ColorBrewer in Print: A Catalog of Color Schemes for Maps

Cynthia A. Brewer, Geoffrey W. Hatchard, and Mark A. Harrower

ABSTRACT: ColorBrewer is a tool that assists mapmakers in choosing and creating color schemes. It is available online at <www.ColorBrewer.org>. The color schemes range from 3 to 12 classes and are organized into three basic categories: sequential, diverging, and qualitative. Each of these scheme types has general perceptual characteristics which are described using Munsell hue, value, and chroma specifications. Each scheme has been proofed from color-separated negatives and adjusted to offer CMYK (cyan, magenta, yellow, and black) specifications that produce a readable map when they are used in process-printed publications. This paper offers a printed catalog of all of the ColorBrewer schemes to allow mapmakers to evaluate the appearance of each scheme before they commit to using them in print publications. Since process-color proofing is expensive, this catalog will reduce mapmakers' costs and allow them to be more confident that their maps will make the transition from the desktop computing environment to publication without compromising the intended message through poor color specification.

KEYWORDS: Symbolization, color, design, thematic mapping, printing

Introduction

The online tool ColorBrewer <www.ColorBrewer.org> provides specifications for a wide range of color schemes designed to be used on thematic maps. Users set the number of classes and the type of color scheme they would like to see (sequential, diverging, or qualitative) and are then offered 2 to 18 scheme choices. Next they see the scheme they chose on a choropleth-like map, along with color specifications for a variety of systems: CMYK, RGB, Hex, Lab, and HSV for ArcView 3.x (AV3).[1] In this paper, we present the schemes in print and describe how they are arranged in perceptual color space.

The ColorBrewer project was funded by the National Science Foundation's Digital Government Program and was directly inspired by experiences with collaborators at three government agencies: the Census Bureau, National Cancer Institute, and National Center for Health Statistics. The first author, Brewer, has been involved with a variety of mapping projects at these agencies, either making maps or doing research on map types they were planning to use. In each situation she was drawn into tangentially related projects for which analysts had already made maps and were seeking help with "good colors" for them. Sometimes they asked for specific CMYK numbers to reproduce a scheme they had seen her use in another product, sometimes they showed her a scheme they had been working with and asked for help to improve it, and sometimes they were starting from scratch. ColorBrewer is designed for these mapmakers, who want to present their data well, but for whom professional demands leave little time for learning how to specify color.

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Harrower and Brewer (in press) describe the basic function of and principles behind ColorBrewer. They make recommendations on choosing numbers of classes, choosing scheme types, selecting a color specification system (for example, RGB on screen and CMYK for print), using the on-screen map as a diagnostic tool to evaluate simultaneous contrast impacts on readability, examining readability of overlaid text and lines, and testing different background colors. They describe the meanings of the usability icons for colorblind readers and varied display media,

[1] Color specification definitions: CMYK is cyan, magenta, yellow, black; RGB is red, green, blue; Hex is a hexadecimal specification of RGB; Lab is lightness, red-green, and yellow-blue dimensions (specified by CIE, an international standards group); and AV3 is hue, saturation, value scaled for use in ArcView 3.x GIS software from ESRI.

Scheme name	Description
Sequential schemes, hue transitions (Figures 9 and 10)	
YlGn	light yellow to dark green
YlGnBu	light yellow to green to dark blue
GnBu	light green to dark blue
BuGn	light blue to dark green
PuBuGn	light purple to blue to dark green
PuBu	light purple to dark blue
BuPu	light blue to dark purple
RdPu	light red to dark purple
PuRd	light purple to dark red
OrRd	light orange to dark red
YlOrRd	light yellow to orange to dark red
YlOrBr	light yellow to orange to dark brown
Sequential schemes, single hue (Figure 10)	
Purples	light to dark purple
Blues	light to dark blue
Greens	light to dark green
Oranges	light to dark orange
Reds	light to dark red
Grays	light to dark gray
Diverging schemes (Figure 11)	
PuOr	dark orange to light to dark purple
BrBG	dark brown to light to dark blue-green
PRGn	dark reddish-purple to light to dark green
PiYG	dark magenta to light to dark yellow-green
RdBu	dark red to light to dark blue
RdGy	dark red to light to dark gray
RdYlBu	dark red to light yellow to dark blue
Spectral	dark red, orange, light yellow, green, dark blue
RdYlGn	dark red, orange, light yellow, yellow-green, dark green
Qualitative (Figure 12)	
Set 1	includes bold, readily named, basic colors (such as red, green, blue)
Pastel 1	lighter version of Set 1
Set 2	includes mostly mixture colors (such as blue-green, red-orange)
Pastel 2	lighter version of Set 2
Dark 2	darker version of Set 2
Set 3	medium saturation set with more lightness variation and more classes than Set 1 or 2
Paired	light/dark pairs for namable hues
Accents	includes lightness and saturation extremes to accent small or important areas

Table 1. General description of each color scheme in ColorBrewer. Sequential and diverging scheme names are built from two-letter abbreviations of names of hues in the scheme (for example, 'Bu' for 'Blue'). For sequential schemes, the lightest color is listed first. Hues in sequential scheme names are adjacent on the hue circle, while diverging schemes include hues with greater contrast. Qualitative scheme names are less descriptive since they include multiple hues.

and they describe development of the tool in Macromedia Flash. The Flash interface Harrower programmed is shown in Figure 7 (in the section of color figures). The paper also includes references to related discussions of choropleth mapping and color use.

Harrower and Brewer (in press) describe the simple algorithm ("recipe") used to pull schemes that vary from 3 to 12 classes from limited sets of colors. Sequential schemes with 3 to 9 classes are pulled from a set of 13 colors, and diverging schemes (3 to 11 classes) are pulled from 15 colors.

The full set of schemes for sequential YlGnBu and diverging RdYlBu are shown as full-color examples in Figure 8 (in color section). This figure reiterates the relationships between the related schemes in a set, which was described using tables of letters in Harrower and Brewer. Qualitative schemes are built with simpler series from sets of up to 12 colors. For example, a four-class scheme uses the first four colors from a qualitative set. The full sets with varying numbers of colors are shown in the catalog of printed schemes in Figure 12f. The abbreviated color scheme names, such as YlGnBu, are explained in Table 1.

ColorBrewer in Print

Geoffrey Hatchard joined the project in the summer of 2002, when Brewer and Hatchard took the next step of making sure the color schemes work in print. A mapmaker's decision to go to press with a compelling map is often the last stage in the development of a map that may have been used primarily on screen or as cheap laser prints passed among a group of colleagues. The task of making sure that a map will look its best in this last stage, when it is presented to peers or to the public in a print publication, is often a step for which mapmakers are not prepared. They do not have experience specifying CMYK colors and they do not anticipate differences in color appearance between media. The graphic arts and prepress professionals who work on other parts of a publication may not understand the logical relationships between data categories that are represented by colors in map figures, and thus they may not be able to effectively adjust colors to suit these data-rich representations. ColorBrewer in print offers assistance for this last crucial step in map making.

The primary goal of this paper is to provide a catalog of printed choropleth map color schemes, so that their quality and suitability may be evaluated by mapmakers who are seeking assistance in choosing colors for print projects. The bulk of this paper simply presents the color schemes. Paths through color space followed by the basic categories of schemes are also characterized. These generalizations will assist other researchers who seek to automate color design. The concept of selecting systematic paths through printed Munsell color sets was introduced in Brewer (1989).

The schemes shown here were not generated in an automatic fashion. They are each a small piece of design work by Brewer. She planned a general route through perceptual color space for each (such as light yellow through green to dark blue) and then worked in CMYK to produce the desired appearance. These schemes were not designed to have perceptually equal steps (Kimerling 1985), though she did seek to make each color identifiably different from other colors in the scheme while retaining a basic perceptual ordering (such as light to dark).

Criteria such as following arcs through color space and creating perceptually equal color steps are valid approaches but, in the end, getting a series of schemes online in a timely fashion outweighed the need to perfect their perceptual structure. The ColorBrewer schemes were first designed in Adobe Illustrator 9.0 using a PC laptop and consumer-grade 20-inch Trinitron CRT by Dell. Hatchard and Brewer then prepared the compact page layouts seen in Figures 9 to 12, which show large legend patches and a strip of small intermixed color patches (derived from U.S. county geography) for each scheme. The CMYK percentages used to print the colors are listed vertically to the left of each legend patch.

Hatchard and Brewer had these Illustrator files imageset to 175-lpi (lines-per-inch) color-separated negatives through QuarkXpress and proofed using Fuji ColorArt laminate material by a local printing company (Advanced Color Graphics). Proofed colors for seven-class schemes were matched by eye to the nearest Munsell chip in *The Munsell Book of Color* (Munsell Color 1999) with indirect daylight illumination (Table 2). The figures you see in this journal are printed at 133 lpi. Black outlines around legend boxes in these figures are 0.43 points and lines between county polygons are 0.21 points.

Cartography and Geographic Information Science is printed from digital files "direct to plate," so the colors you see here are not printed directly from the negatives Hatchard and Brewer used to evaluate and adjust these schemes. A few individual colors will be unsatisfactory in appearance with the new combination of processing, materials, inks, and press used to print this publication. Colors may shift to an inconsistent hue or become lighter or darker, losing crucial contrast with other colors in the scheme. These problems will be more common within schemes with more classes. So, the schemes with eight or more colors are more likely to fail in this media. It is unlikely that sequential schemes with eight and nine classes will not include colors that look the same when they are intermixed in the map strips beside each legend.

Use the strips of counties next to each legend to evaluate color differentiability. If a scheme has nine colors in it, are you able to count through

Sequential Schemes			Sequential Schemes (Continued)			Diverging Schemes			Qualitative Schemes		
Hue		**Value/Chroma**	**Hue**		**Value/Chroma**	**Hue**		**Value/Chroma**	**Hue**		**Value/Chroma**
YlGn			OrRd			PuOr			Set3		
7.5	Y	9/ 2	5	YR	8.5/ 1	10	YR	5/ 8	5	B	7/ 4
5	GY	8/ 2	7.5	YR	8/ 2	10	YR	6.5/ 6	7.5	Y	9/ 3
10	GY	7/ 4	5	YR	7/ 4	10	YR	9/ 2	7.5	PB	7/ 4
2.5	G	7/ 4	2.5	YR	7/ 6		N	9/	5	R	6/ 8
5	G	6/ 8	10	R	6/ 6	7.5	PB	8/ 4	2.5	PB	6/ 6
2.5	G	5/ 8	7.5	R	4.5/ 8	10	PB	6/ 5	7.5	YR	7/ 6
5	G	4/ 8	7.5	R	3/ 9	2.5	P	4/ 7	7.5	GY	7/ 7
YlGnBu			YlOrRd			BrBG			Pastel1		
7.5	Y	9/ 2	10	Y	9/ 2	2.5	Y	5/ 6	5	R	7/ 4
10	GY	8/ 2	2.5	Y	8/ 4	2.5	Y	7/ 4	2.5	PB	7.5/ 4
10	BG	6/ 4	10	YR	7/ 6	2.5	Y	8.5/ 2	10	G	8/ 2
5	B	6/ 8	5	YR	6.5/ 8		N	8.5/	2.5	P	8/ 4
10	B	5/ 10	10	R	5.5/ 10	10	B	8/ 4	10	YR	8/ 4
2.5	PB	4.5/ 8	5	R	4.5/ 10	2.5	B	6/ 6	10	Y	9/ 2
5	PB	3/ 8	10	RP	4/ 10	5	BG	4/ 8	5	Y	8/ 1
GnBu			YlOrBr			PRGn			Set1		
10	G	10/ 1	5	Y	9/ 1	7.5	P	4/ 8	7.5	R	4/ 12
10	G	8/ 1	2.5	Y	8/ 4	5	P	6/ 5	2.5	PB	5/ 9
2.5	G	8/ 2	2.5	Y	7.5/ 6	5	P	8/ 4	2.5	G	6/ 8
2.5	B	7/ 4	7.5	YR	7/ 8		N	9/	7.5	P	5/ 6
10	B	6/ 9	7.5	YR	6/ 8	2.5	G	8/ 2	7.5	YR	6/ 12
10	B	5/ 9	7.5	YR	5/ 8	2.5	G	7/ 4	10	Y	8.5/ 10
10	B	4/ 8	7.5	YR	4/ 6	2.5	G	5/ 8	10	YR	5/ 4
BuGn			Purples			PiYG			Pastel2		
2.5	PB	9/ 2	7.5	PB	8.5/ 2	6.25	RP	4/ 12	7.5	BG	8/ 2
5	B	8/ 2	7.5	PB	8/ 3	2.5	RP	7/ 6	5	YR	8/ 3
2.5	B	7/ 4	7.5	PB	7/ 4	2.5	RP	8/ 4	7.5	PB	8/ 4
10	BG	6/ 4	7.5	PB	6/ 6		N	9/	10	P	8/ 4
2.5	BG	6/ 6	7.5	PB	5.5/ 6	10	GY	8.5/ 2	10	GY	9/ 2
2.5	G	5/ 8	10	PB	5/ 6	7.5	GY	7/ 6	5	Y	8.5/ 3
2.5	G	4/ 8	2.5	P	3/ 8	7.5	GY	5/ 10	10	YR	8/ 1
PuBuGn			Blues			RdBu			Set2		
5	P	9/ 1	2.5	PB	8.5/ 2	5	R	4/ 8	10	BG	7/ 6
5	P	7/ 2	2.5	PB	7.5/ 4	2.5	YR	6/ 6	2.5	YR	7/ 6
5	PB	6.5/ 4	2.5	PB	7/ 6	2.5	YR	8/ 2	5	PB	6/ 6
2.5	PB	6/ 7	2.5	PB	6/ 8		N	9/	2.5	RP	6.5/ 6
10	B	5.5/ 8	2.5	PB	5.5/ 8	5	PB	8/ 4	7.5	GY	7/ 6
2.5	B	4/ 8	2.5	PB	5/ 9	2.5	PB	6/ 7	5	Y	8/ 10
2.5	BG	4/ 8	2.5	PB	3.5/ 8	2.5	PB	4/ 9	2.5	Y	7.5/ 2
PuBu			Greens			RdGy			Dark2		
5	P	8.5/ 1	10	G	10/ 1	5	R	4/ 8	5	BG	6/ 8
5	P	7/ 2	7.5	G	8/ 2	2.5	YR	6/ 6	7.5	YR	5/ 8
5	PB	6.5/ 4	5	G	7/ 4	2.5	YR	8/ 2	7.5	PB	5/ 6
2.5	PB	6/ 7	5	G	6/ 5		N	10/	5	RP	5/ 12
10	B	5.5/ 8	5	G	6/ 8		N	8.25/	7.5	GY	6/ 10
10	B	5/ 10	2.5	G	5/ 8		N	6.5/	5	Y	7/ 10
10	B	3.5/ 8	5	G	4/ 6		N	4/	5	Y	5/ 6
BuPu			Oranges			RdYlBu			Paired		
2.5	PB	9/ 2	5	YR	8.5/ 1.5	7.5	R	5/ 9	2.5	PB	7.5/ 4
5	PB	7/ 4	5	YR	8.5/ 4	2.5	YR	7/ 6	2.5	PB	5/ 10
5	PB	7/ 6	5	YR	7/ 5	2.5	YR	8/ 4	10	GY	8/ 4
7.5	PB	5.5/ 6	5	YR	6.5/ 7	10	Y	9/ 2	10	GY	6/ 12
2.5	P	5.5/ 6	5	YR	6/ 10	2.5	PB	8/ 2	5	R	7/ 6
7.5	P	4.5/ 6	5	YR	5/ 10	2.5	PB	7/ 6	7.5	R	4/ 12
2.5	RP	3/ 10	10	YR	4/ 4	2.5	PB	4.5/ 6	10	YR	8/ 4

Continued on page 9....

