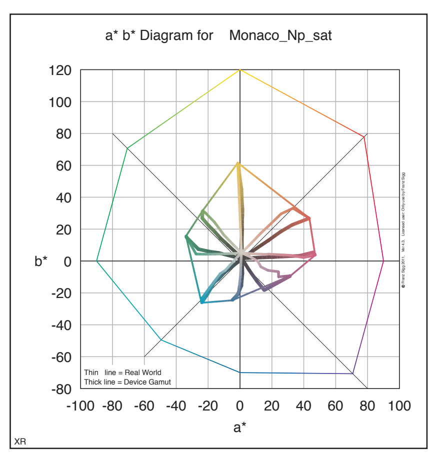




Perceptual

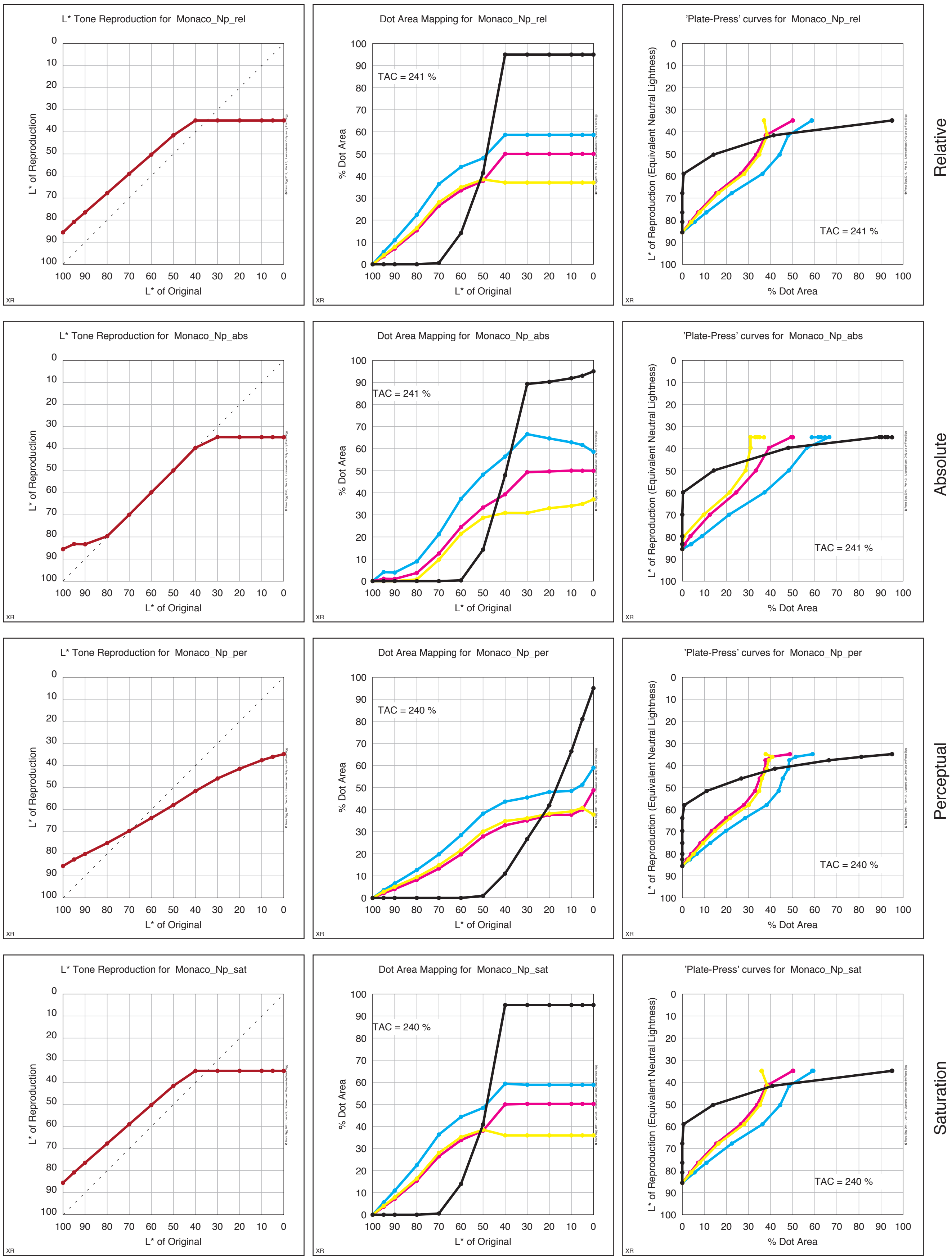






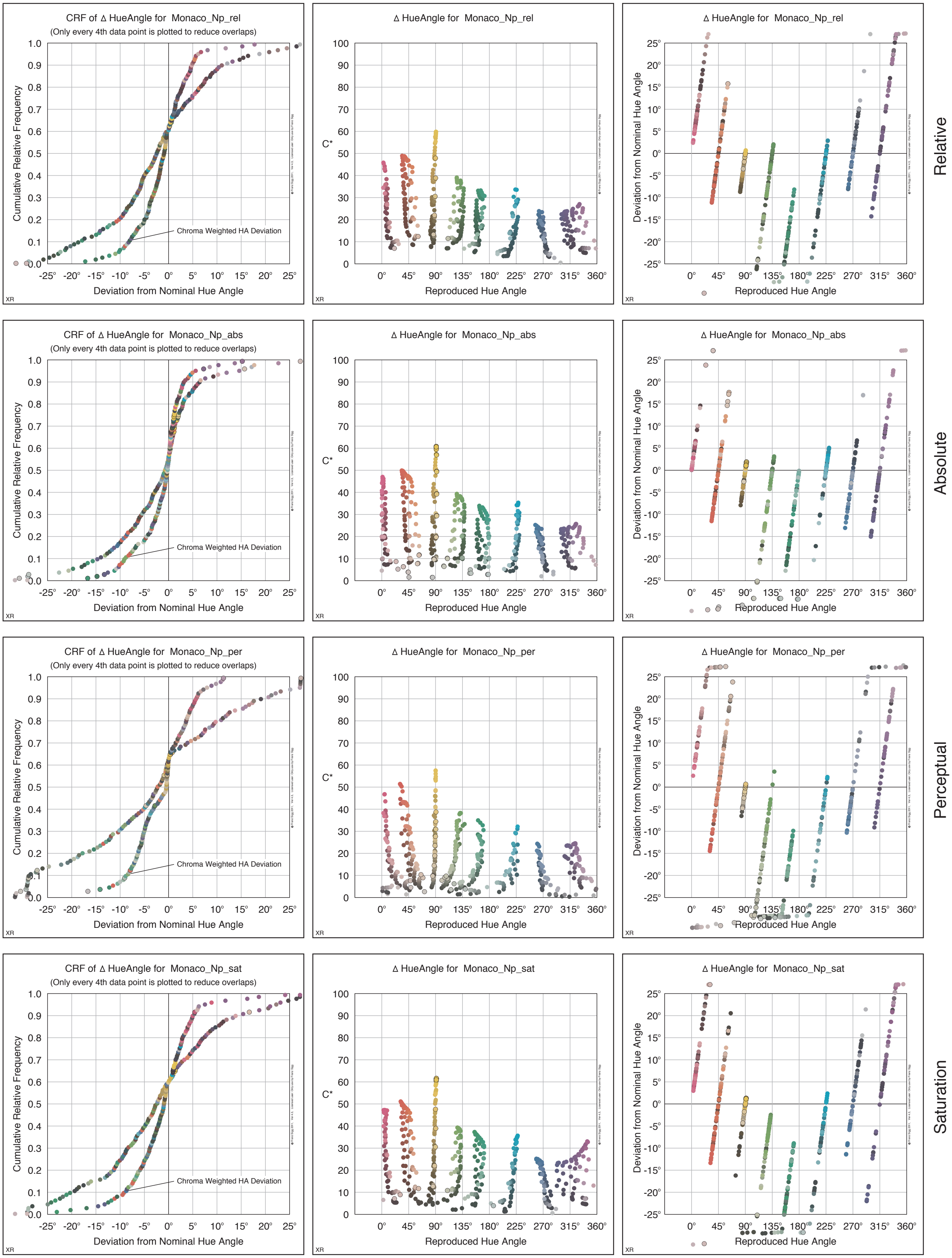
Saturation

Tone Reproduction Curves for Monaco_Np.ICC



Accuracy of Reproduction of Hue Angles for Monaco_Np.ICC

Large hue angle errors are prevented from plotting outside the graphs. Chroma weighted hue angle deviations are proportional to the maximum chroma at each of the 8 hue angles.



Monaco_Np.ICC

Summary of areas of L*C* sclices in terms of CIELAB square units (for absolute color rendering):

Color	Hue_Angle	Reference OrigRealWorld	Sample Monaco_Np_abs	% Sample of OrigRealWorld	Max C*
Magenta	0	5351	1308	24 %	47
Red	45	6301	1495	24 %	50
Yellow	90	6280	1599	25 %	61
Green	135	5702	1151	20 %	39
Emerald	180	5126	894	17 %	34
Cyan	225	4351	928	21 %	35
Blue	270	4252	658	15 %	25
Purple	315	5726	794	14 %	26
Total		43089	8827	20 %	

Values are calculated for absolute rendering. Different rendering intents show different L*C* areas due to rounding errors. The values were obtained using colors defined by LC_11U-6.6.EPS.

Note: It is well known that step differences for yellow are visually less significant than step differences for blue. Gamut comparisons in CIELAB should therefore be limited to comparing same hue angles only. CIELAB is not visually equidistant. The Totals are therfore to be used with caution.

Real World colors are all the colors that might have to be reproduced as specified by ISO-WD 12640-3.4.