Sequential Schemes			Sequential Schemes (Continued)			Diverging Schemes			Qualitative Schemes		
Hue		Value/Chroma	Hue		Value/Chroma	Hue		Value/Chroma	Hue		Value/Chroma
RdPu			Reds			Spectral			Accents		
5	R	9/ 1	7.5	R	8/ 2	2.5	R	5/ 8	5	G	7/ 6
5	R	8/ 4	10	R	7.5/ 4	2.5	YR	7/ 6	10	PB	7/ 4
7.5	RP	7/ 6	7.5	R	7/ 6	2.5	Y	8/ 4	7.5	YR	7.5/ 4
7.5	RP	6/ 8	7.5	R	6/ 8	10	Y	9/ 2	10	Y	9/ 4
5	RP	5/ 10	7.5	R	5/ 10	5	GY	8/ 4	2.5	PB	5/ 8
3.75	RP	4/ 12	5	R	4/ 10	5	G	7/ 4	8.75	RP	4/ 14
2.5	RP	3/ 10	5	R	3/ 9	10	B	5.5/ 8	10	YR	5/ 8
PuRd			Grays			RdYlGn					
5	P	8.5/ 1		N	9/	7.5	R	5/ 9			
5	P	7/ 4		N	8.25/	2.5	YR	7/ 6			
7.5	P	6.5/ 6		N	7.5/	2.5	Y	8/ 4			
2.5	RP	6/ 8		N	6.25/	10	Y	9/ 2			
5	RP	5/ 12		N	5.5/	5	GY	8/ 4			
8.75	RP	4/ 14		N	4.5/	7.5	GY	7/ 6			
7.5	RP	3/ 8		N	2.75/	5	G	5/ 10			

Table 2. Munsell notations for seven-class color schemes.

nine colors in the adjacent strip of map? Likewise, keep in mind that if you use these colors in your own printed product, the combination of processing, materials, inks, and press you use will produce slightly different colors. Do not rely on a slight difference that holds up here to carry key data differences in another printed product because it may not hold up in the new production context.

Characterizing Schemes in Color Space

Each of the three types of color schemes has a different general shape in color space (Figure 1). The graphs in Figures 2 to 6 show two-dimensional views of the three-dimensional Munsell color space. The Munsell system is structured as cylindrical 3D polar coordinates, with each dimension perceptually scaled. The horizontal axis of the hue-value graphs (Figures 2, 4, and 6) portrays the hue dimension, which is an angular measure. The vertical axis for the graphs is value, the lightness of a color, which ranges from 0 to 10. Chroma, the saturation of a color, is shown for example schemes in Figures 3 and 5.

Graphs in Figures 2 to 6 show the key perceptual structure of the schemes: their arrangement through hue, value, and chroma dimensions. The hue-value graphs can be viewed as cylindrical projections of the color schemes from their 3D arrangement to the flat page. Colors with varied chroma are projected onto a vertical cylinder, which is unrolled to form these graphs (Figure 1a). The value-chroma graphs collapse the hue dimension to a single plane intersecting the cylinder at its central value axis (Figure 1b).

A full Munsell specification for a color lists hue, value, and chroma. Small numbers above the hue axis in Figures 2 to 6 indicate hue numbers from zero to 100, with ticks every ten units. Example hue labels for ten Munsell hues are listed below the hue axis: 5R, 5YR, 5Y, 5GY, etc. (For example, 5BG has a hue number of 55.) In the Munsell system, these hues are arrayed radially around a central neutral axis that runs from black through grays to white. A full Munsell designation for a color is of the form "7.5 B 8/4:" this example color is a blue hue that is light (it has a high value number of 8) and desaturated (with a low chroma number of 4).

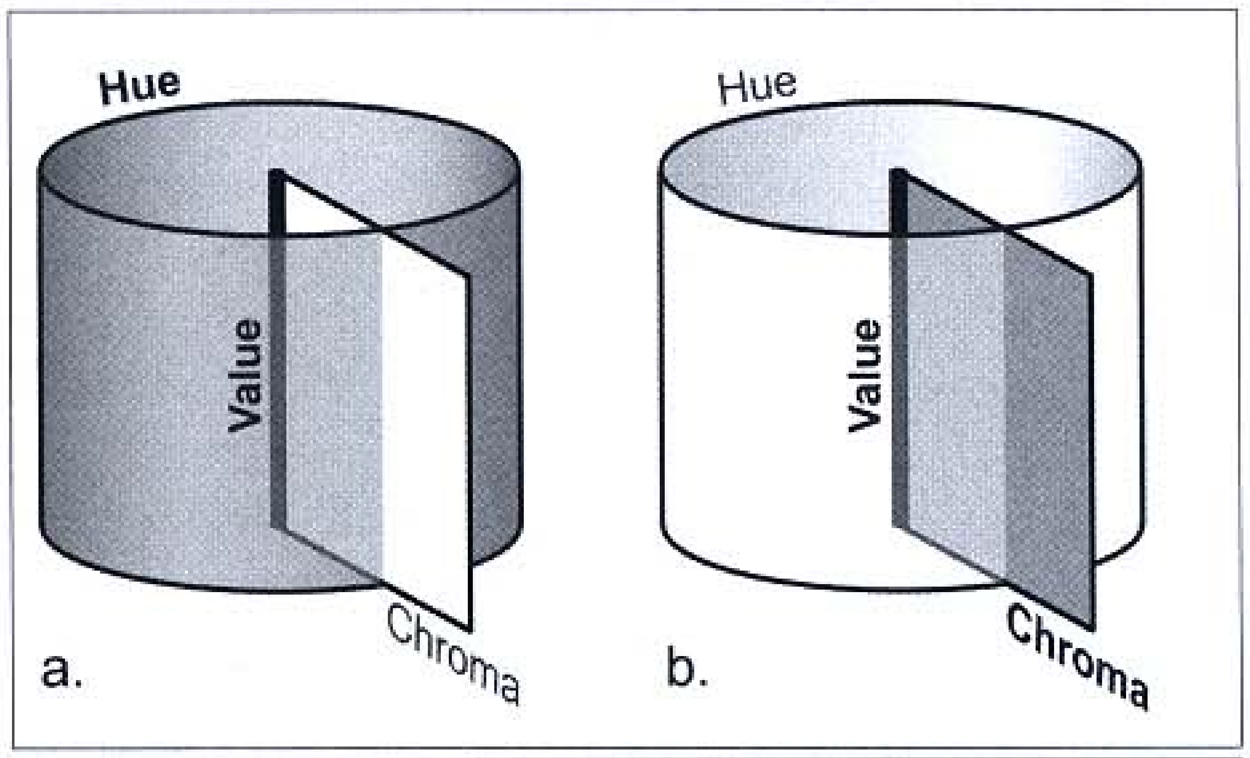

Figure 1. Three dimensions of Munsell color space. Figures 1a and 1b show the three-dimensional structure of Munsell color space. The graphs in Figures 2, 4, and 6 show colors projected onto the hue-value cylinder shown in Figure 1a. The graphs in Figures 3 and 5 show colors projected onto value-chroma planes like the one shown in Figure 1b.

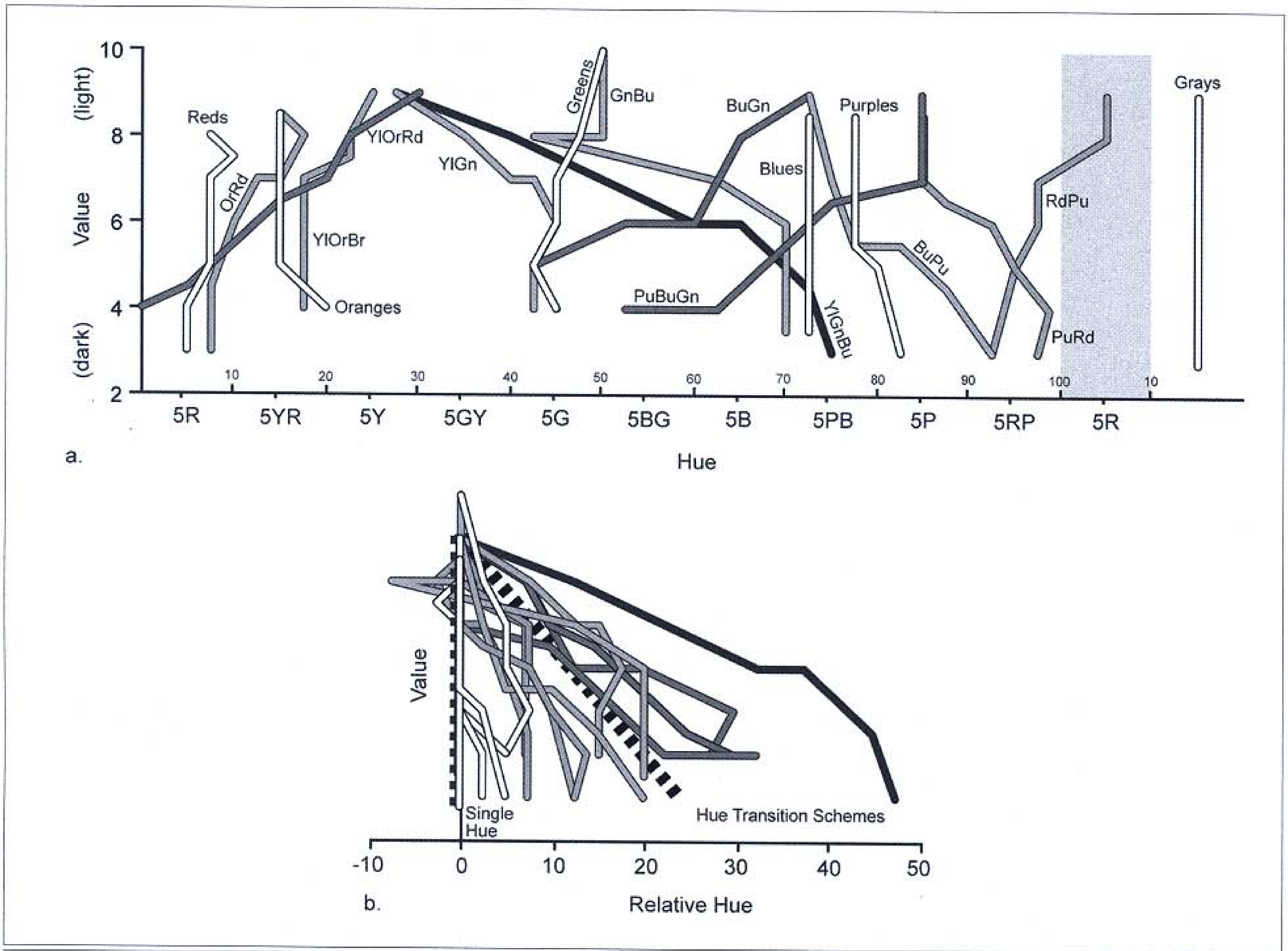

Figure 2. Hue and value graph of sequential schemes. Figure 2a shows all of the sequential schemes graphed to hue and value axes (listed in Table 2 and shown in Figures 9 and 10). Scheme names are described in Table 1. Figure 2b shows all of the schemes repositioned with lightest colors beginning at the same vertical axis. Eight lines are reflected so they all trend to the right. These lines allow comparison of the range of slopes for sequential schemes. Light-to-dark line fills indicate general classes of slope; the black line shows the scheme with the greatest hue range, while vertical white segments show schemes with minimal hue variation. Dashed lines sketch the general character of the single-hue and hue-transition schemes. The grayed zone at the right side of the 2a graph repeats hues for continuity.

The notations for the central axis of neutral colors use N for hue and include no chroma designation, since they contain no hue. The value number for each of these colors identifies their lightness (for example, "N 5/" is a middle gray).

Sequential Schemes

Brewer decided on a set of sequential schemes by beginning with the set of commonly named basic colors from a saturated hue circle: red, orange, yellow, green, blue, purple. Other basic colors are desaturated: brown (dark desaturated orange), pink (light desaturated red), white, gray, and black. She then constructed hue and lightness transitions between the following adjacent hues: YlGn, GnBu, BuPu, RdPu, PuBu, BuGn, YlOrBr, OrRd (the first color in each name is light and the second dark). YlOr is labeled YlOrBr since orange becomes brown when it is dark.