Notes:

White point in profile: L*= 85.54 a*= 0.92 b*= 5.14
Black point in profile: L*= 34.85 a*= 1.22 b*= 1.52

The copyright string in the header of the Monaco_Np.ICC profile is:
(c) X-Rite, Inc.
The letter XR in the lower left corner of the graphs indicates which profile making software was used.

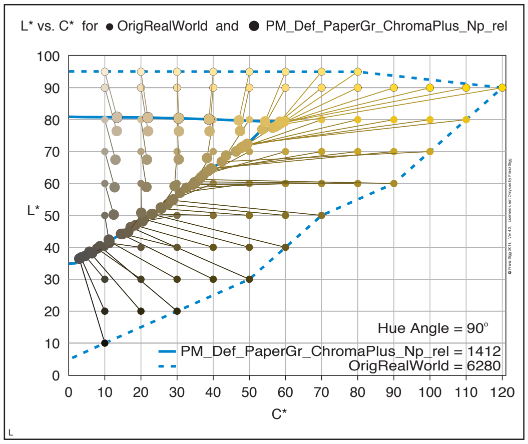
Individual graphs can be extracted from this PDF file by opening the file in Adobe Illustrator, then select the graph, and copy and paste it into a new Illustrator file. Save as EPS format, then use Acrobat Distiller to convert to PDF. This way the graph remains a high quality vector graphic.

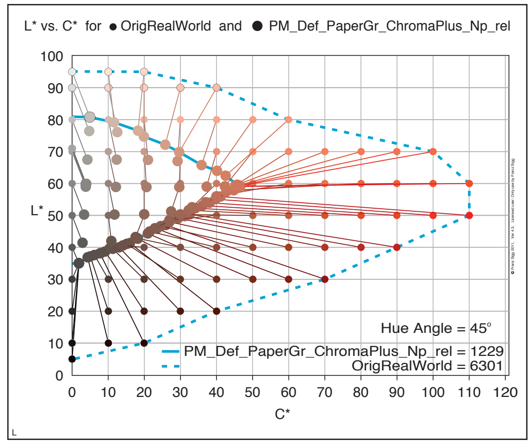
At the center of the hue circle, where the neutrals are, hue angle deviations can be large, while they have a much smaller visual effect than at the perifery. This is the reason for weighing the hue angle errors by C*. The formula to calculate the weight is: hue angle deviation times C* divided by C*max, where C* is chroma of the color, and C*max is the maximum possible chroma at the nominal hue angle.

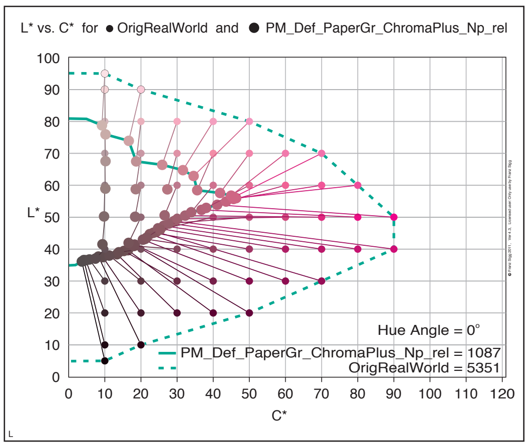
Appendix B: Gretagmacbeth ProfileMaker 5.0 Analysis

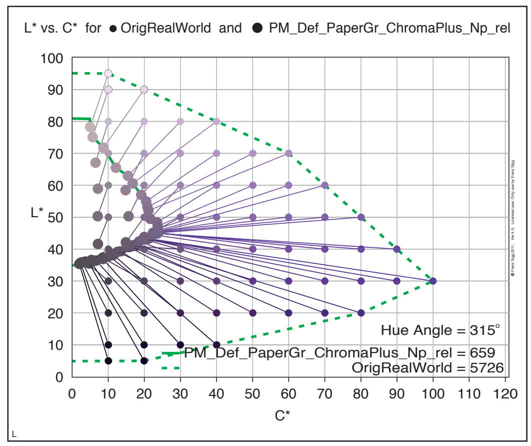
CIELAB Data from LC_11U-6.6.EPS chart with ISO-WD 12640-3.4 colors was taken, and the PM_Def_PaperGr_ChromaPlus_Np.ICC profile was applied using ColorThink, first converting Lab to CMYK using Relative color rendering intent. Then, to simulate printing, this CMYK data file was converted back to Lab, using the same profile back to Lab using the same profile with Absolute rendering. The L*C* charts below show this data compared against the original Lab data from LC_11U-6.6.EPS.

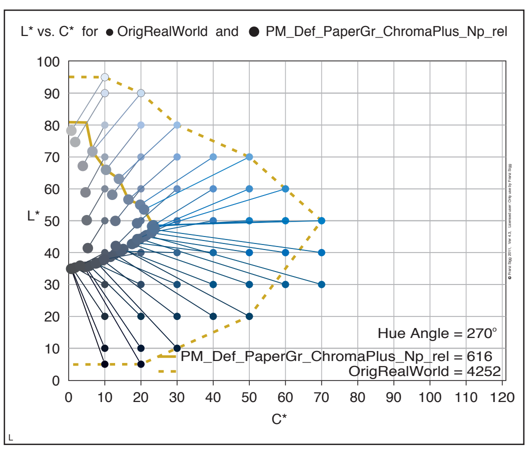
Note: The indicated gamut size numbers are in terms of L*C* CIELAB area units. It is well known that a step difference in yellow is visually less significant than a step difference in blue. Gamut comparisons in CIELAB should therefore be limited to comparing same hue angles only. CIELAB is not visually equidistant.

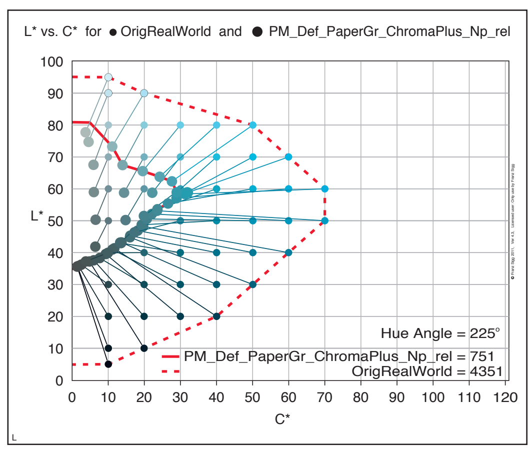


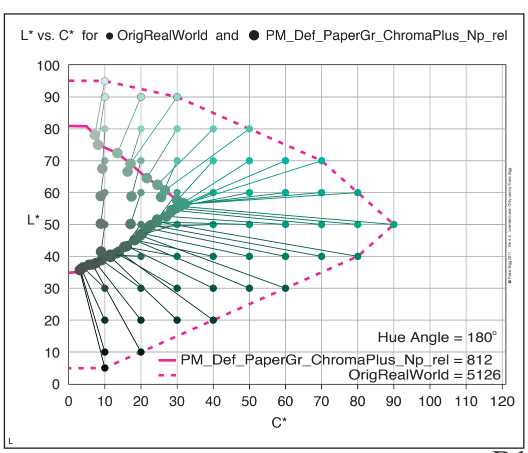


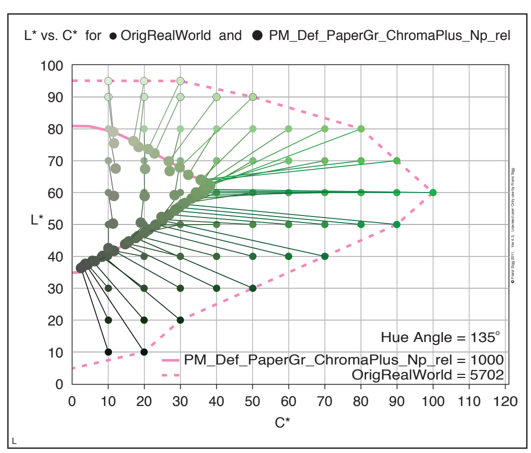








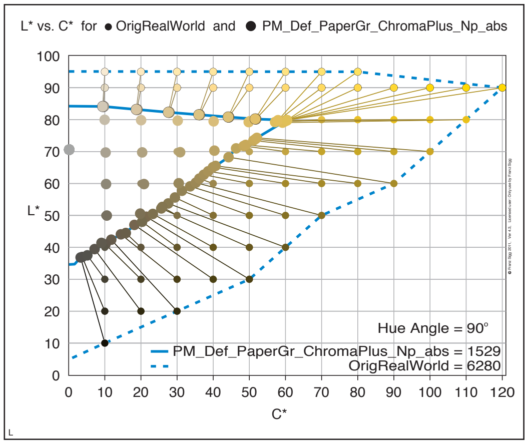


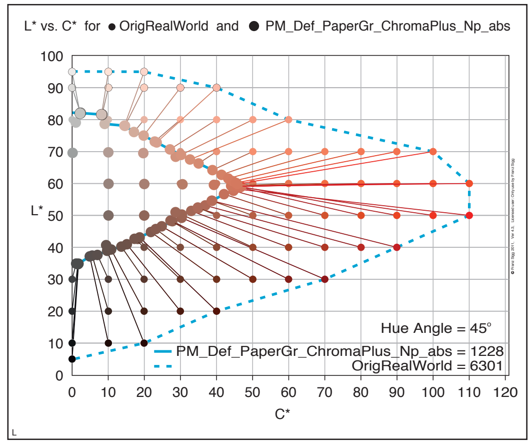


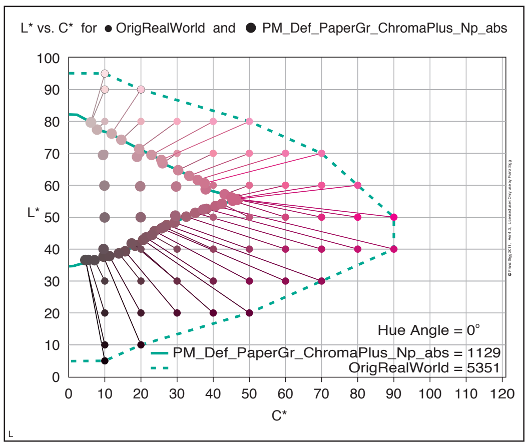
Relative Rendering, PM_Def_PaperGr_ChromaPlus_Np.ICC,

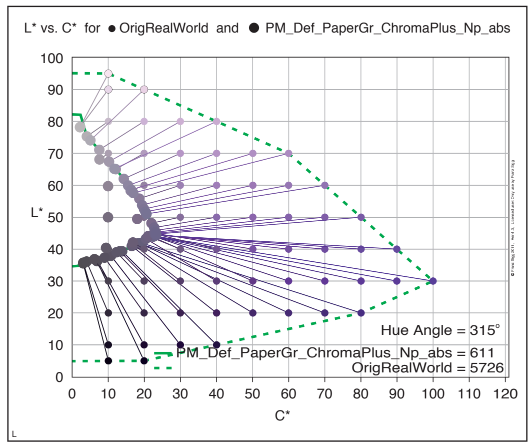
CIELAB Data from LC_11U-6.6.EPS chart with ISO-WD 12640-3.4 colors was taken, and the PM_Def_PaperGr_ChromaPlus_Np.ICC profile was applied using ColorThink, first converting Lab to CMYK using Absolute color rendering intent. Then, to simulate printing, this CMYK data file was converted back to Lab, using the same profile back to Lab using the same profile with Absolute rendering. The L*C* charts below show this data compared against the original Lab data from LC_11U-6.6.EPS.

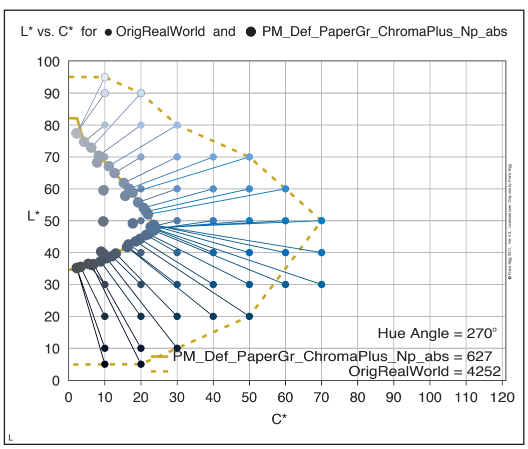
Note: The indicated gamut size numbers are in terms of L*C* CIELAB area units. It is well known that a step difference in yellow is visually less significant than a step difference in blue. Gamut comparisons in CIELAB should therefore be limited to comparing same hue angles only. CIELAB is not visually equidistant.

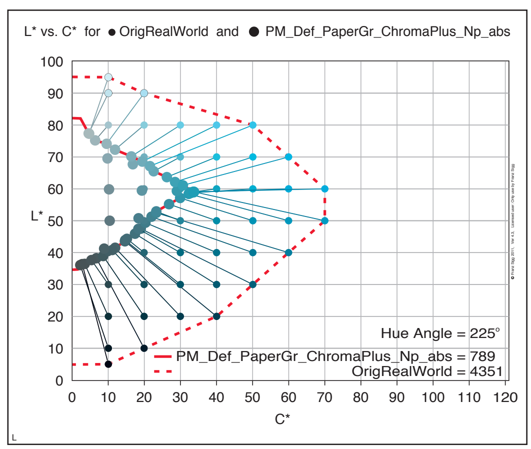


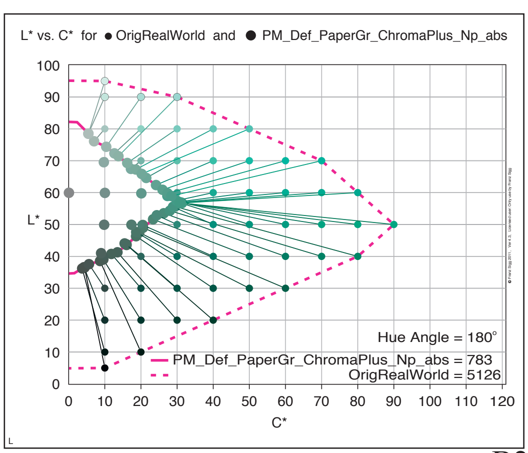


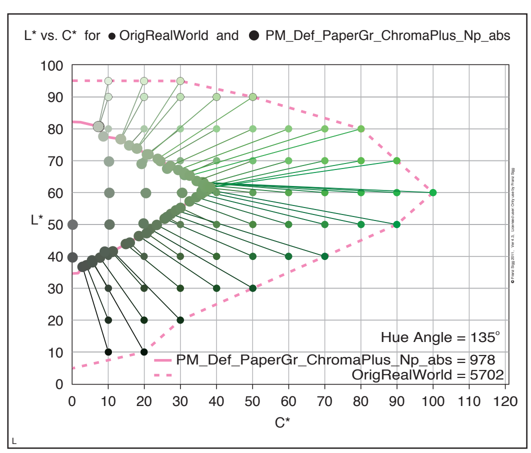








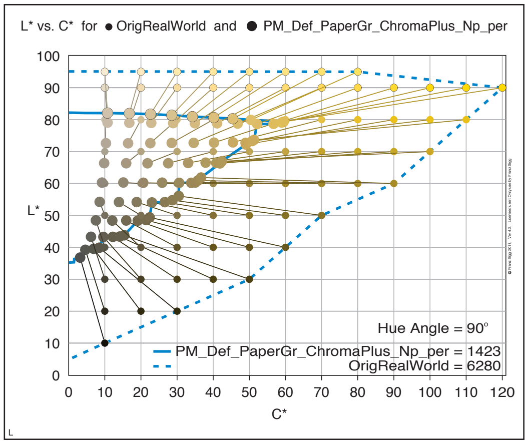


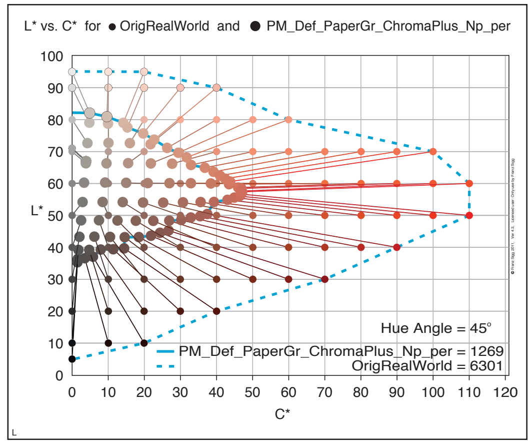


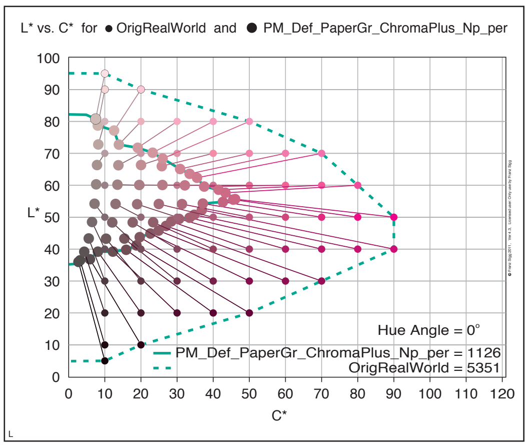
Absolute Rendering, PM_Def_PaperGr_ChromaPlus_Np.ICC,

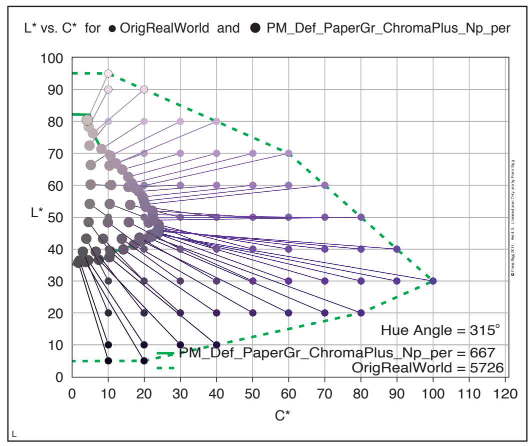
CIELAB Data from LC_11U-6.6.EPS chart with ISO-WD 12640-3.4 colors was taken, and the PM_Def_PaperGr_ChromaPlus_Np.ICC profile was applied using ColorThink, first converting Lab to CMYK using Perceptual color rendering intent. Then, to simulate printing, this CMYK data file was converted back to Lab, using the same profile back to Lab using the same profile with Absolute rendering. The L*C* charts below show this data compared against the original Lab data from LC_11U-6.6.EPS.

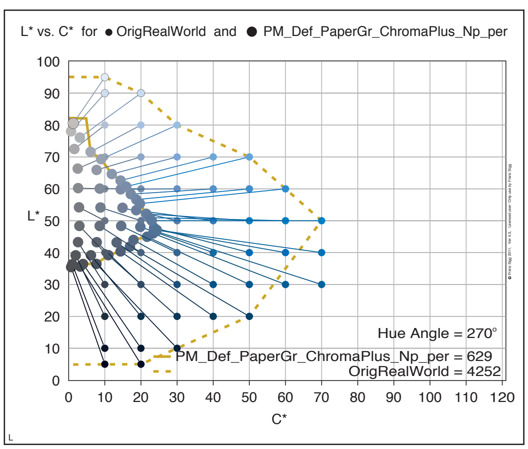
Note: The indicated gamut size numbers are in terms of L*C* CIELAB area units. It is well known that a step difference in yellow is visually less significant than a step difference in blue. Gamut comparisons in CIELAB should therefore be limited to comparing same hue angles only. CIELAB is not visually equidistant.