A few adjacent hue pairs are omitted from ColorBrewer. OrYl and GnYl are not satisfactory schemes because yellow is not available as a dark saturated color. RdOr and PuRd are also omitted because their overall appearance was not much different than OrRd and RdPu. These warm colors are generally less well liked than the cooler schemes (the most common favorite color is blue; see Brewer et al. (1997) for further discussion on color naming and color preferences). RdOr and PuRd added more clutter to ColorBrewer than their usefulness warranted, though they are generally satisfactory schemes. A few promising hue transitions that spanned three adjacent hues were also included in the ColorBrewer set: YlOrRd, YlGnBu, and PuBuGn. The colorfulness of light yellow is

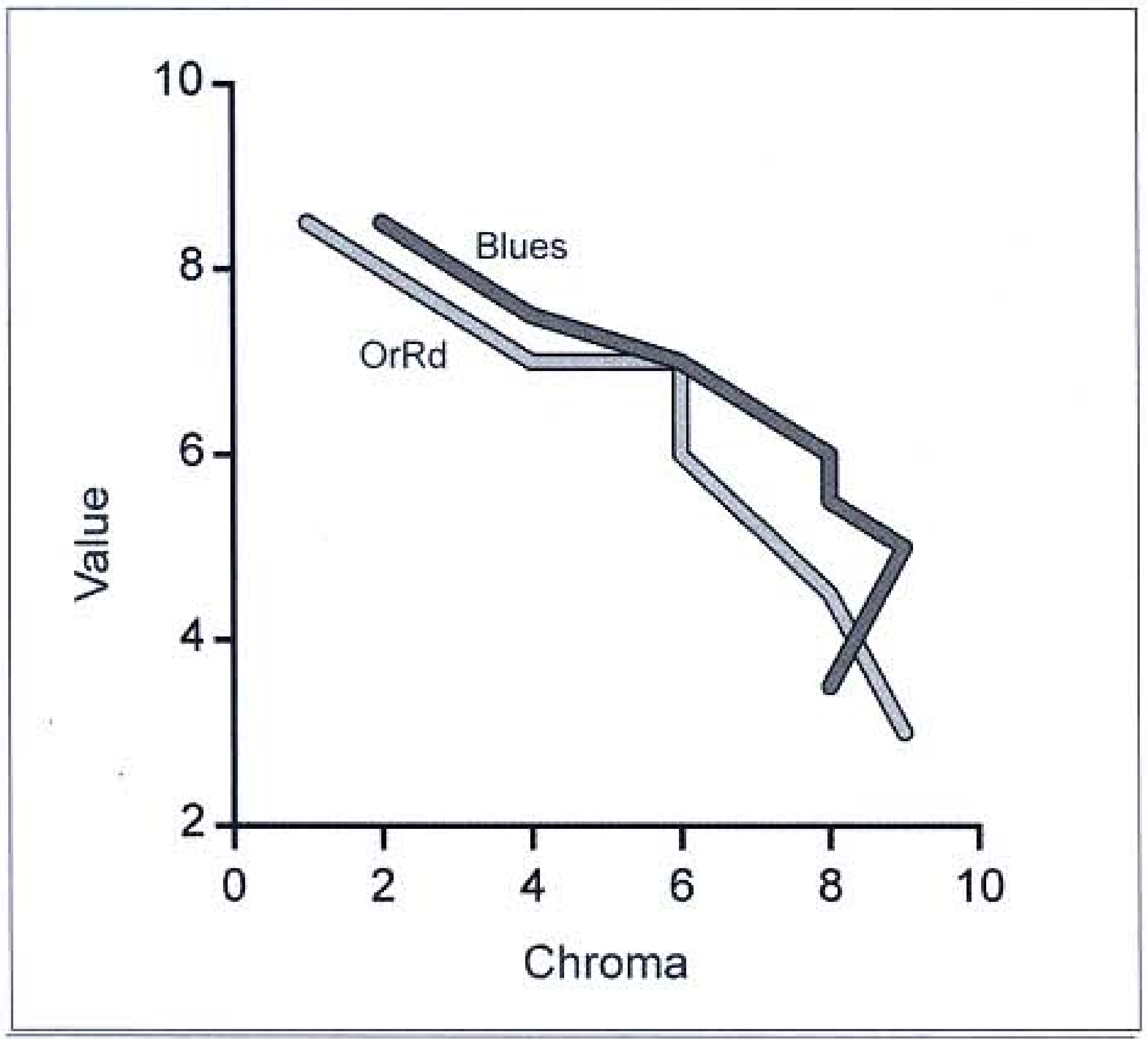

Figure 3. Value and chroma graph of example sequential schemes. Two example sequential schemes are graphed on a single value-chroma plane. The graph omits hue information. The lines for all of the sequential schemes share a general trend from light and low chroma to dark and high chroma.

particularly useful for building pleasing extended hue transitions into a scheme. A set of simple single-hue schemes is also offered in a second palette of sequential schemes in ColorBrewer.

Most of the sequential schemes offered in ColorBrewer include hue transitions because these more colorful schemes are difficult for novice map designers to construct. Thus, ColorBrewer offers users somewhat advanced designs, beyond single-hue lightness sequences. Additional extended transitions that span more than two hues could also be constructed, such as BuPuRd. Care needs to be taken with these so that hue contrast does not become so large that classes appear to represent categorical rather than magnitude differences (producing a qualitative rather than sequential scheme).

Sequential schemes are graphed in Figures 2 and 3. Each line represents a single seven-class scheme in ColorBrewer that is printed in Figures 9 and 10, and listed in Table 2. Each scheme begins with a light color and follows a vertical or angled path down to a darker color. The more angled schemes include greater hue differences from color to color within the scheme. For example, on the left side of the graph in Figure 2a, hues in the Reds scheme vary by only 5 units, so hue is relatively consistent through the scheme. In contrast, OrRd has a modest hue transition from light orange to dark red, with the line varying more from the vertical—by a difference of 10 hue units overall. YlOrRd includes even more of a hue transition, from light yellow to dark red, spanning 30 hue units in Figure 2.

All of the sequential schemes are collected together in Figure 2b, with their light beginning colors positioned on a common vertical axis. Each line on the graph in Figure 2a was moved to the left so its uppermost color landed on the same vertical line. Eight of the 18 schemes were also reflected on that vertical, so all schemes trend in the same direction. This arrangement allows us to see the common characteristics in the tangle of schemes in Figure 2a. They all start light, between values of 8 and 10, and progress in a systematic manner down to dark colors (values 3 to 4), but with varied slopes. The runs of the slopes range from zero to 47.5 hue units, with the YlGnBu (the black line) including the greatest hue differences between colors. Two example schemes are also shown on a value-chroma graph in Figure 3. They are representative of the general trend in all the sequential schemes, sloping from light value/low chroma to dark value/high chroma.

The straight dashed lines in Figure 2b characterize sequential schemes with a single hue (vertical) and hue transition (sloped line) on the hue-value graph. When sketching these generalized dashed lines, we wondered whether the printed schemes would be improved by straightening their trajectories in color space, by making hue and lightness steps completely systematic. We did not have the funds (or desire) to continue proofing and adjusting colors to perfect the color steps, and there is no automatic process to precisely reproduce desired Munsell colors in CMYK (variation at the press makes this a hopeless pursuit, reiterating Monmonier's 1980 sentiments).

Producing seven readily differentiable colors is actually quite difficult, given the limited contrast range available in print (and on screen). Schemes include deviations in hue progressions (lines zigzag slightly, such as PuRd), and some adjacent colors have minimal lightness contrast (lines have horizontal segments, such as midway through BuPu). These imperfections in scheme lines may be necessary to increase contrast between similar colors so that map colors remain individually identifiable while retaining an obvious general progression: from light to dark among similar hues or through a hue transition.

When taking the time to perfect a color-space trajectory in our past projects, maps sometimes ended up with less successful schemes than initial draft designs. They were less successful because map readers had a harder time distinguishing

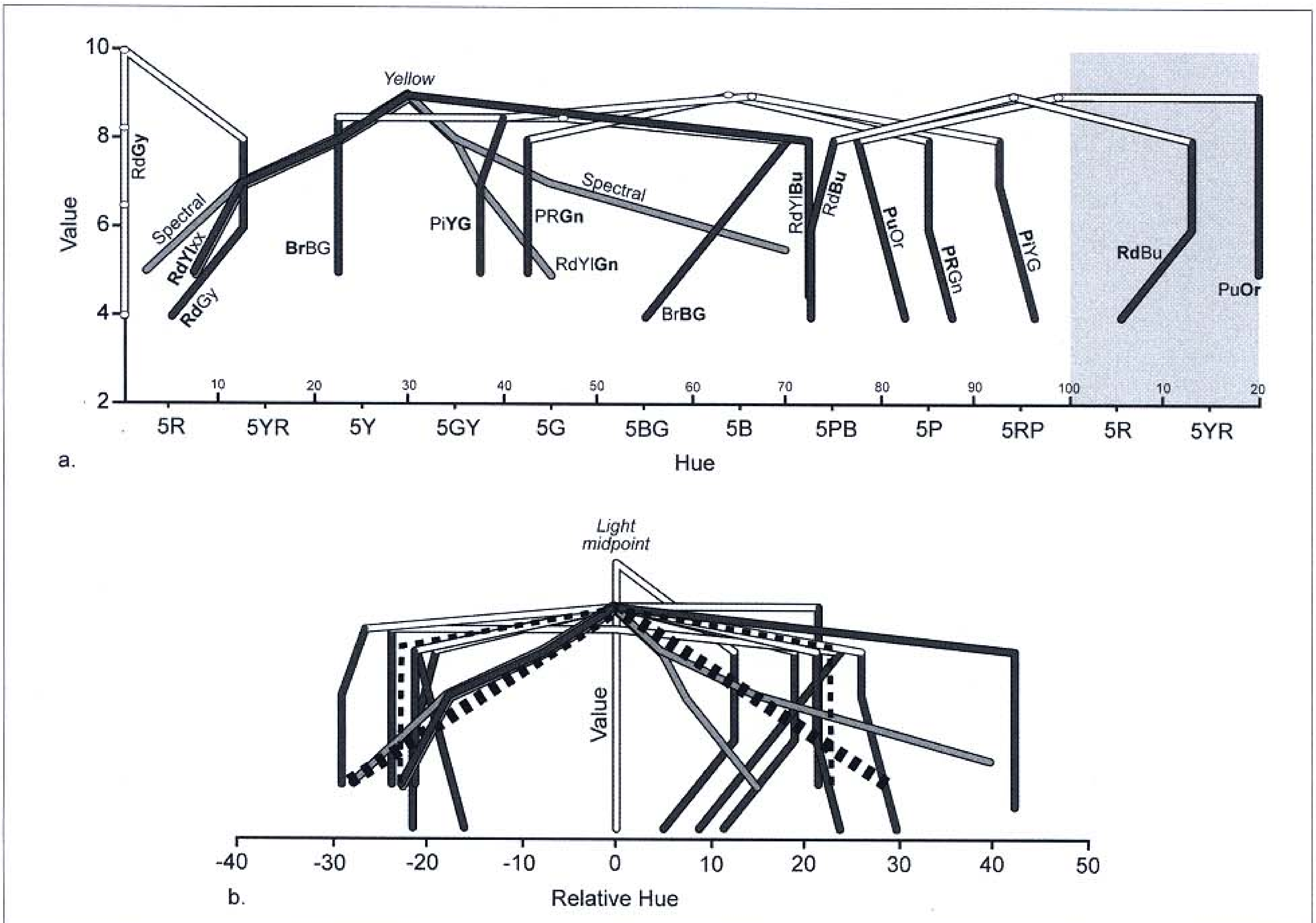

Figure 4. Hue and value graph of diverging schemes. Figure 4a shows all of the diverging schemes graphed to hue and value axes (schemes are listed in Tables 1 and 2 and shown in Figure 11). The hue for each half of the scheme is shown in bold type in the 4a labels. Figure 4b shows all of the schemes repositioned with their midpoints at the same vertical axis. White segments extend to neutral colors that have no hue and thus no specific position along the hue axis (they are centered between the positions of the third and fifth colors within a scheme). The group of lines in 4b show the general character of diverging schemes, which is summarized by two dashed lines.

individual colors: the smooth trajectory through color space perfected the logical relationships between colors but had a negative impact on identification of map polygons. It may be that introducing some jitter among colors along a trajectory in color space suits the goals of map design, which include understanding overall patterns and distinguishing individual colors. Evaluation of this suggestion is a topic ripe for additional research.

Diverging Schemes

Diverging schemes include a light midpoint and lightness progressions that extend out from that critical break or class toward two different hues. The diverging schemes included in ColorBrewer have almost all been presented in previous publications, and so the intention was to make color specifications available for versions of these schemes seen elsewhere. Versions of PuOr, BrBG, PRGn, PiYG, RdBu, and spectral schemes were each tested with epidemiological data in Brewer et al. (1997). RdYlBu is suggested in Brewer (1997) as a colorful alternative to spectral schemes to accommodate colorblind map readers. RdGy was used in Eicher and Brewer (2001) to represent map error. RdYlGn is often used as a diverging scheme because mapmakers want to take advantage of the stop/go association offered by these hues (though the hues may completely confound a colorblind reader). We include it in ColorBrewer to show a well designed example but also explicitly mark it as confusing for colorblind map readers. Brewer (1996) offers further discussion of diverging scheme design, and Olson and Brewer (1997) discuss map design for colorblind readers.

The set of nine diverging seven-class schemes in ColorBrewer are graphed in Figures 4 and 5, shown in Figure 11, and listed in Table 2. In contrast to the sequential schemes, the diverging

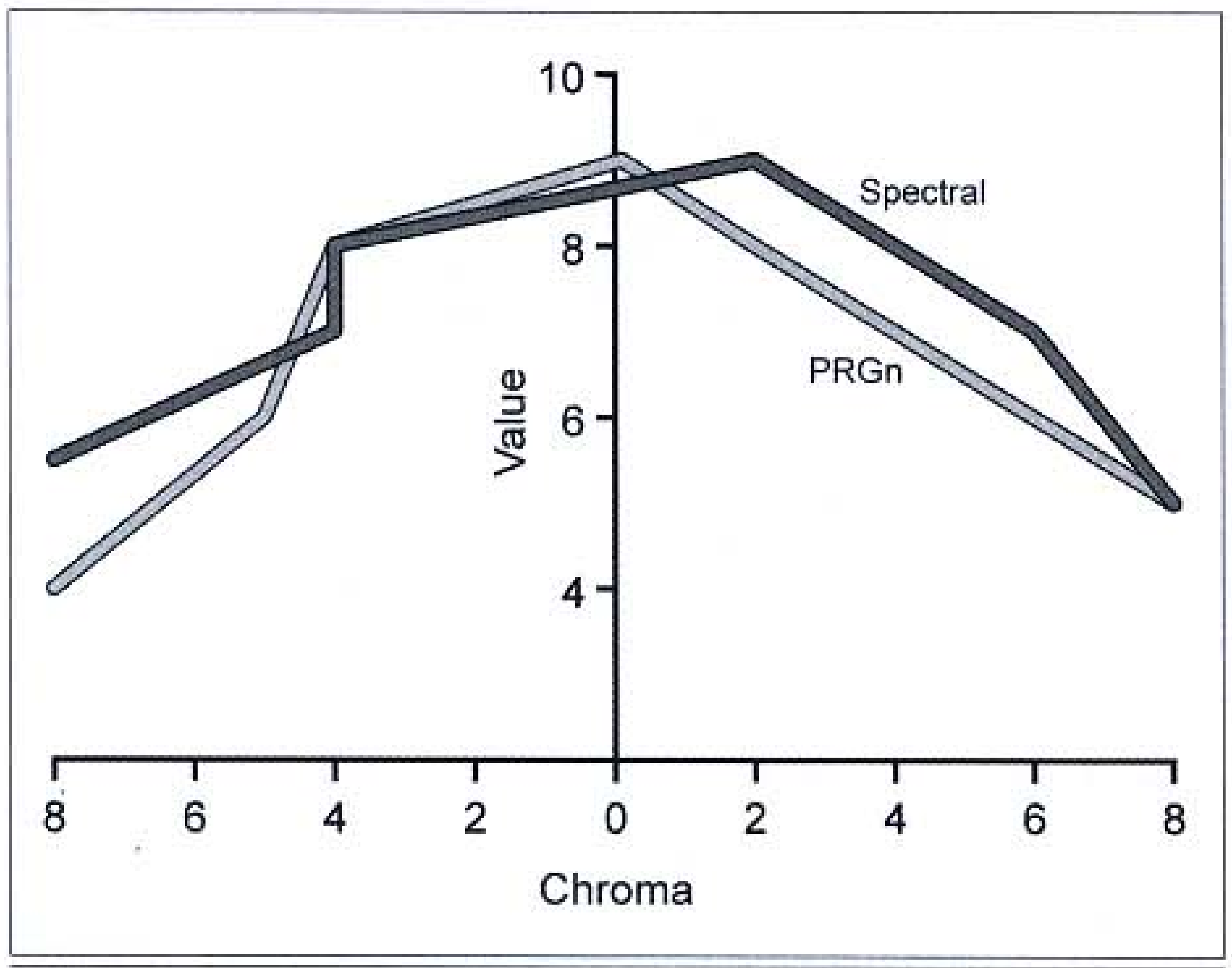

Figure 5. Value and chroma graph of diverging schemes. Two example diverging schemes (PRGn and Spectral) are graphed on two value-chroma planes, one for each half of the diverging schemes. The lines for all of the diverging schemes share this general peaked form, from dark value/high chroma to light value/low chroma and back down to dark value/high chroma.

schemes each have an inflection point at a light middle color. Most of the diverging schemes meet at a near-white gray (neutral colors are marked by a small oval on the graph). Since these neutral colors have no hue, their position on the Figure 4 graphs is arbitrary; each is positioned midway between the two hue sequences within a diverging scheme, and schemes are arranged so that most do not span more than 50 hue units. White-filled lines in this graph represent connections to these neutral middle colors, which are positioned on the value axis at the center of the cylindrically arranged hues. The gray sequence in the RdGy scheme is also arbitrarily positioned within the hue-value graph.