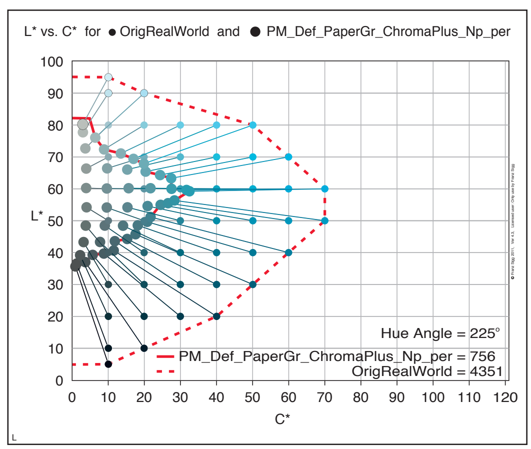


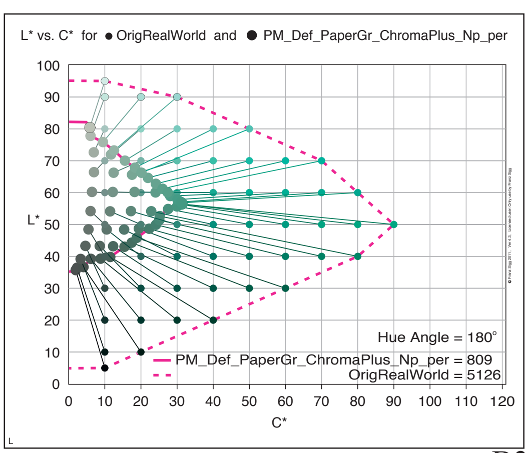


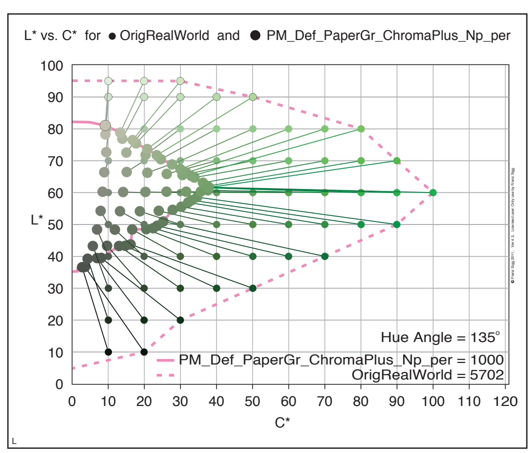








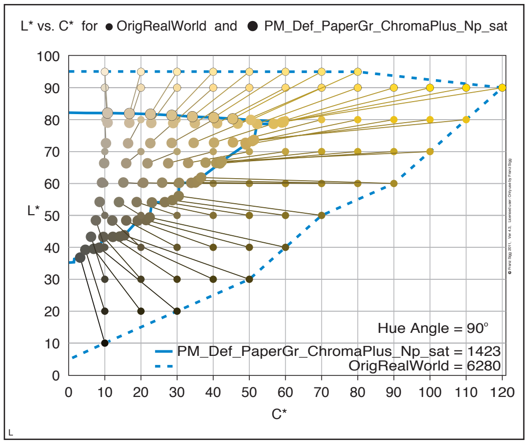


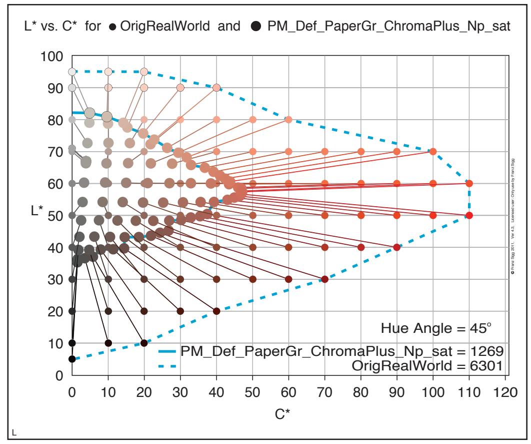


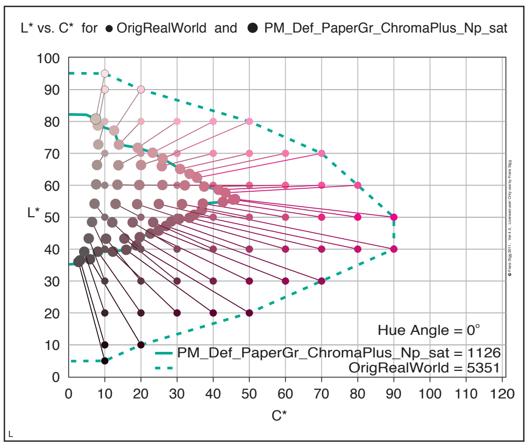
Perceptual Rendering, PM_Def_PaperGr_ChromaPlus_Np.ICC,

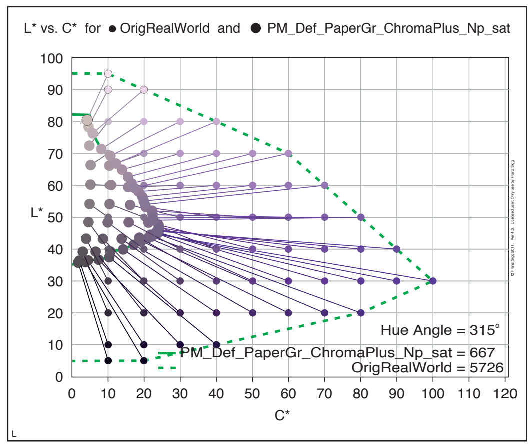
CIELAB Data from LC_11U-6.6.EPS chart with ISO-WD 12640-3.4 colors was taken, and the PM_Def_PaperGr_ChromaPlus_Np.ICC profile was applied using ColorThink, first converting Lab to CMYK using Saturation color rendering intent. Then, to simulate printing, this CMYK data file was converted back to Lab, using the same profile back to Lab using the same profile with Absolute rendering. The L*C* charts below show this data compared against the original Lab data from LC_11U-6.6.EPS.

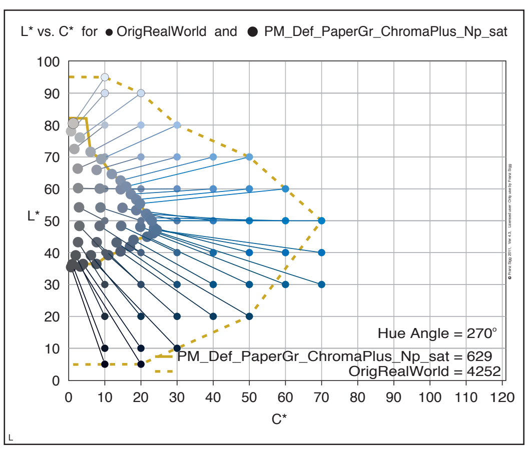
Note: The indicated gamut size numbers are in terms of L*C* CIELAB area units. It is well known that a step difference in yellow is visually less significant than a step difference in blue. Gamut comparisons in CIELAB should therefore be limited to comparing same hue angles only. CIELAB is not visually equidistant.

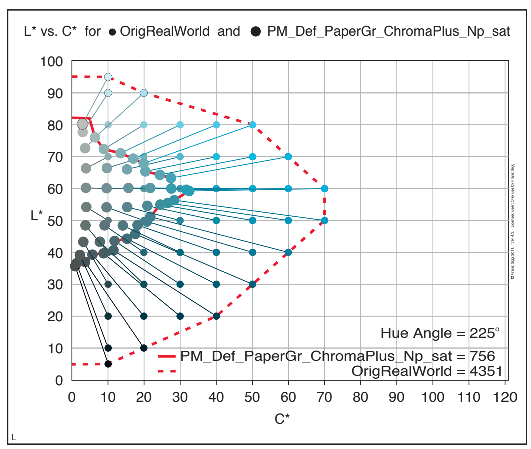


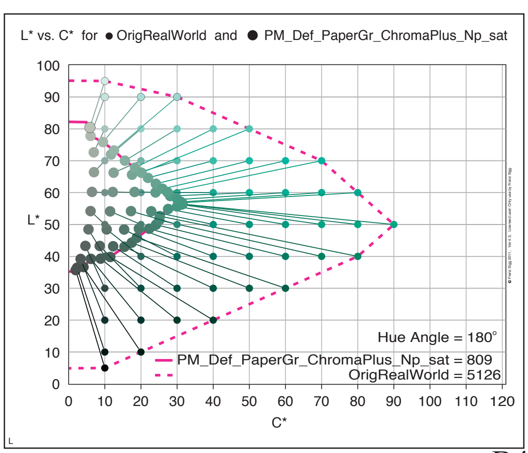


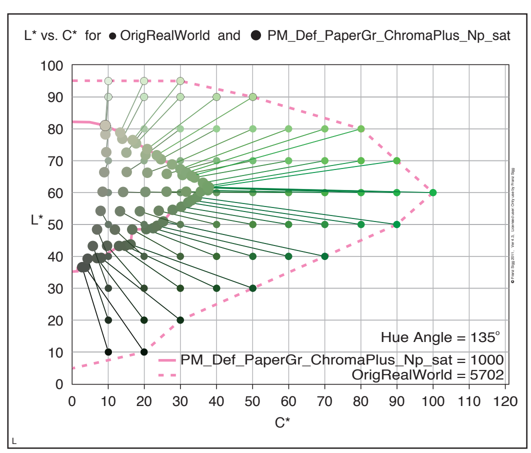








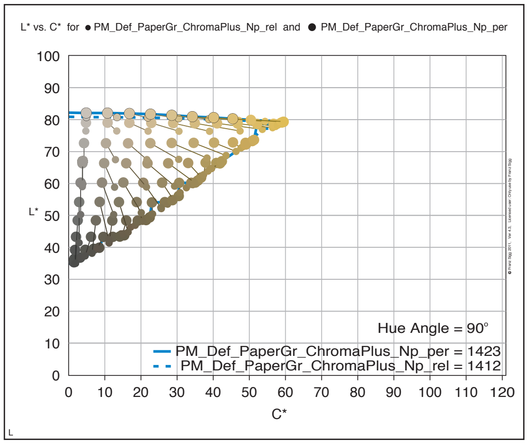


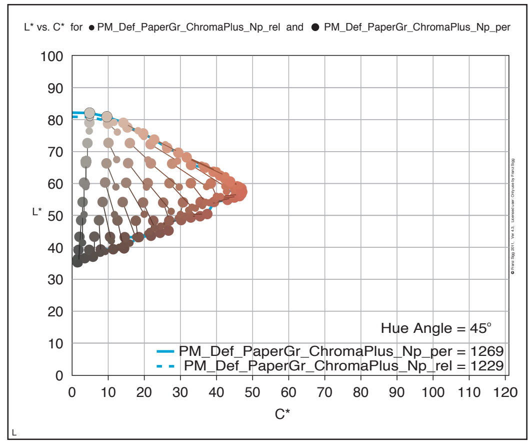


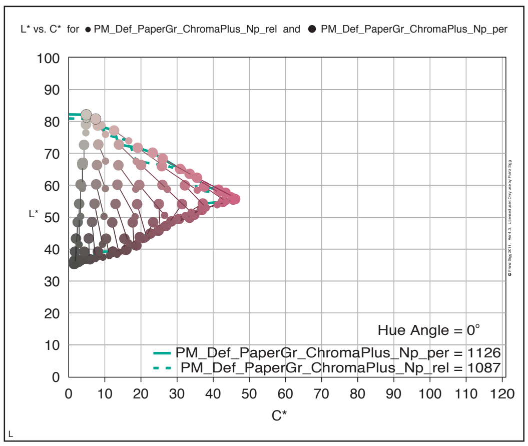
Saturation Rendering, PM_Def_PaperGr_ChromaPlus_Np.ICC,

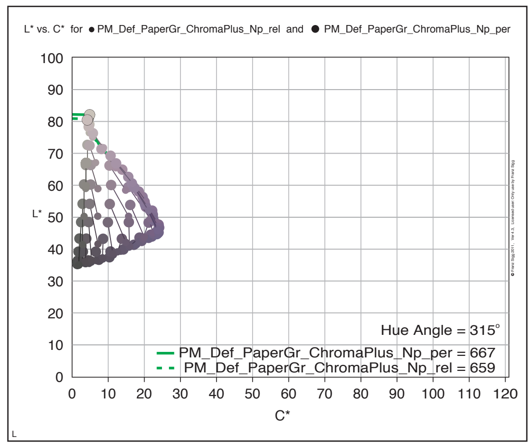
CIELAB Data from LC_11U-6.6.EPS chart with ISO-WD 12640-3.4 colors was taken, and the PM_Def_PaperGr_ChromaPlus_Np.ICC profile was applied using ColorThink, first converting Lab to CMYK using Relative color rendering intent. Then, to simulate printing, this CMYK data file was converted back to Lab, using the same profile with Absolute color rendering. The same was done for Perceptual rendering and the two data sets are compared below.

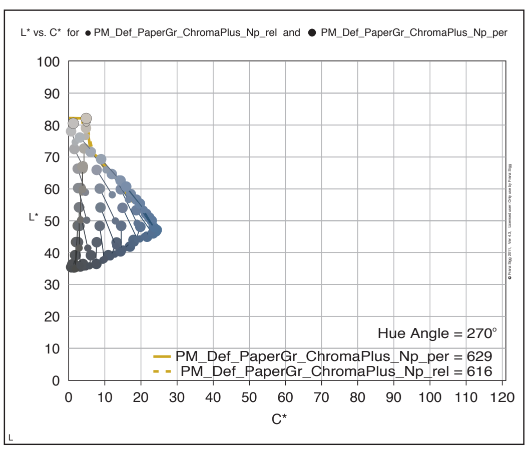
Note: The indicated gamut size numbers are in terms of L*C* CIELAB area units. It is well known that a step difference in yellow is visually less significant than a step difference in blue. Gamut comparisons in CIELAB should therefore be limited to comparing same hue angles only. CIELAB is not visually equidistant.

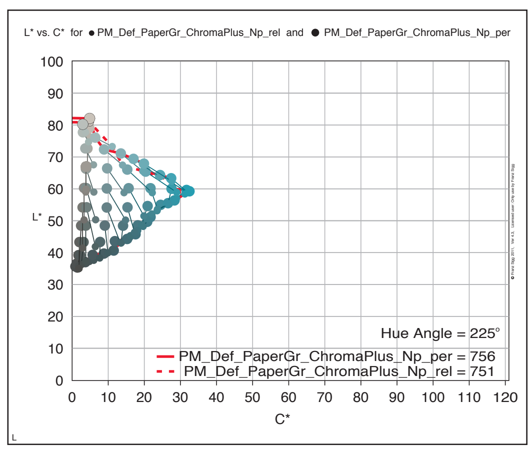


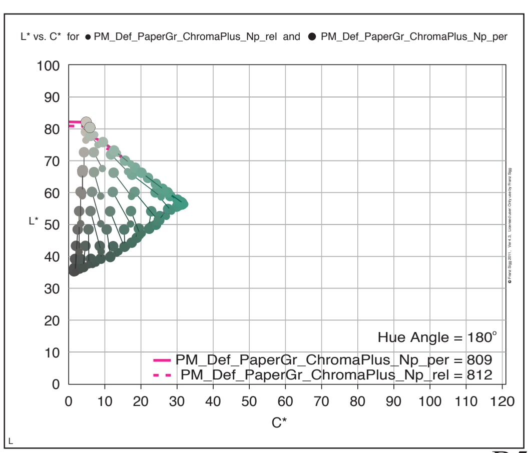


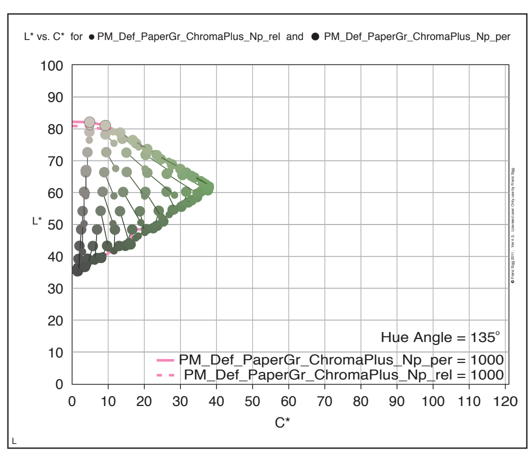










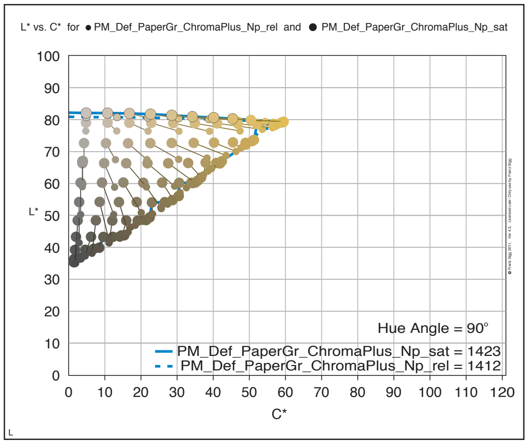


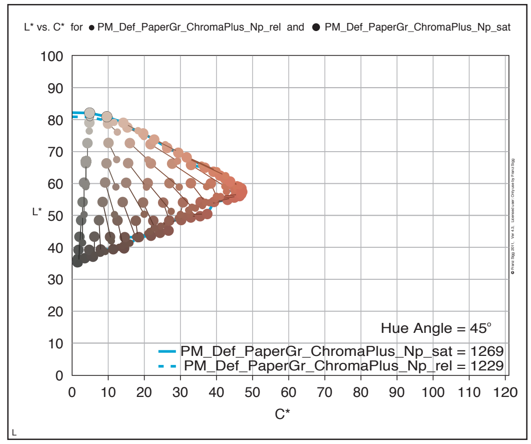
Relative vs. Perceptual Rendering, PM_Def_PaperGr_ChromaPlus_Np.ICC,

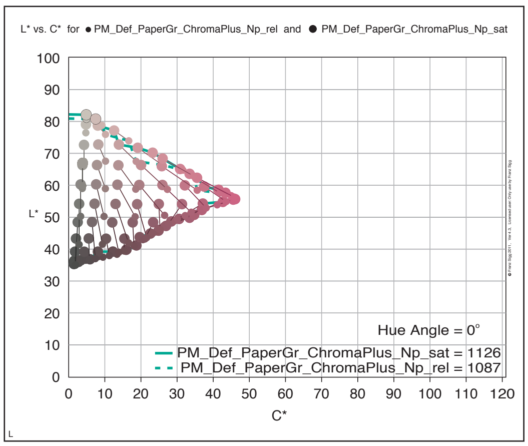
CIELAB Data from LC_11U-6.6.EPS chart with ISO-WD 12640-3.4 colors was taken, and the PM_Def_PaperGr_ChromaPlus_Np.ICC profile was applied using ColorThink, first converting Lab to CMYK using Relative color rendering intent. Then, to simulate printing, this CMYK data file was converted back to Lab, using the same profile with Absolute color rendering. The same was done for Saturation rendering and the two data sets are compared below.