Figure 4 shows the variety of shapes diverging schemes form in the hue-value view of color space. Spectral and RdYlGn schemes include slopes that describe simultaneous variation on both hue and value. Most of the schemes form square arches in the hue-value graph. The near-vertical legs of each arch plot single-hue sequences that make up halves of the diverging schemes. This square form suggests a large contrast in the middle of each scheme, but the chroma dimension is missing from this representation. Figure 5 shows the PRGn and spectral schemes graphed with value and chroma axes to illustrate the chroma reduction near the lightest colors, which produces a smoother transition between colors than implied by the squared angles seen on the hue-value graphs. All of the diverging schemes have a peaked shape similar to the examples in Figure 5.

Qualitative Schemes

Qualitative schemes each include less lightness variation and wider variation in hue than the sequential and diverging schemes. The qualitative schemes differ partly in the number of basic colors they include (basic colors are red, green, blue, yellow, orange, purple, pink, brown, white, gray, black; see Brewer et al. 1997 for further discussion). Set 1 includes mostly basic colors, Set 2 includes more colors that are mixtures not readily named, and Set 3 offers a mix of the two to produce more classes. The paired and accents schemes have special purposes. Light and dark versions of each hue in the paired scheme should be used for related categories on a map. The light, dark, and saturated colors in the accents scheme are intended for small or important categories that benefit from emphasis on a map. For example, the saturated magenta, dark blue, and dark brown could be used for categories with few polygons within larger expanses of medium green, orange, and purple.

Table 2 presents Munsell notations for seven-class qualitative schemes, and Figure 12 shows printed examples of all the qualitative scheme colors. Figure 6 shows three related seven-class qualitative schemes: Pastel 2, Set 2 and Dark 2. We selected a subset to more clearly diagram the perceptual relationships between colors in the qualitative schemes, rather than showing all of the schemes on the graph (which produces an intermixed jumble of points).

Boxes outline the three schemes. Notice that the colors in the Pastel 2 set (the set of triangles surrounded by a light gray box) have consistently high values that range between 8 and 9. The Dark 2 set (diamonds in a black box) includes a wider range in values (from 5 to 7). These three schemes are related because they use approximately the same hues with different lightness ranges. The similarity in hue can be seen in the vertical arrangement of the colors among schemes. For example, the blue-green hues used in each scheme all fall in the middle of the graph, stacked near each other along the hue axis. The different hues found in these three schemes are fairly well spaced along the horizontal axis, demonstrating good hue contrast. The exception is the nearness of browns (small symbols) to yellow, orange, and red hues on the left side of the graph. The contrast between

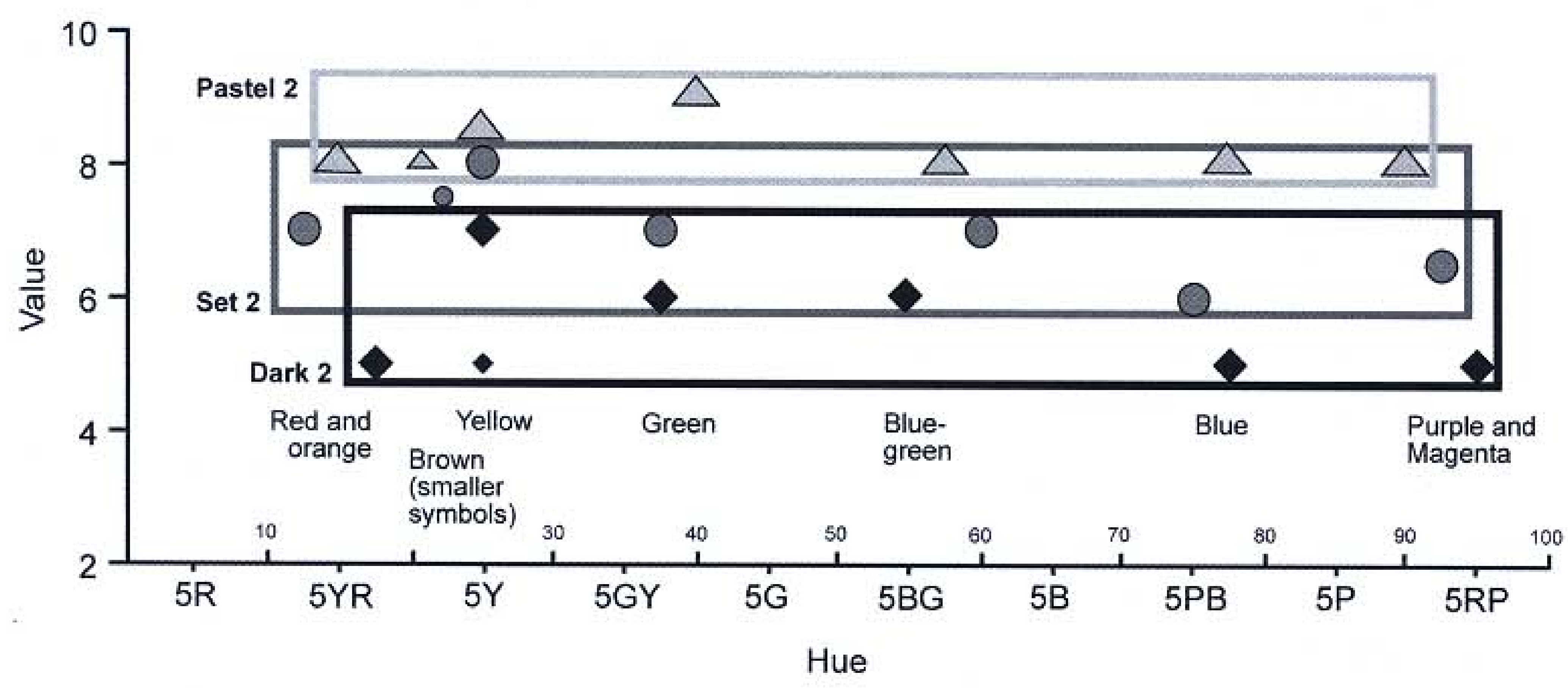

Figure 6. Hue and value graph of example qualitative schemes. Three example qualitative schemes are shown on hue and value axes. The Pastel (triangles) and Dark (diamonds) schemes are variations on the Set 2 scheme (circles). The value range of each is sketched with a rectangle on the graph. Note the spacing of hues along the horizontal axis for each scheme, which is a common characteristic of the qualitative schemes. The three smaller symbols are browns, which have lower chroma, the color dimension not shown on this graph. Qualitative schemes are shown in Figure 12, described in Table 1, and Munsell notations are listed in Table 2.

brown and these other colors is in chroma, which is not represented on the graph (see Table 2).

Notice that there is some variation in value among the colors within a scheme. This variation functions just as the imperfections along the sequential scheme paths discussed above. The variation in value adds contrast to improve identification of individual colors. A qualitative scheme with colors arranged in a perfectly horizontal line across the graph (equal value) would include so little contrast that category identification would be difficult with more than a few colors. Again, jitter along the path produces a more readable scheme.

Customizing Schemes

The catalog of schemes presented here should be used flexibly. Part of a scheme may be omitted, and schemes may be combined to build customized schemes. For example, a five-class scheme could be constructed by choosing a seven-class sequential scheme, but using only colors 1, 2, 3, 4, and 7 (skipping a couple of colors to achieve greater contrast for the last class).

Longer diverging schemes or diverging schemes with different hue pairings could be produced by setting a pair of the sequential schemes end to end. The lightest color in each sequential scheme would be replaced by a shared middle class, or the schemes could meet at a middle class break. For example, PuBu and PuRd could be joined at the light purple both schemes share to produce a RdPuBu diverging scheme.

Longer sequential schemes can be produced by using a selection of colors from a scheme as anchor points and "ramping" between them. For example, 25 colors could be generated by using a five-class sequential scheme to define the first color and every sixth color that follows (colors 1, 7, 13, 19, and 25). Colors for the six classes between each of these known color specifications would be interpolated by the mapping software.

Asymmetrical diverging schemes can be designed by selecting halves of diverging schemes with different numbers of classes. For example, the first two oranges from a four-class PuOr scheme may be used with the five purples from the ten-class counterpart. This combination would produce a PuOr scheme with more classes on one side of the critical value (for example, two classes of loss in population and five classes of gain with zero change as the break between the second and third classes).

The order of colors in the qualitative schemes is somewhat arbitrary and should be customized to suit the particular categories in a data set that is mapped. At the simplest level, the first five colors in Set 1 (red, blue, green, purple, and orange) could be arranged in any order in a map legend. It is also reasonable to select colors from throughout a qualitative set (such as colors 1, 3, 6, and 9 from Set 3) to build a four-class scheme, rather than using the first four in the set. Some caution is required though, so that the scheme does not appear ordered. For example, colors 9, 8, 3, and 10 from Set 3 would look much like a sequential scheme (gray, pink, medium purple, red-purple;

see Figure 12f). Selection from throughout the set of colors in the qualitative schemes is expected for the "Paired" and "Accents" schemes because use of colors within these schemes is more specialized. Pairs need to be matched to related categories (such as wetland and open water land cover), and accent colors (dark, saturated, or light) should be matched with small or important categories that require visual emphasis.

Pairs of colors for a binary scheme (a scheme type with only two categories; discussed in Brewer 1994) can be selected from any of the schemes printed here. Binary schemes are not presented here as a separate group, partly because they were originally introduced to produce practical two-variable combinations with other scheme types. For example, a two-variable qualitative/binary scheme would be used to show land use types inside and outside an aquifer recharge area. Binary schemes can be viewed as a special case of sequential or qualitative schemes and are not further elaborated in this paper.

ColorBrewer schemes are intended to be used for varied types of graphics and thus are not limited to choropleth maps. Beware however that the subtle color differences included in schemes with many classes are not likely to be differentiable when used for thin lines and small point symbols. The challenge of differentiating small patches of color makes ColorBrewer less useful for symbolizing data on scatter plots and line graphs. Maxwell (2000) reflects on the problem of selecting discriminable colors for map symbols 4 to 6 pixels wide in his discussion of using color to visualize data of high dimensionality.

ColorBrewer schemes were designed with the intention that they be used against a white background, as shown in Figures 9 to 12. The dark colors in the diverging schemes will not contrast sufficiently with a black background to emphasize the end classes. If you would like to display data against a black background, as is common in some visualization contexts, consider strategies such as selecting part of a scheme. For example, using the five lighter colors from a seven-class sequential scheme or the middle five colors from a longer diverging scheme may improve your map.

Future Research and Applications

The next steps will be to systematize and automate color scheme design. This needs to be done in a perceptually scaled color space such as Munsell, OSA-UCS (Optical Society of America's Uniform Color Scales), CIE Lab, CIE Luv, or a variety of others from the color science field (Fairchild 1998). The typical color systems made available in cartographic/GIS software packages (such as HSV, HSB, and HLS) have some of the trappings of perceptual organization but are not perceptually scaled. They use perceptual terminology to label dimensions (such as hue, value, lightness, brightness, saturation), but the use of that terminology does not make them perceptually scaled systems.

HSV, HSB, and HLS systems are made available because conversions to (and from) RGB are easy to calculate, but they are not adequately controlled to function as an effective base for the automatic generation of the perceptually organized color schemes described in this paper. One characteristic that gives away their flaws is their positioning of light saturated yellows at the same lightness (value) level as dark saturated blues. Any color system that organizes all of the saturated hues in a horizontally level hue circle of constant value (or lightness or brightness) immediately fails in its usefulness for creating generalized paths through color space that will generate schemes suitable to present sequential, diverging, and qualitative data. Other difficulties created by the general symmetry of these systems include positioning white and darker saturated hues at the same lightness level and using the same distance between white (or black) and each saturated hue. Three-dimensional perceptual color spaces are asymmetrical, so symmetric forms (such as cone-shaped or double-cone systems) distort the perceptual structure of color. RGB has a cube shape that does not offer links to perceptual terminology and will also perform poorly when attempting to automate color design by using paths through color space.