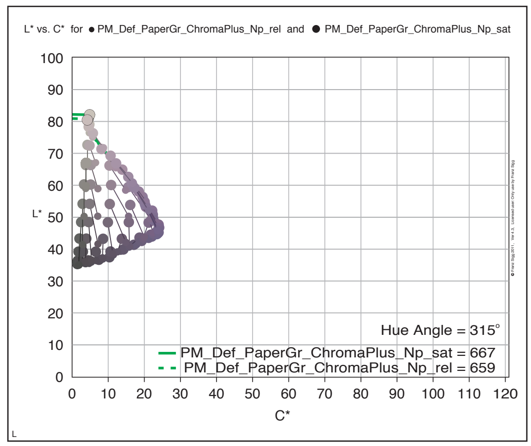
Note: The indicated gamut size numbers are in terms of L*C* CIELAB area units. It is well known that a step difference in yellow is visually less significant than a step difference in blue. Gamut comparisons in CIELAB should therefore be limited to comparing same hue angles only. CIELAB is not visually equidistant.

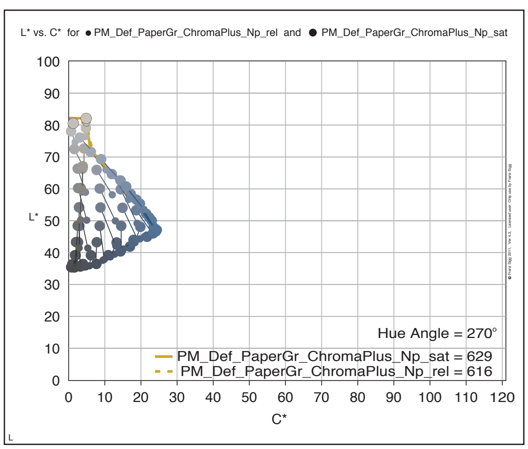
Relative vs. Saturation Rendering, PM_Def_PaperGr_ChromaPlus_Np.ICC,

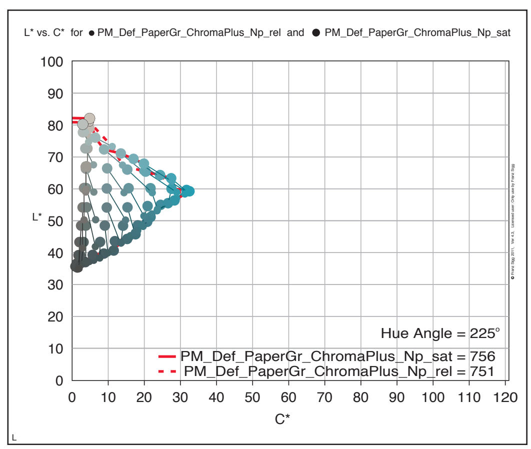


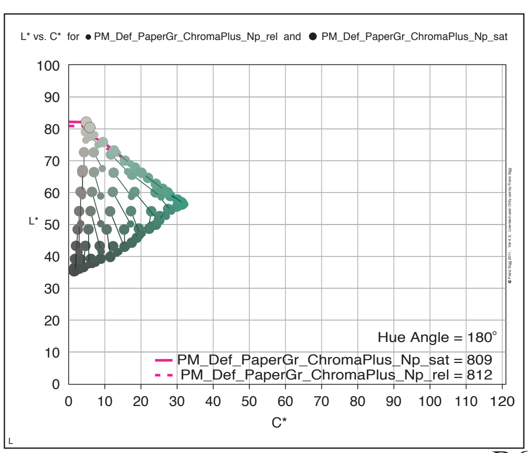


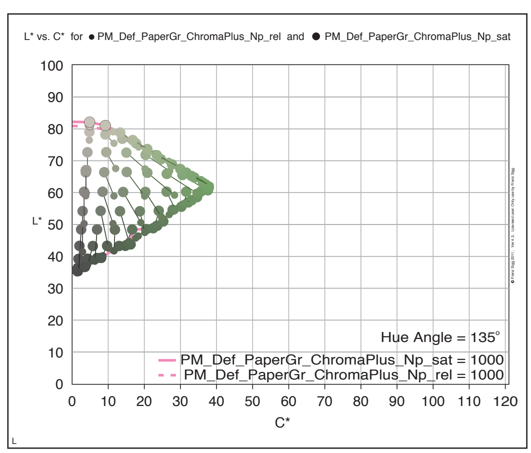






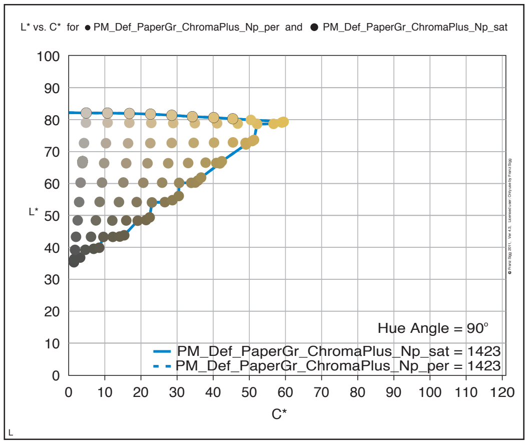


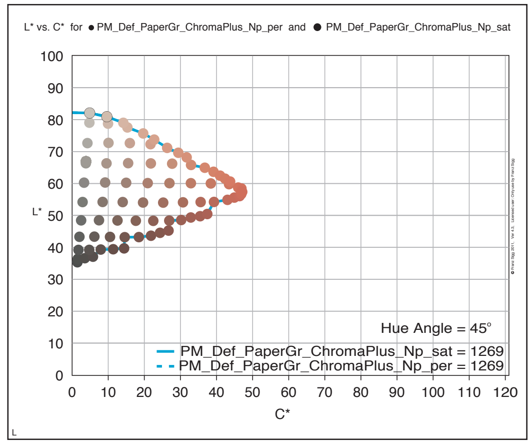


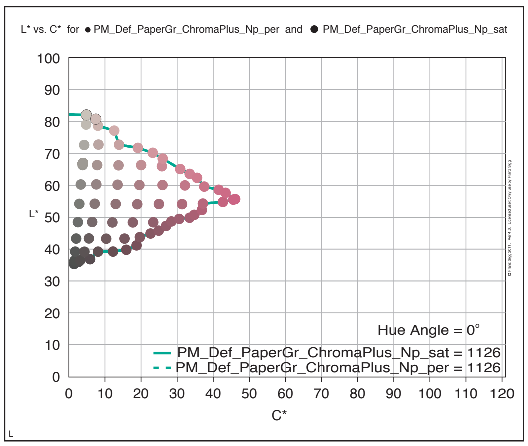


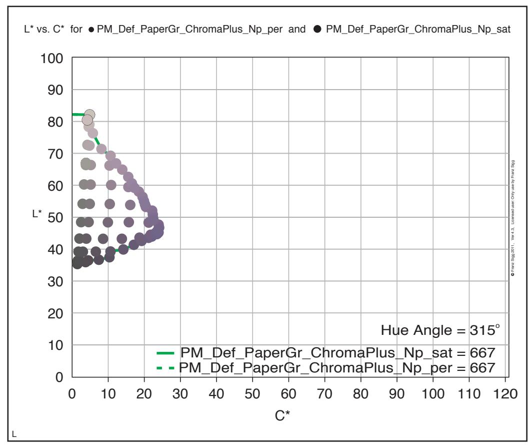
CIELAB Data from LC_11U-6.6.EPS chart with ISO-WD 12640-3.4 colors was taken, and the PM_Def_PaperGr_ChromaPlus_Np.ICC profile was applied using ColorThink, first converting Lab to CMYK using Perceptual color rendering intent. Then, to simulate printing, this CMYK data file was converted back to Lab, using the same profile with Absolute color rendering. The same was done for Saturation rendering and the two data sets are compared below.

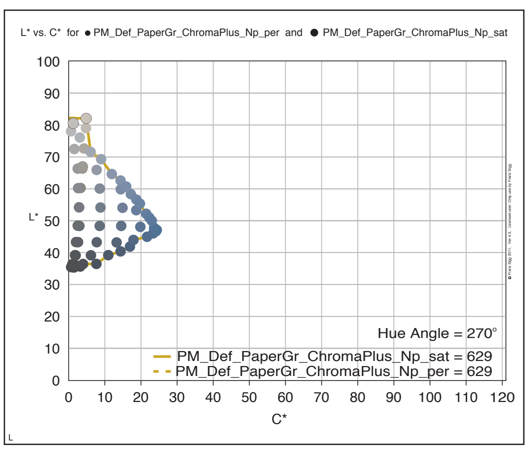
Note: The indicated gamut size numbers are in terms of L*C* CIELAB area units. It is well known that a step difference in yellow is visually less significant than a step difference in blue. Gamut comparisons in CIELAB should therefore be limited to comparing same hue angles only. CIELAB is not visually equidistant.

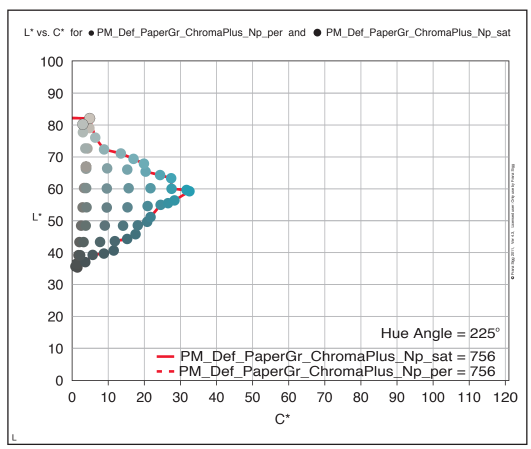


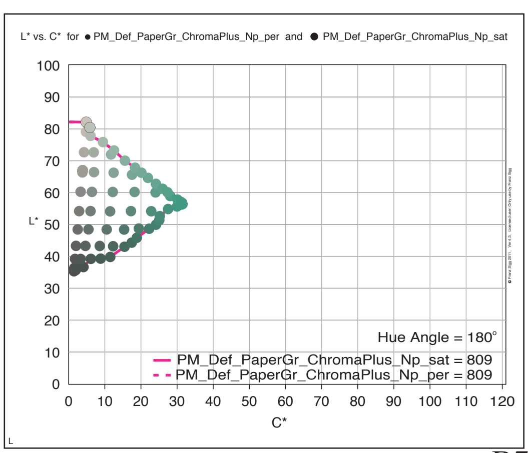


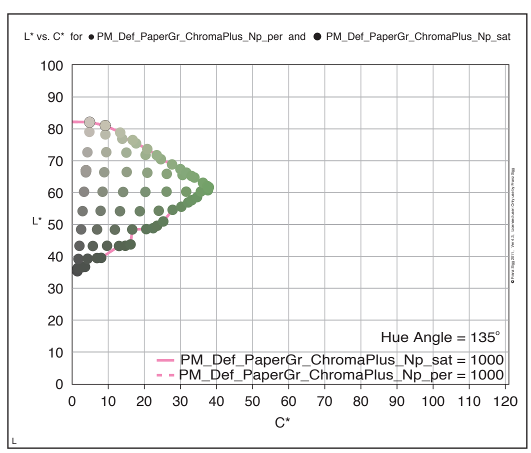






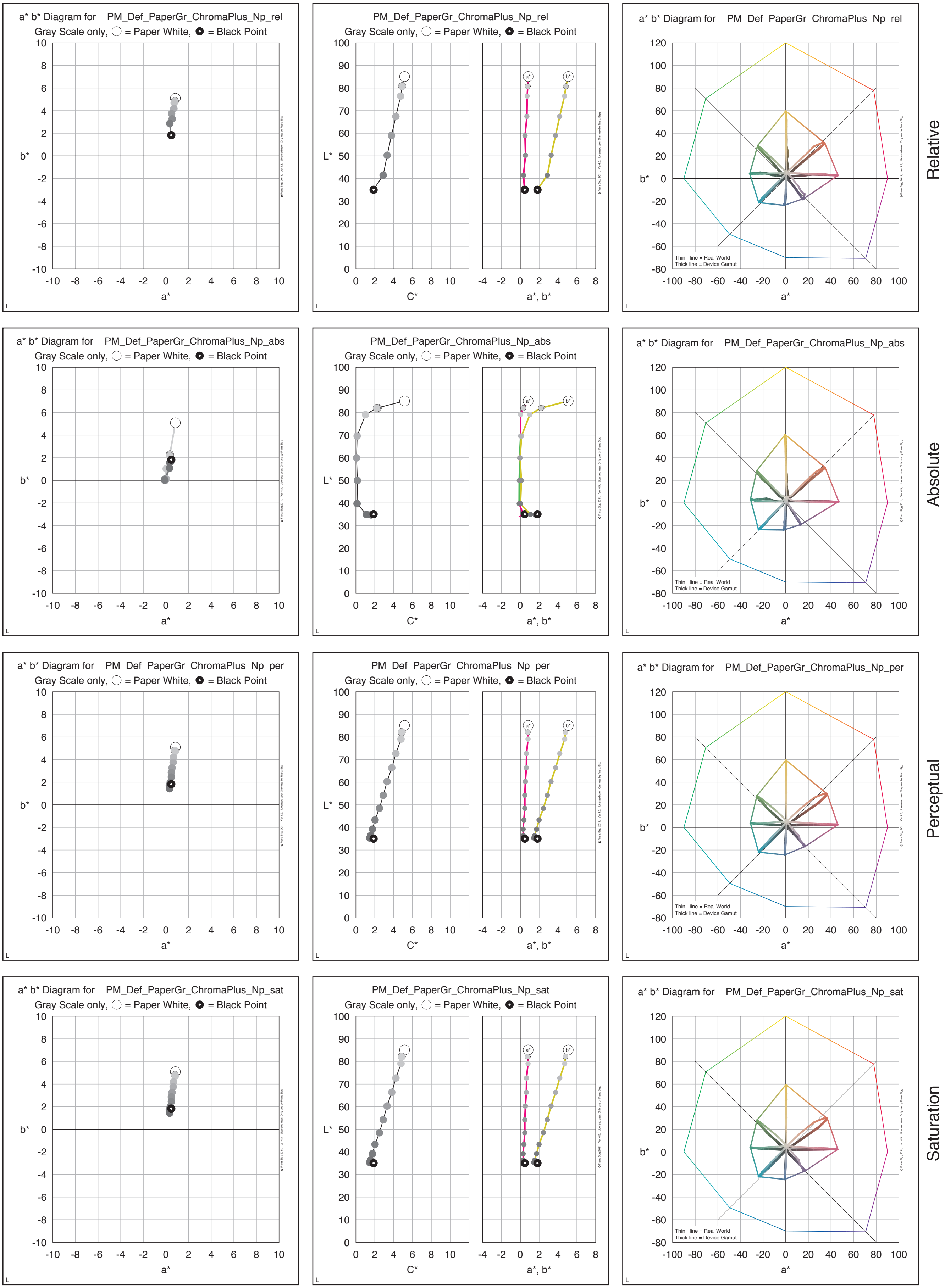




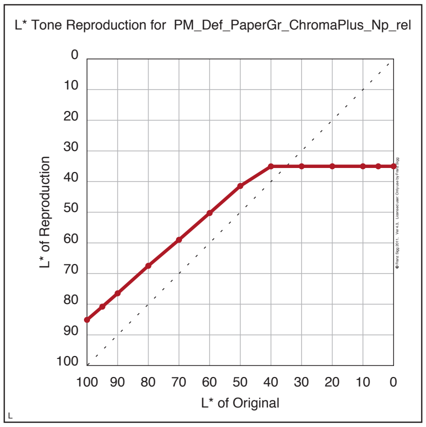


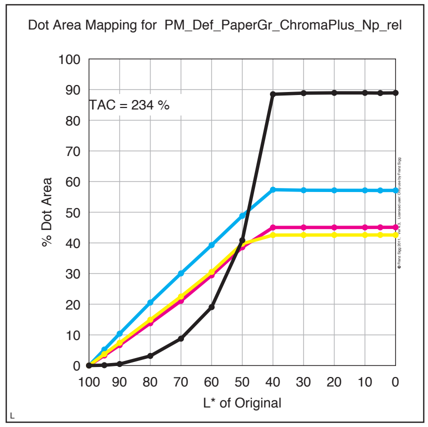
Perceptual vs. Saturation Rendering, PM_Def_PaperGr_ChromaPlus_Np.ICC,

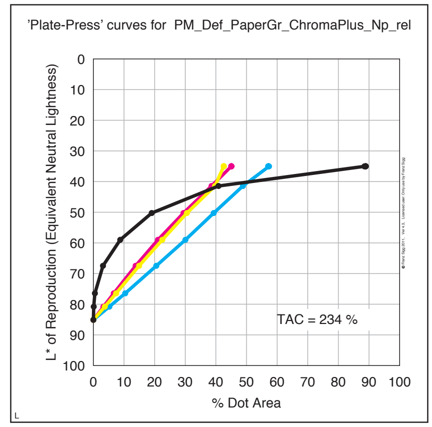
Analysis of Gray Scale Reproduction for PM_Def_PaperGr_ChromaPlus_Np.ICC



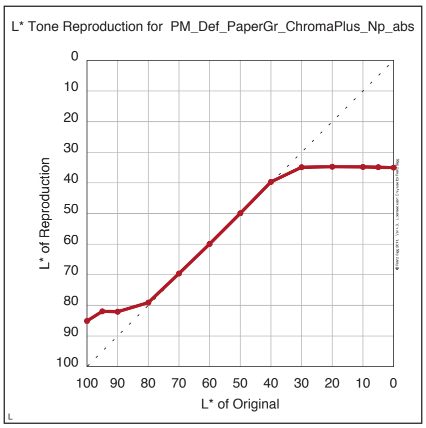
Tone Reproduction Curves for PM_Def_PaperGr_ChromaPlus_Np.ICC