A steady stream of praise for and critique of ColorBrewer has made its way to Brewer and Harrower via email. In response to requests, Brewer has made available an Excel table of RGB numbers for all color schemes. This option has been requested by people who find the schemes useful but want a quicker way to paste them into programming code. For example, Erich Neuwirth (University of Vienna) added ColorBrewer schemes to R, an open-source statistical computing and graphics environment <www.r-project.org>, and Deborah Swayne (AT&T Labs) added ColorBrewer schemes to GGobi, a data visualization system <www.ggobi.org>. Distribution of information on ColorBrewer has been wide, including a mention in the NetWatch section of *Science* (Leslie 2002). We are glad the schemes are useful to people making maps and statistical graphics, and we hope

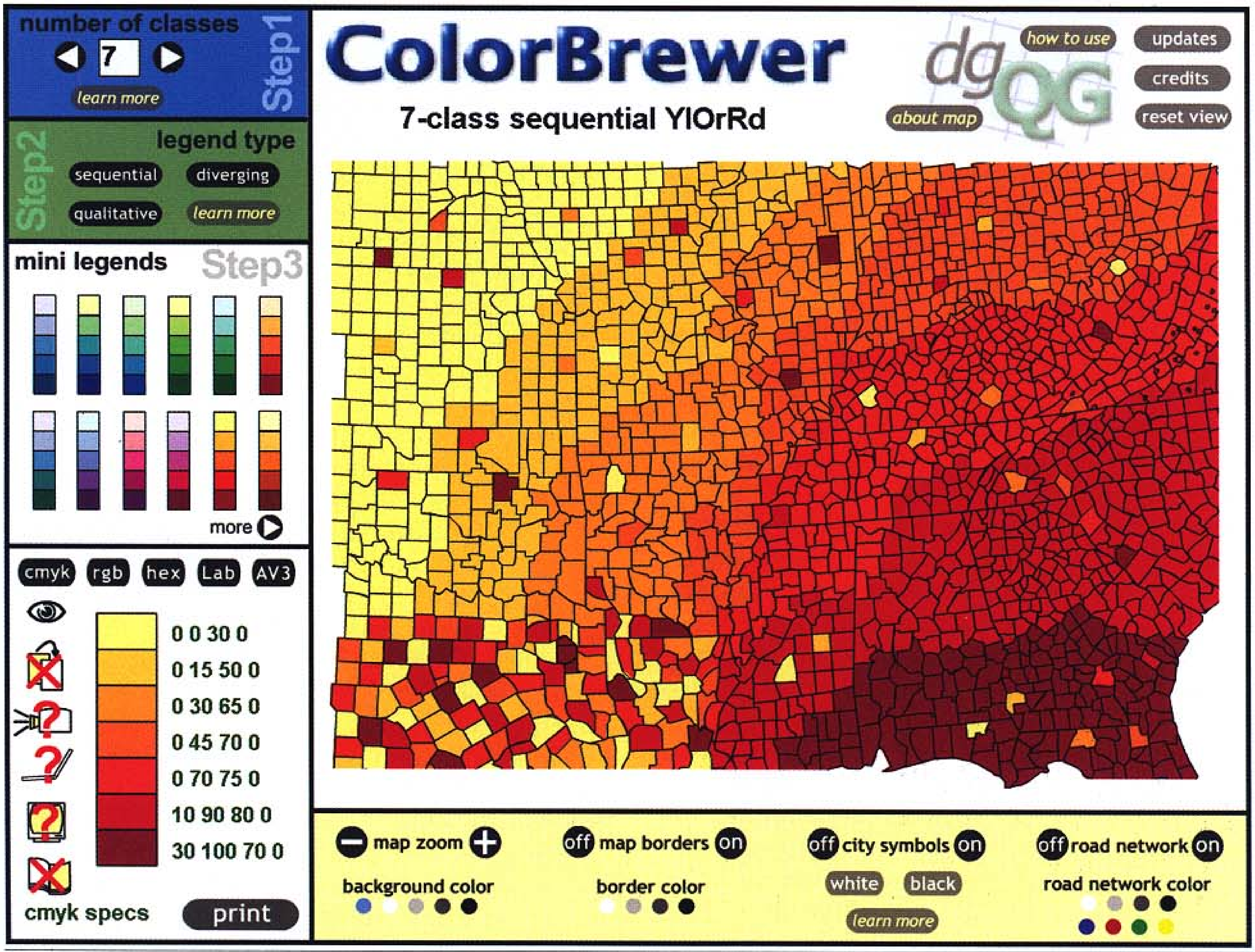

Figure 7. Flash interface for the <www.ColorBrewer.org> online tool.

that the printed versions offered here will support the needs of people whose graphic work appears in print.

ACKNOWLEDGEMENTS

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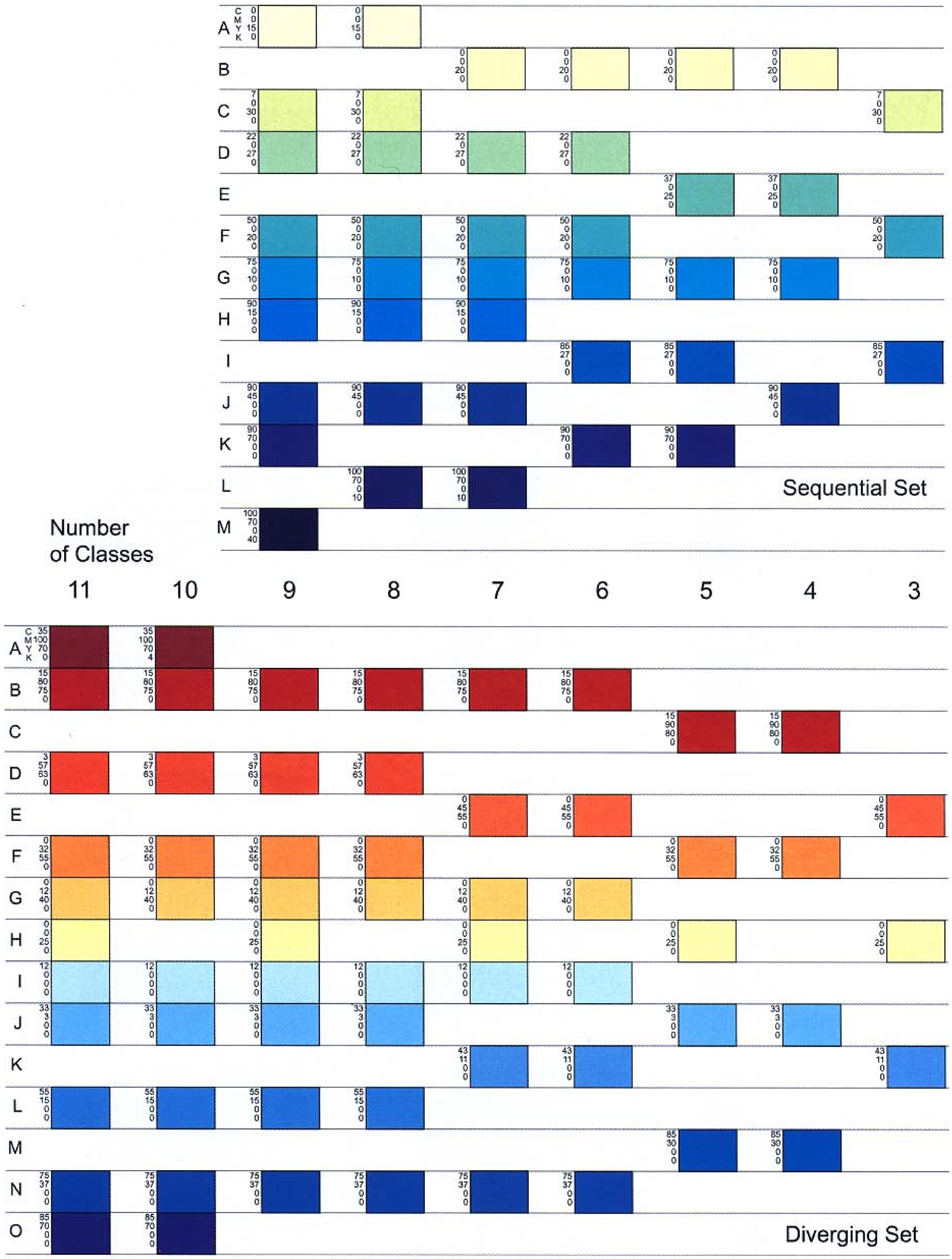


Figure 8. Recipes for sequential and diverging color schemes. A set of sequential schemes with 3 to 9 classes are drawn from a shared set of 13 colors (A to M), as shown in the top group of colors (the example scheme is Y1GnBu). For example, color B (20Y) is used in schemes with 4 to 7 classes. The bottom half of the figure shows a set of diverging schemes with 3 to 11 classes. These schemes are drawn from a shared set of 15 colors (the example scheme is RdYlBu). For example, the 3-, 6-, and 7-class schemes share color E (45M 55Y).

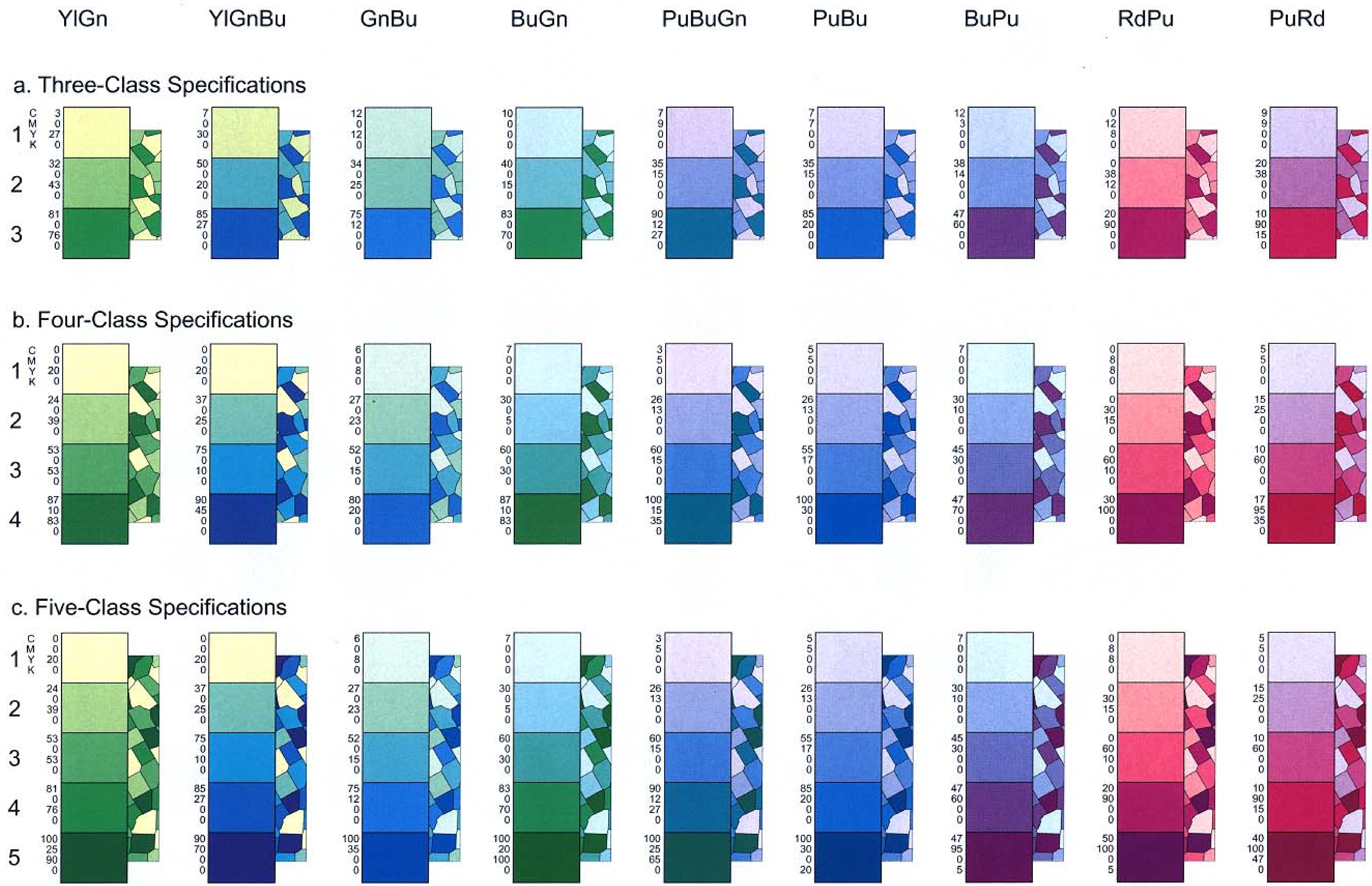
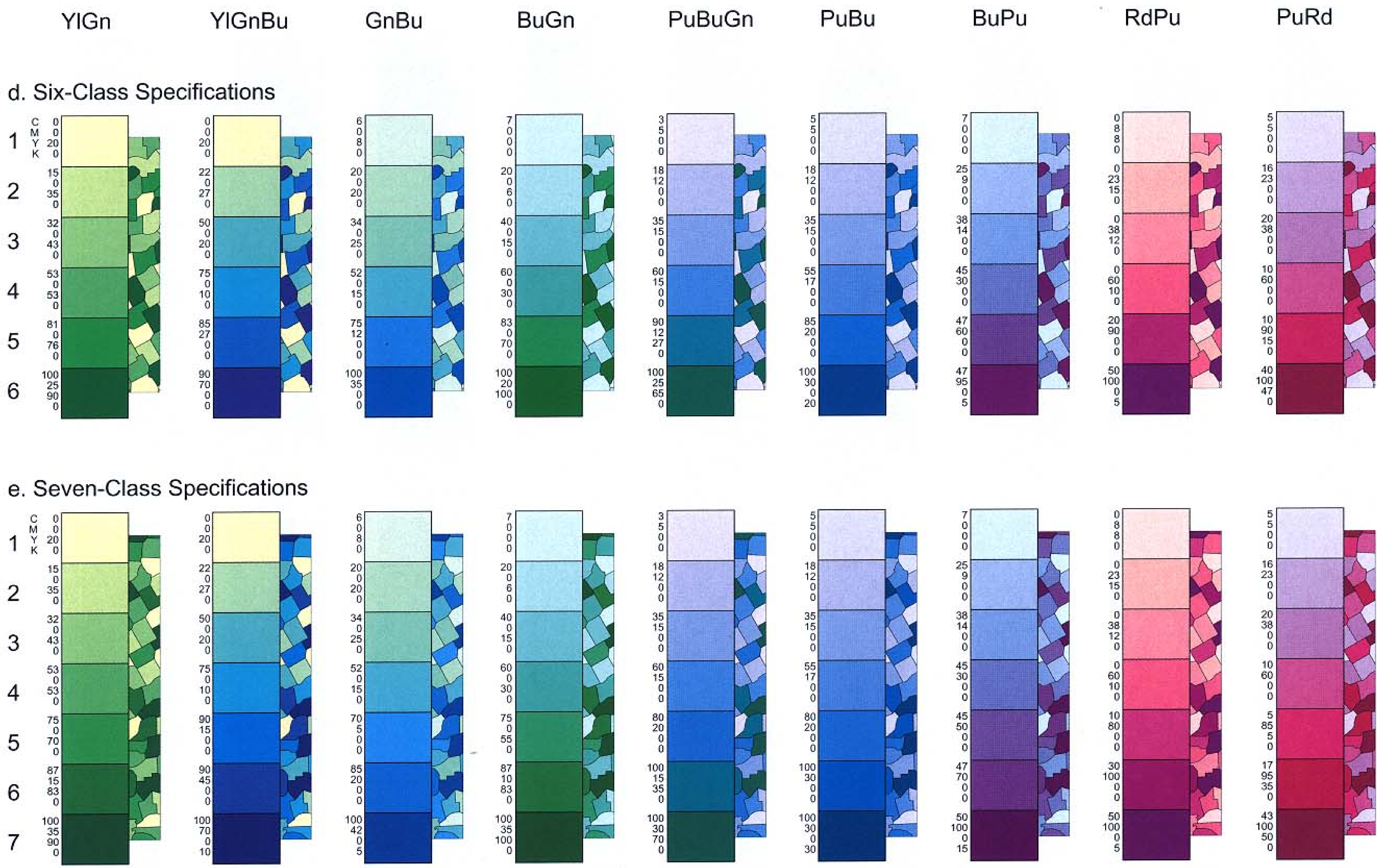


Figure 9. CMYK specifications for nine sequential schemes with hue transitions in ColorBrewer *[three pages]*.