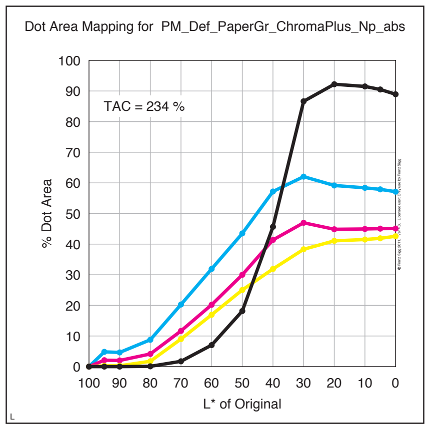


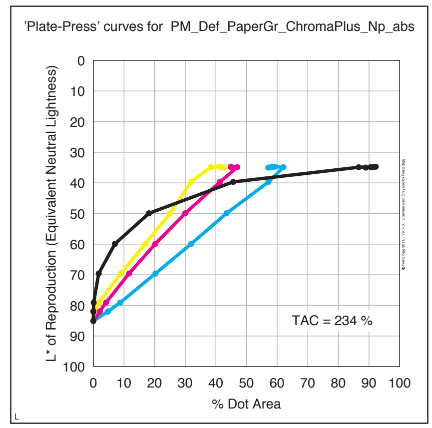




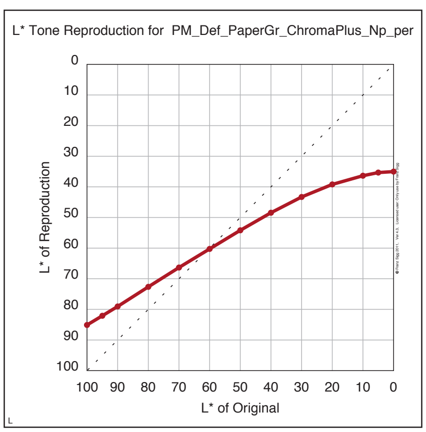
Relative

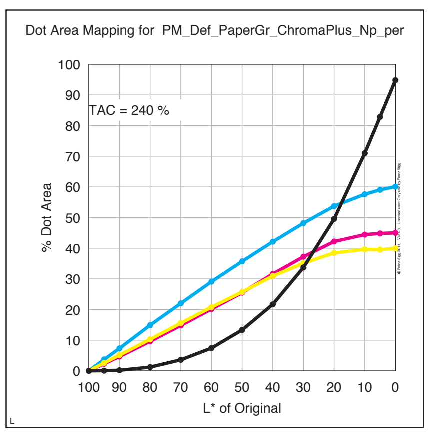


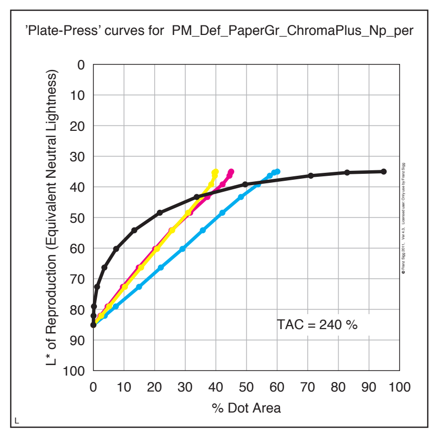




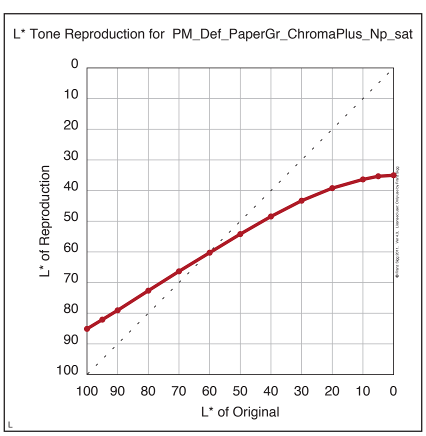
Absolute

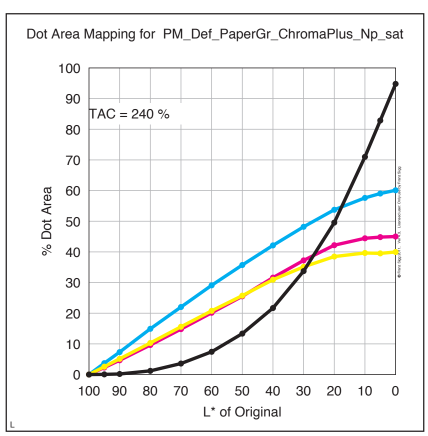


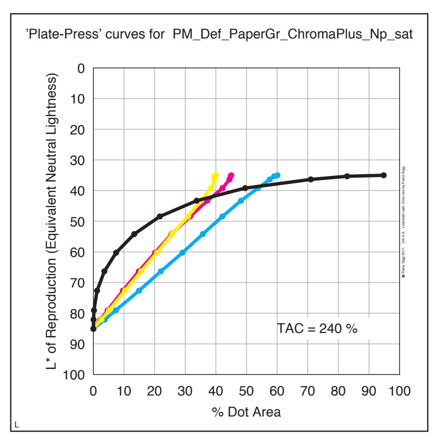




Perceptual



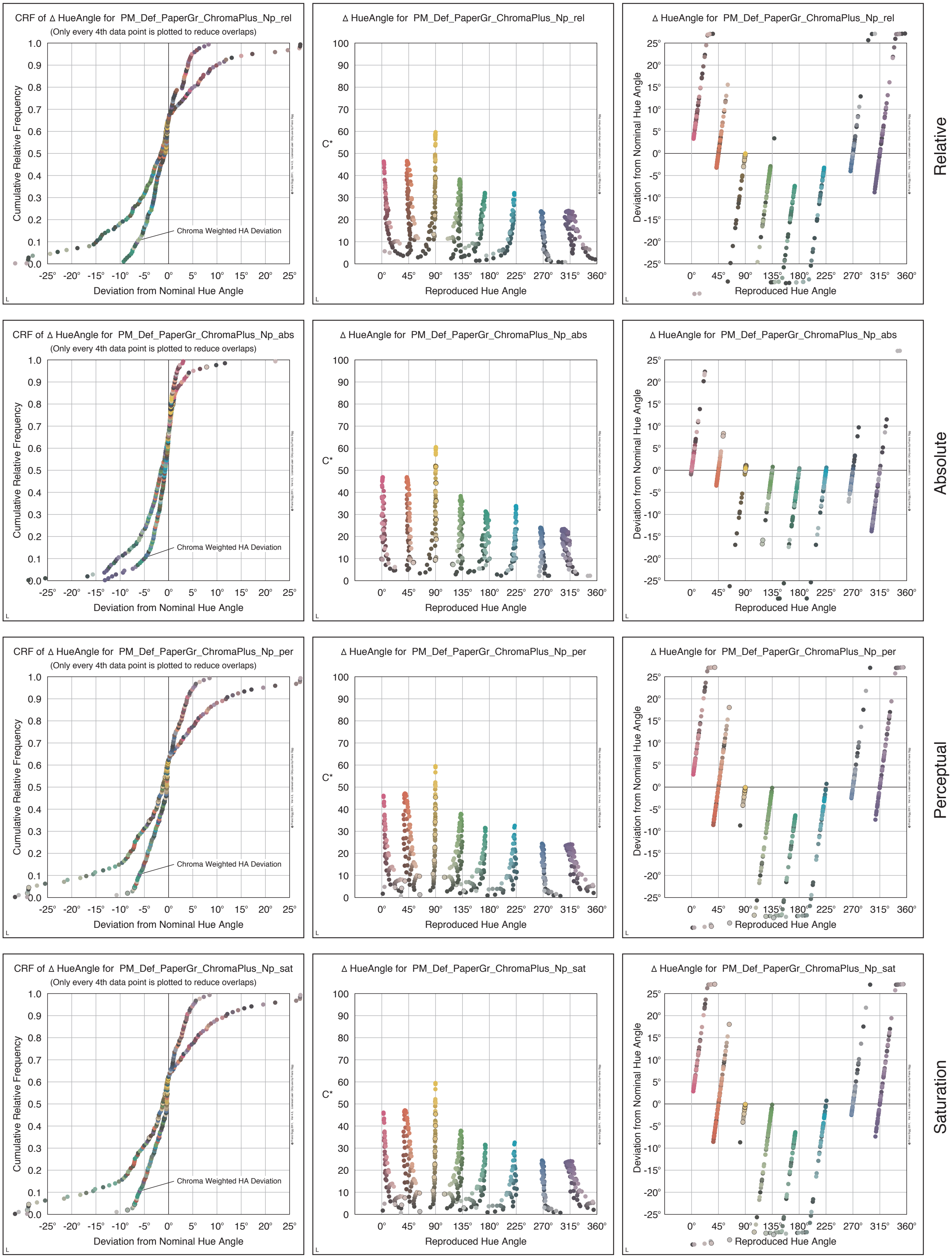




Saturation

Accuracy of Reproduction of Hue Angles for PM_Def_PaperGr_ChromaPlus_Np.ICC

Large hue angle errors are prevented from plotting outside the graphs. Chroma weighted hue angle deviations are proportional to the maximum chroma at each of the 8 hue angles.



PM_Def_PaperGr_ChromaPlus_Np.ICC

Summary of areas of L*C* sclices in terms of CIELAB square units (for absolute color rendering):

Color	Hue_Angle	Reference OrigRealWorld	Sample PM_Def_PaperGr_ChromaPlus_Np_abs	% Sample of OrigRealWorld	Max C*
Magenta	0	5351	1129	21 %	47
Red	45	6301	1228	19 %	47
Yellow	90	6280	1529	24 %	60
Green	135	5702	978	17 %	38
Emerald	180	5126	783	15 %	31
Cyan	225	4351	789	18 %	34
Blue	270	4252	627	15 %	24
Purple	315	5726	611	11 %	23
Total		43089	7674	18 %	

Values are calculated for absolute rendering. Different rendering intents show different L*C* areas due to rounding errors. The values were obtained using colors defined by LC_11U-6.6.EPS.

Note: It is well known that step differences for yellow are visually less significant than step differences for blue. Gamut comparisons in CIELAB should therefore be limited to comparing same hue angles only. CIELAB is not visually equidistant. The Totals are therfore to be used with caution.

Real World colors are all the colors that might have to be reproduced as specified by ISO-WD 12640-3.4.

Notes:

White point in profile: L*= 85.1 a*= 0.84 b*= 5.09
Black point in profile: L*= 35.01 a*= 0.47 b*= 1.82

The copyright string in the header of the PM_Def_PaperGr_ChromaPlus_Np.ICC profile is:
(c) by LOGO GmbH, Steinfurt
The letter L in the lower left corner of the graphs indicates which profile making software was used.

Individual graphs can be extracted from this PDF file by opening the file in Adobe Illustrator, then select the graph, and copy and paste it into a new Illustrator file. Save as EPS format, then use Acrobat Distiller to convert to PDF. This way the graph remains a high quality vector graphic.

At the center of the hue circle, where the neutrals are, hue angle deviations can be large, while they have a much smaller visual effect than at the perifery. This is the reason for weighing the hue angle errors by C*. The formula to calculate the weight is: hue angle deviation times C* divided by C*max, where C* is chroma of the color, and C*max is the maximum possible chroma at the nominal hue angle.