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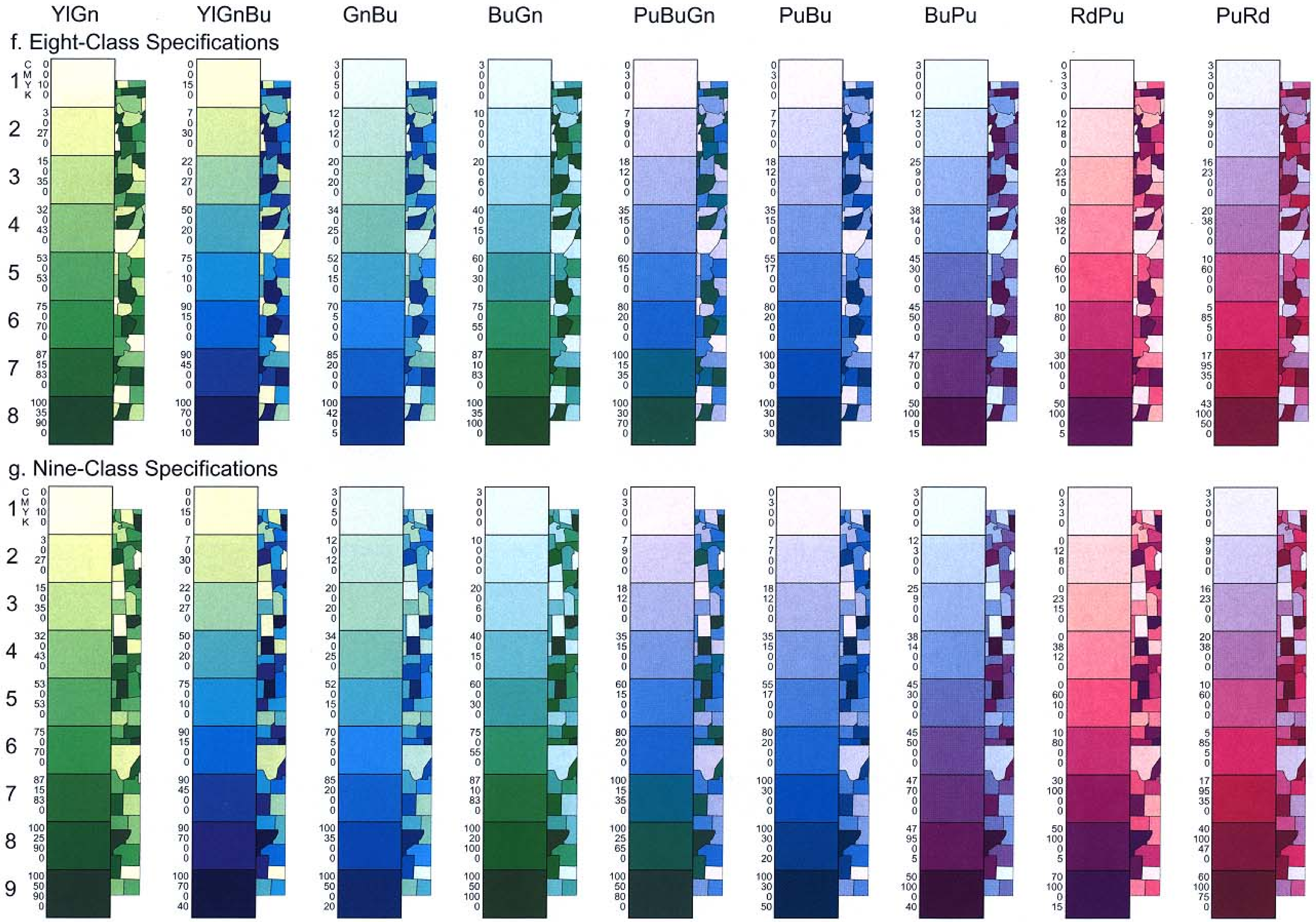

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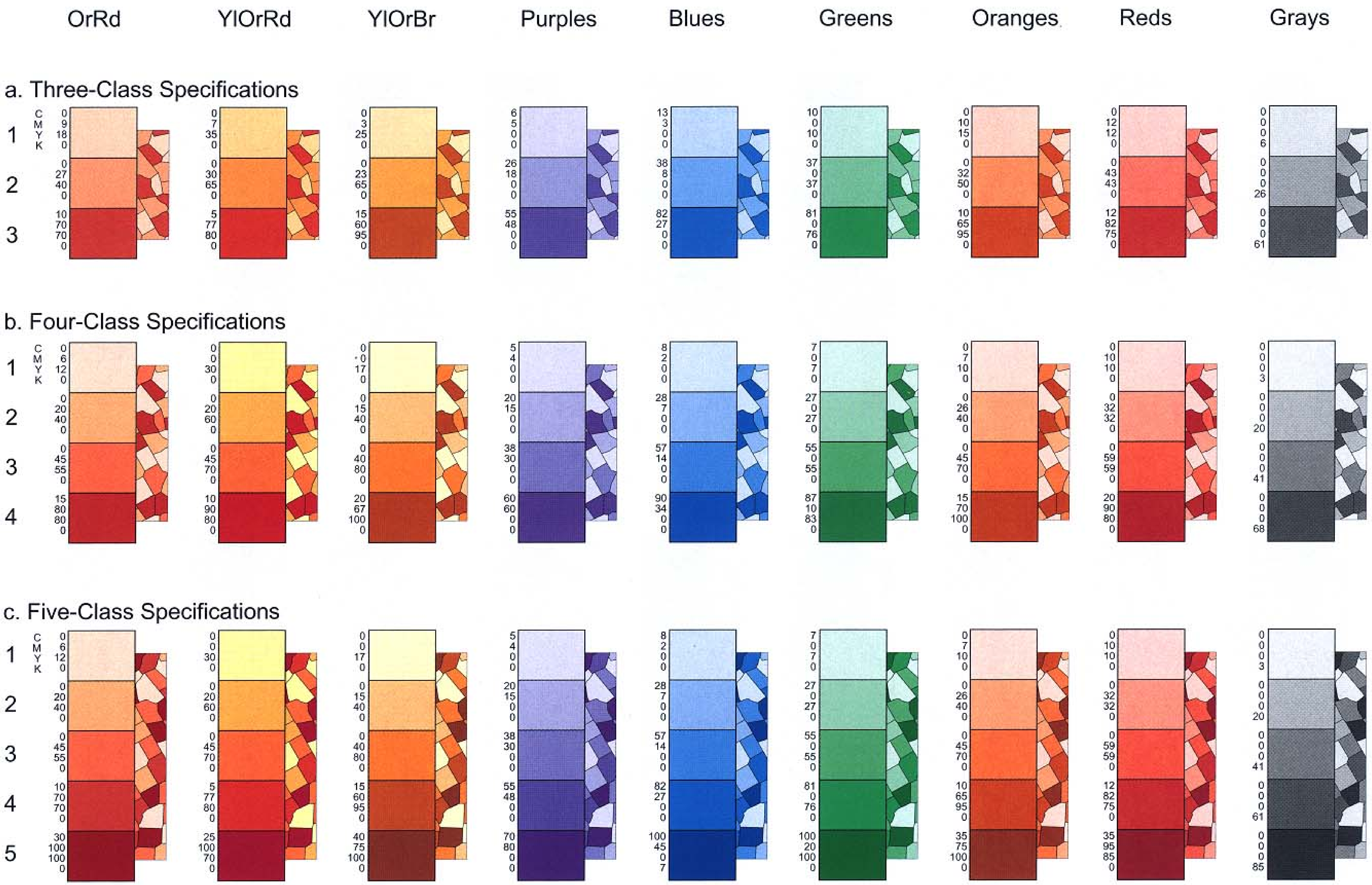
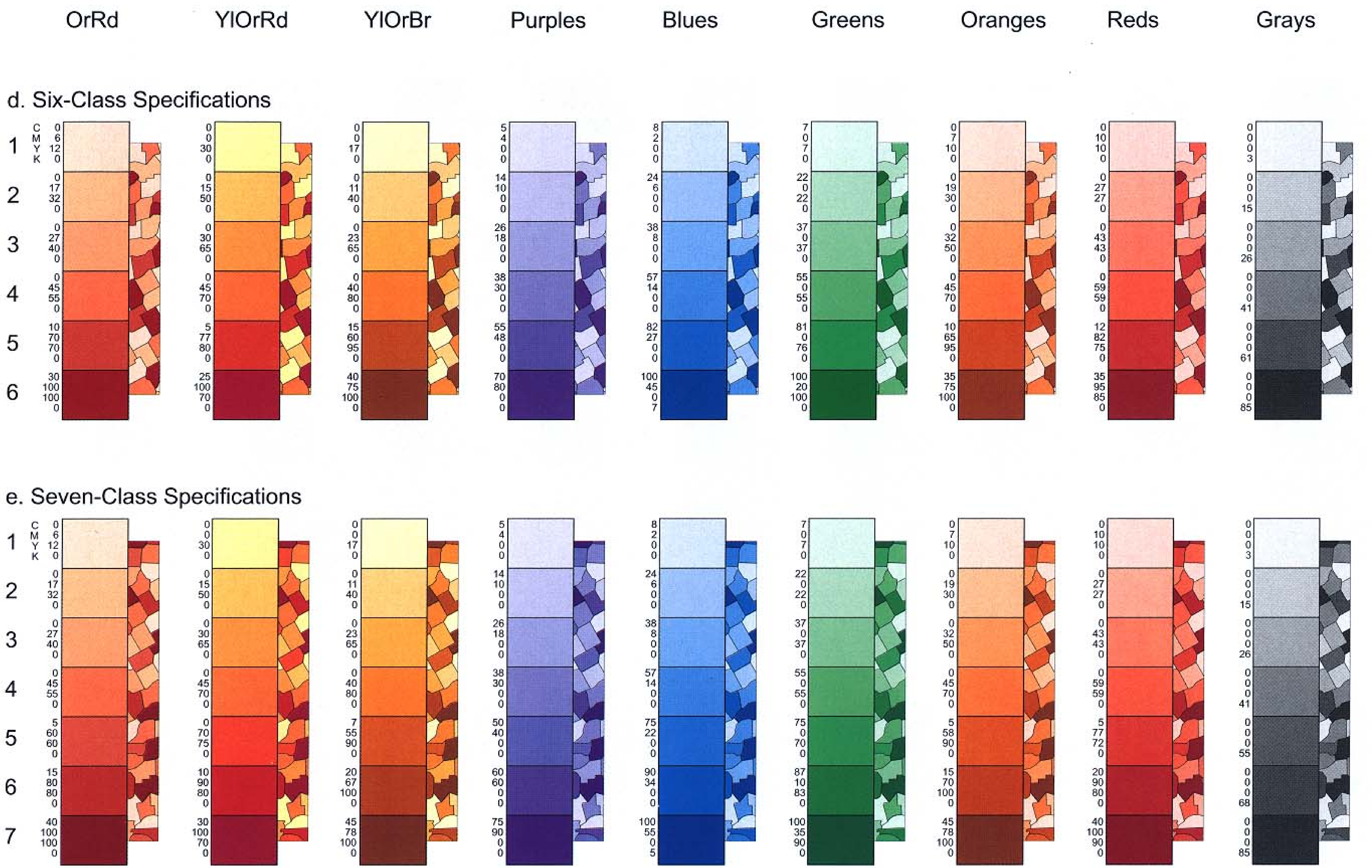


Figure 10. CMYK specifications for additional sequential schemes in ColorBrewer (three with hue transitions and single-hue schemes). *[Three pages].*



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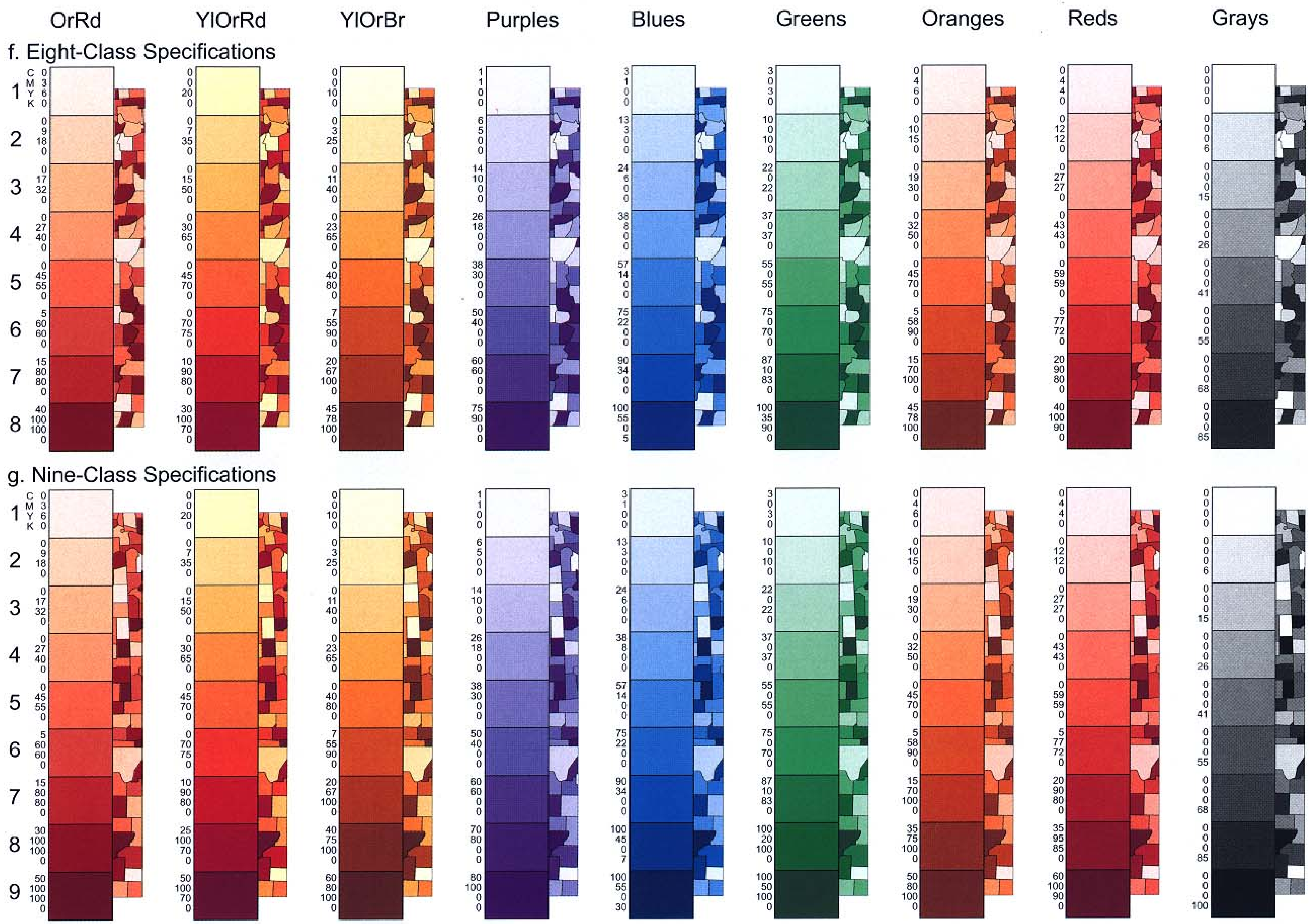

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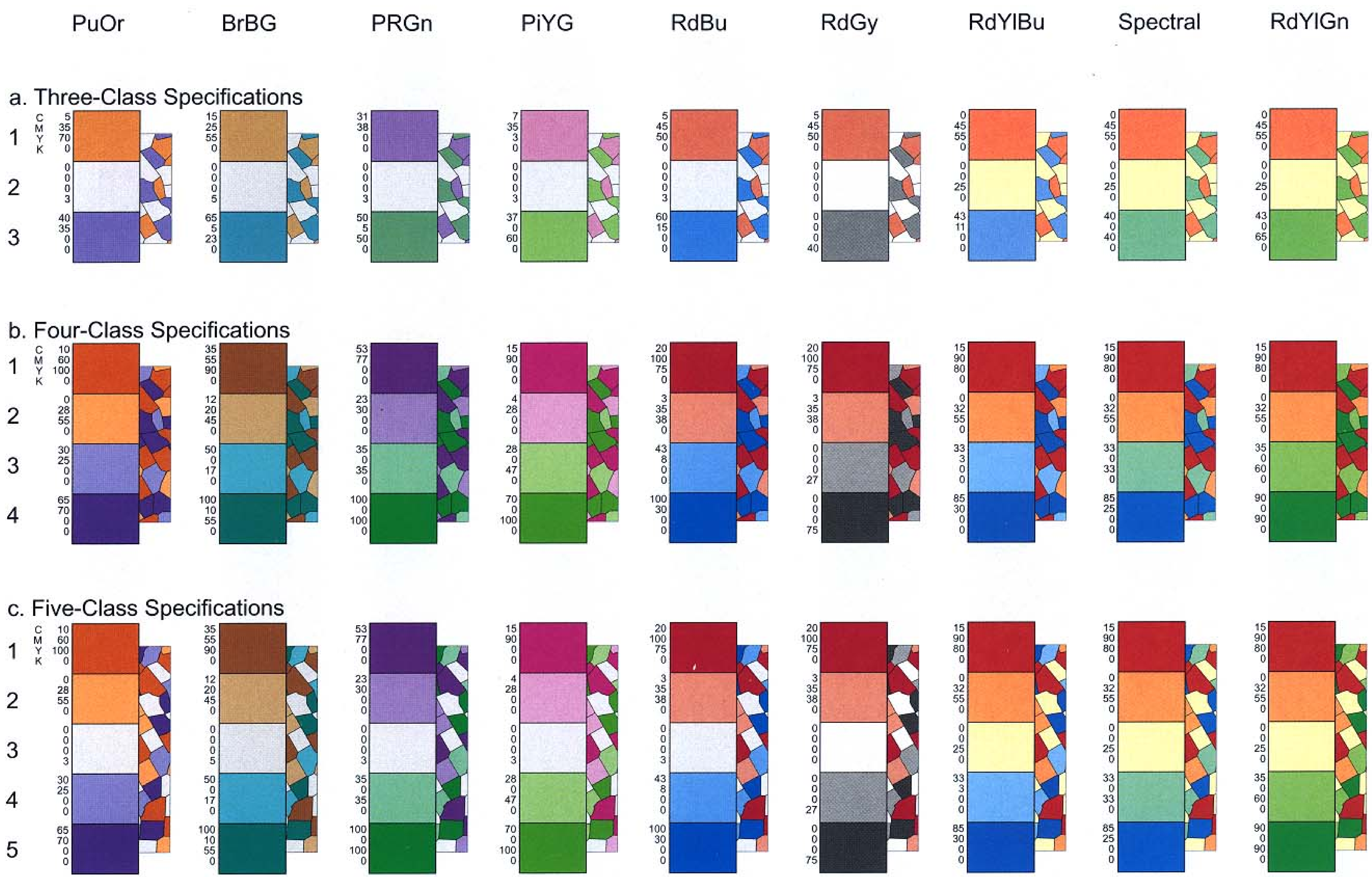
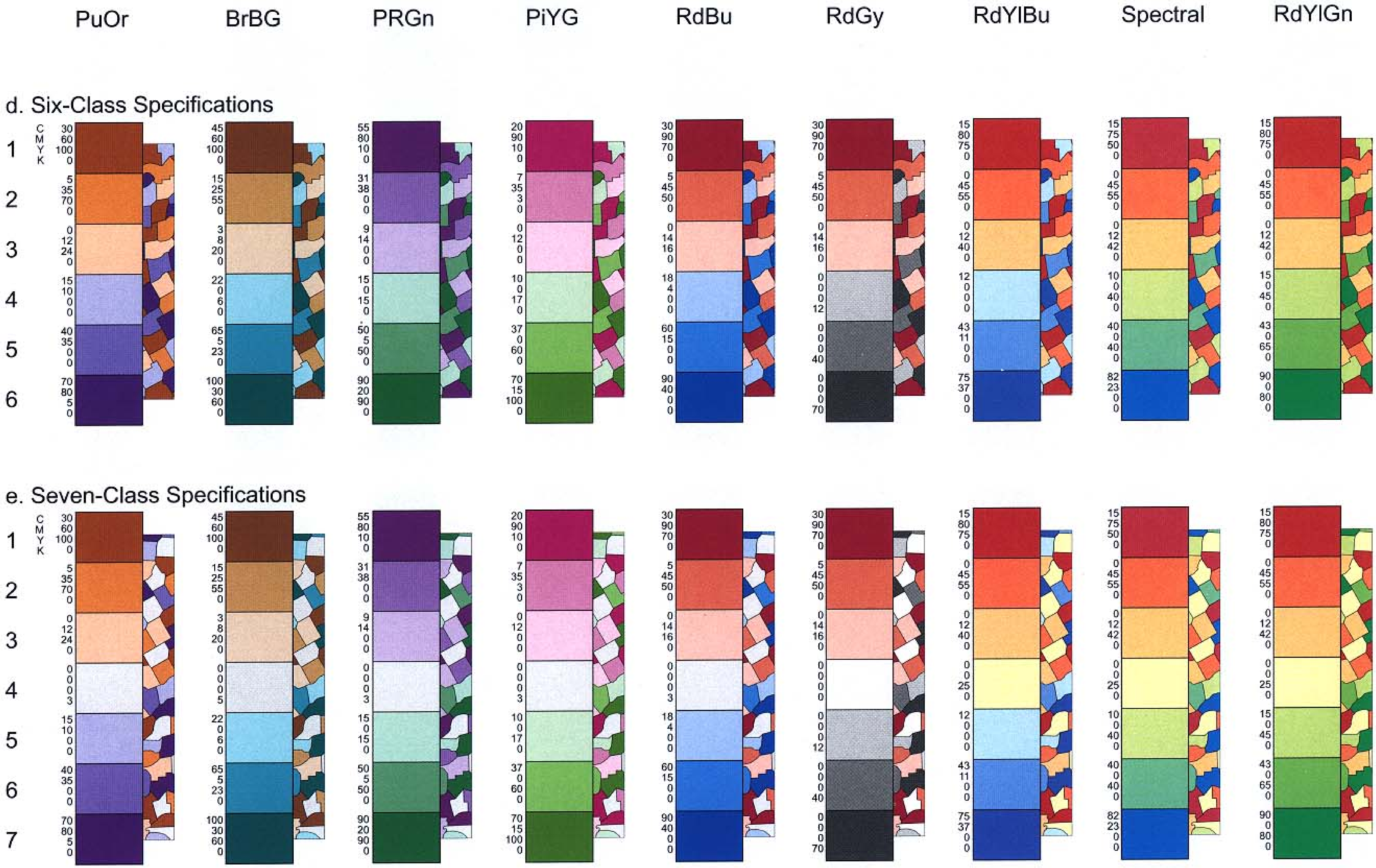


Figure 11. CMYK specifications for diverging schemes in ColorBrewer *[five pages]*.



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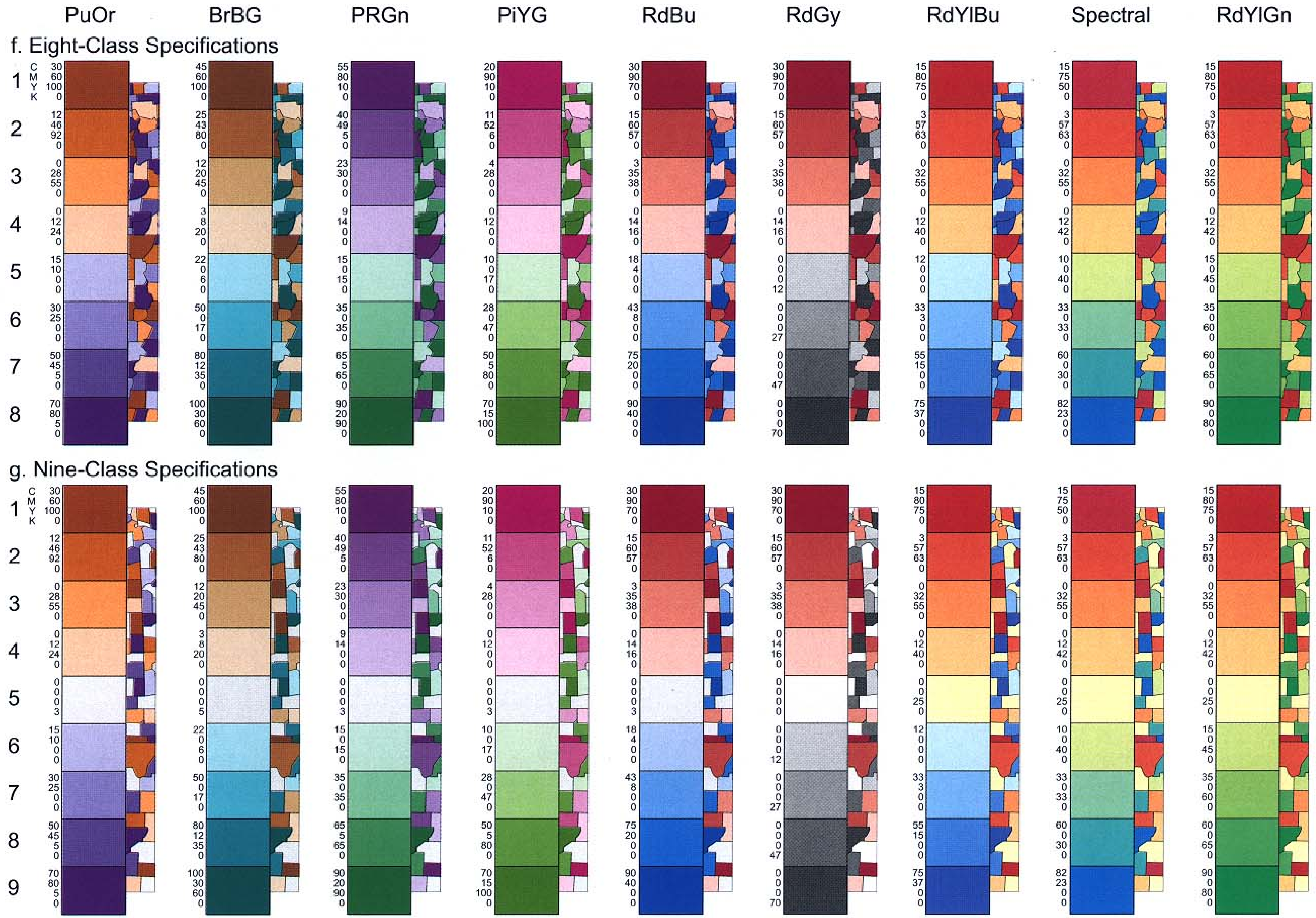

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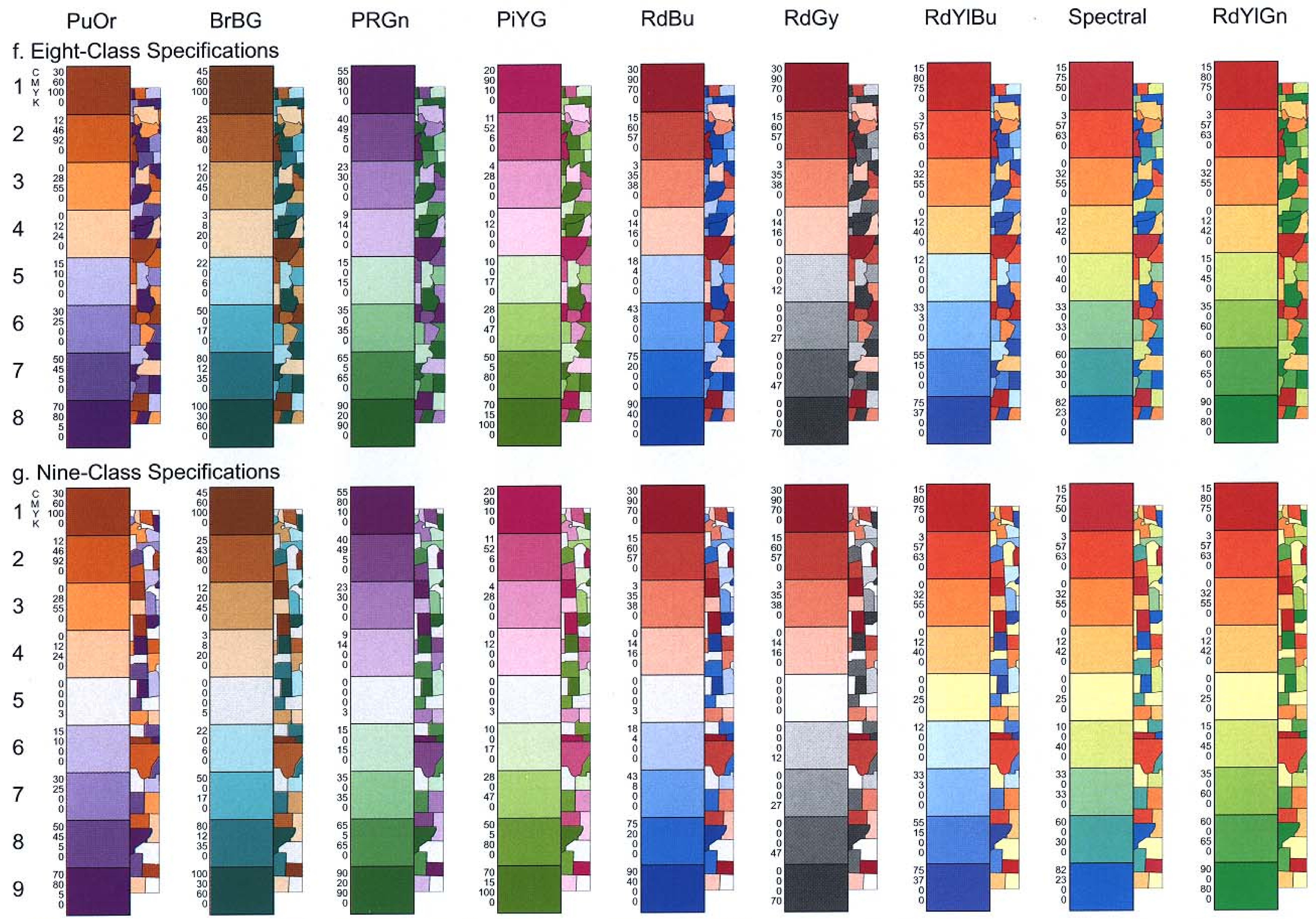

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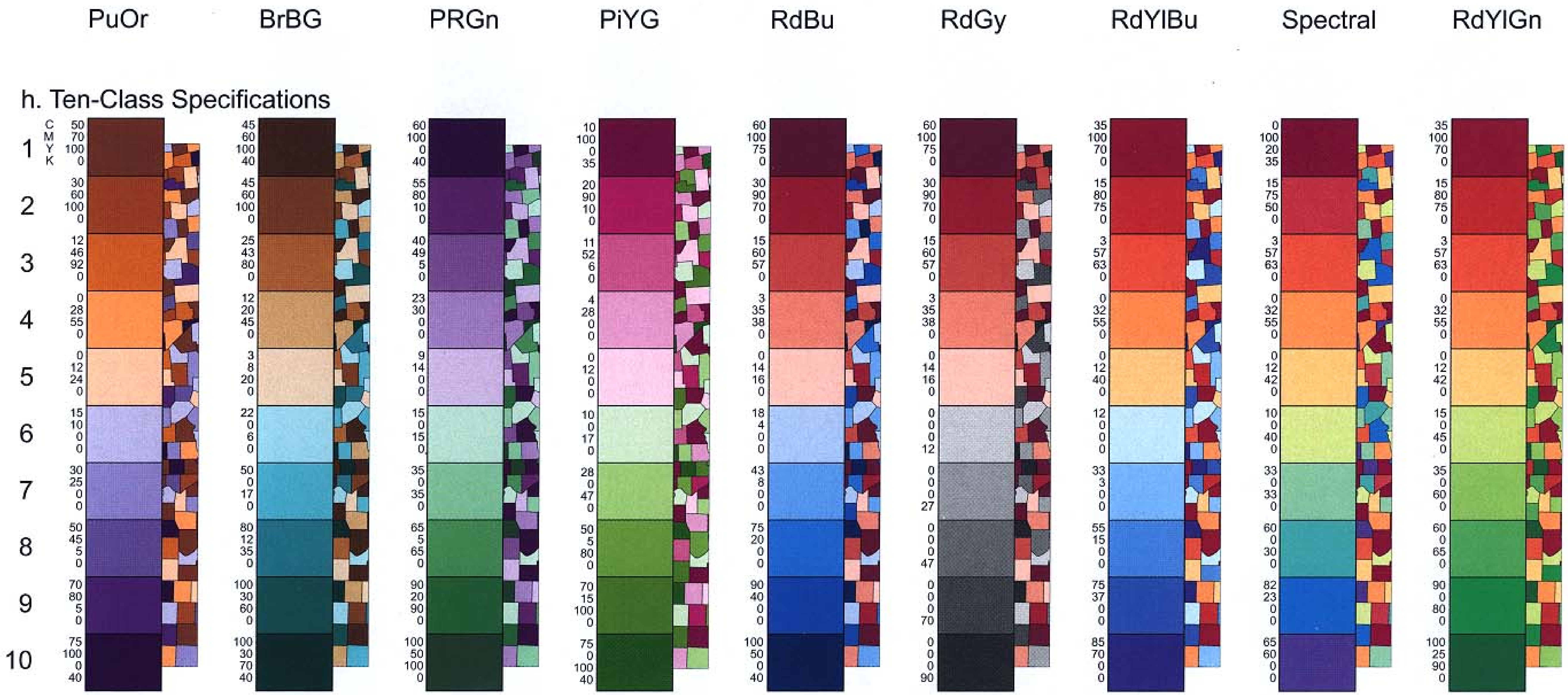

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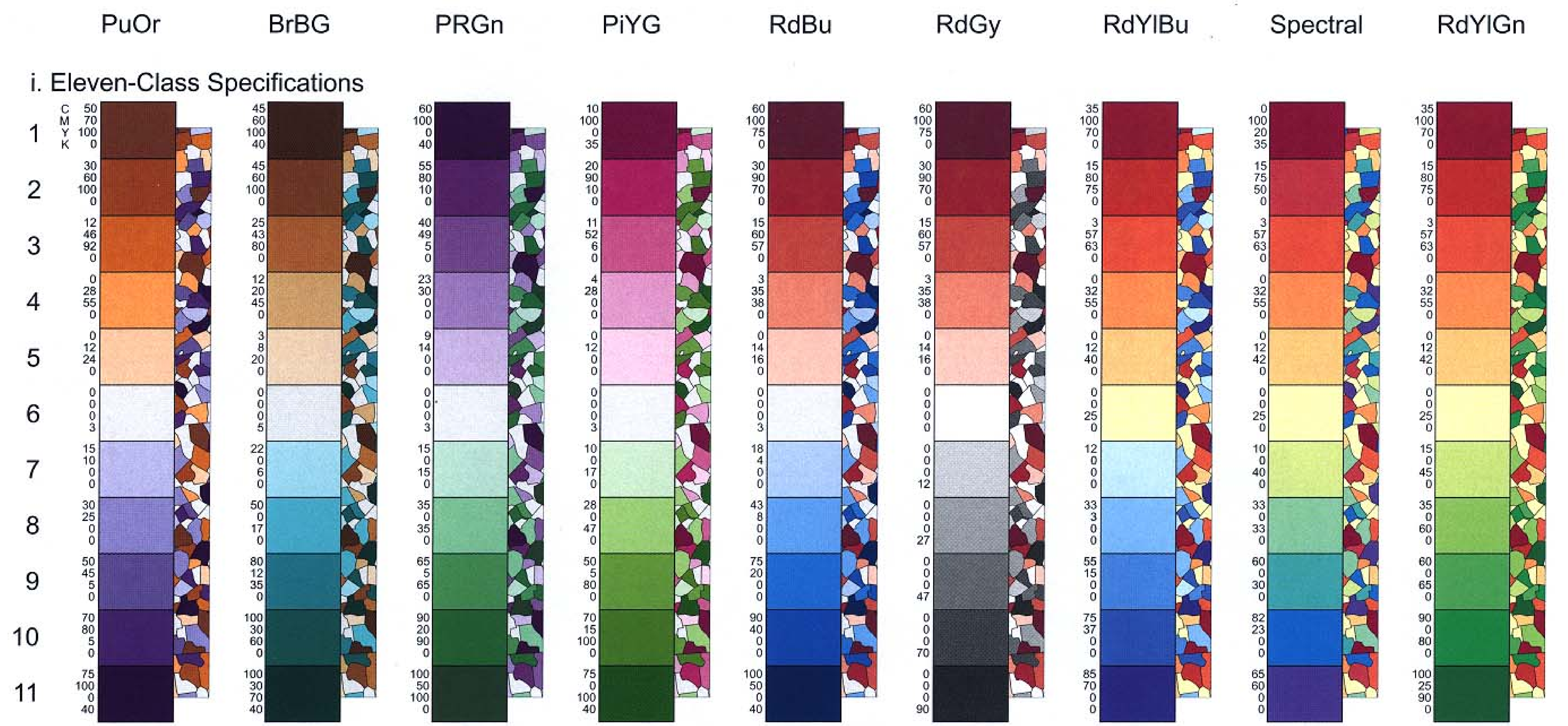

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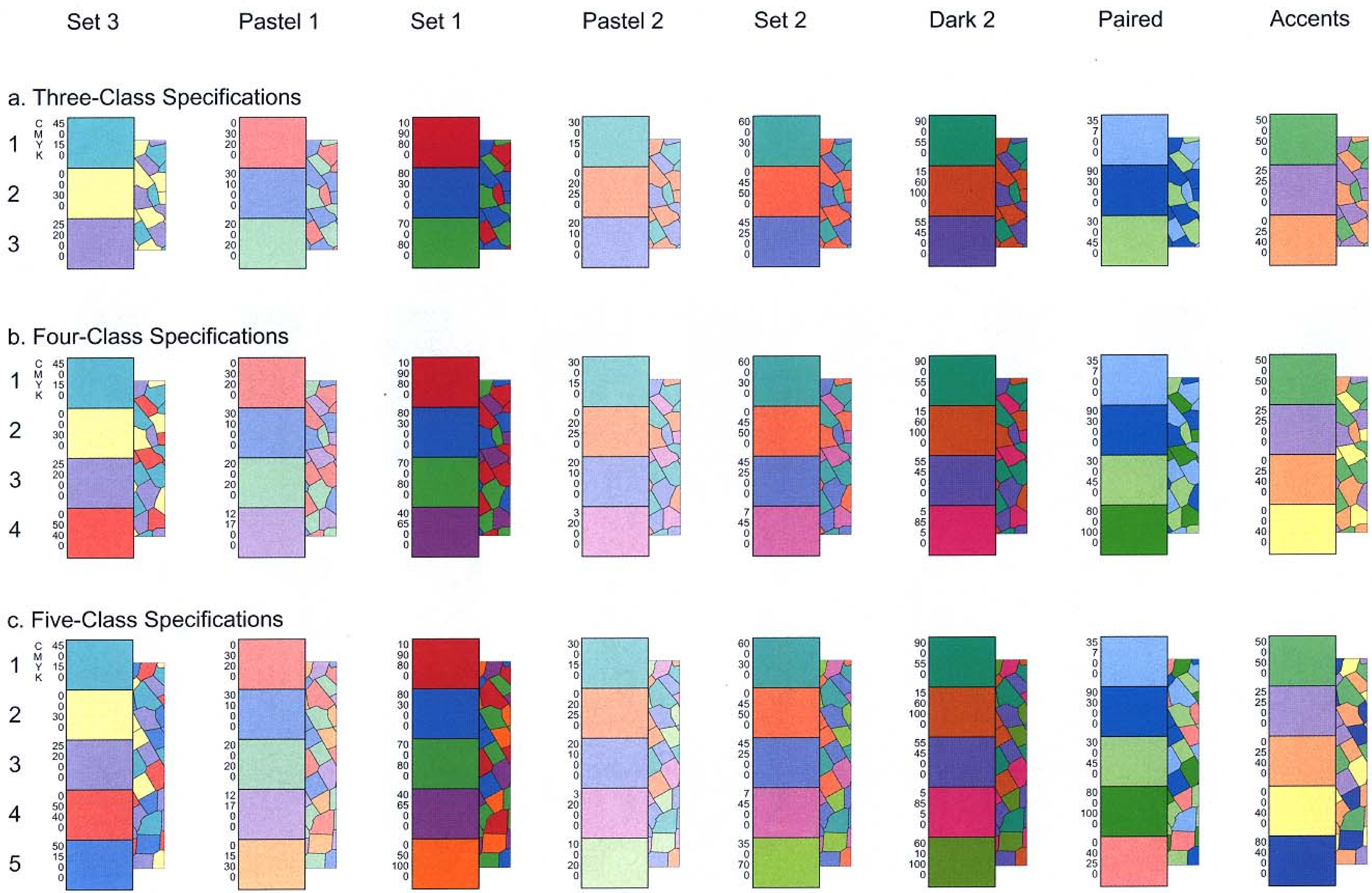
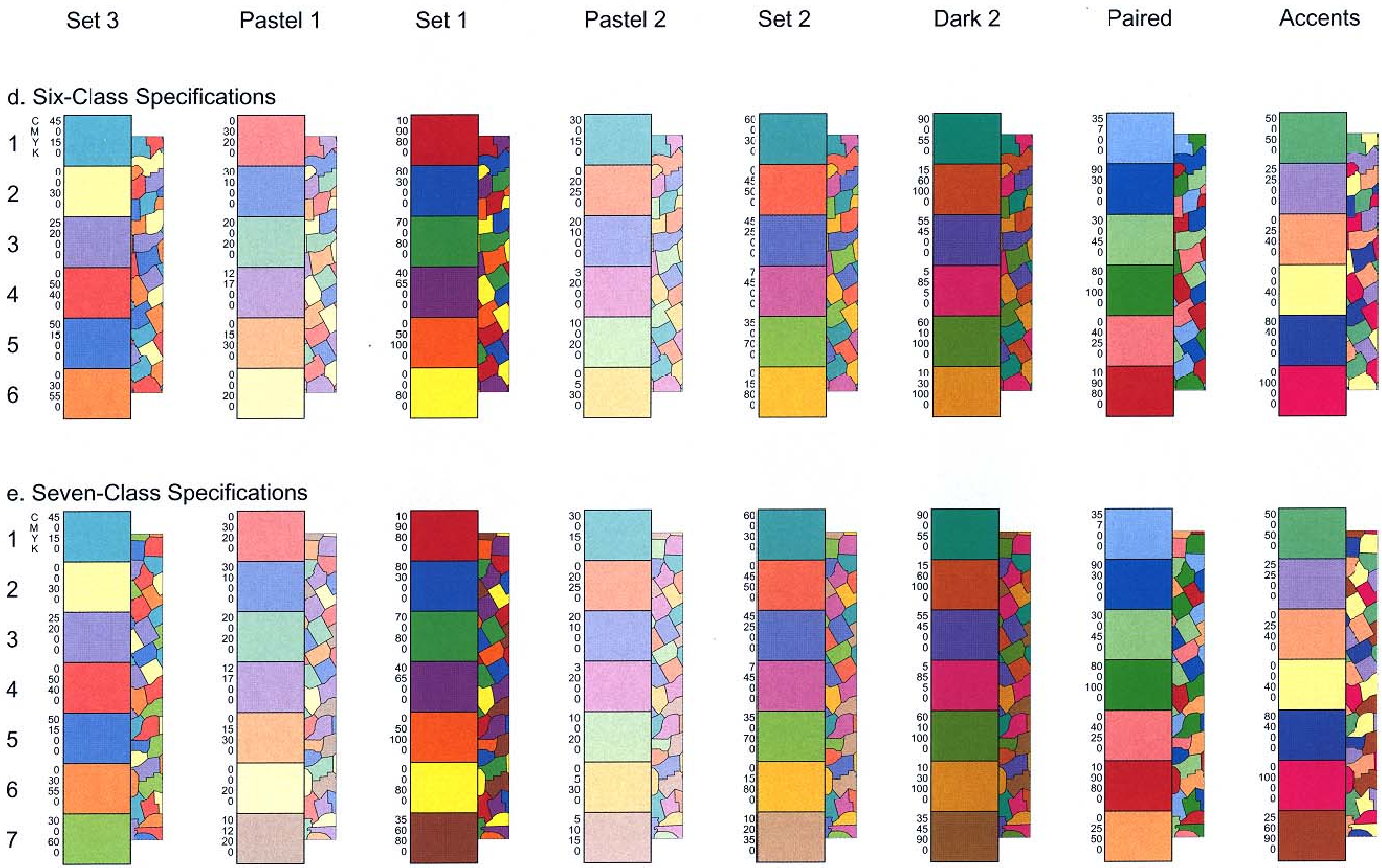


Figure 12. CMYK specifications for qualitative schemes in ColorBrewer *[three pages]*.



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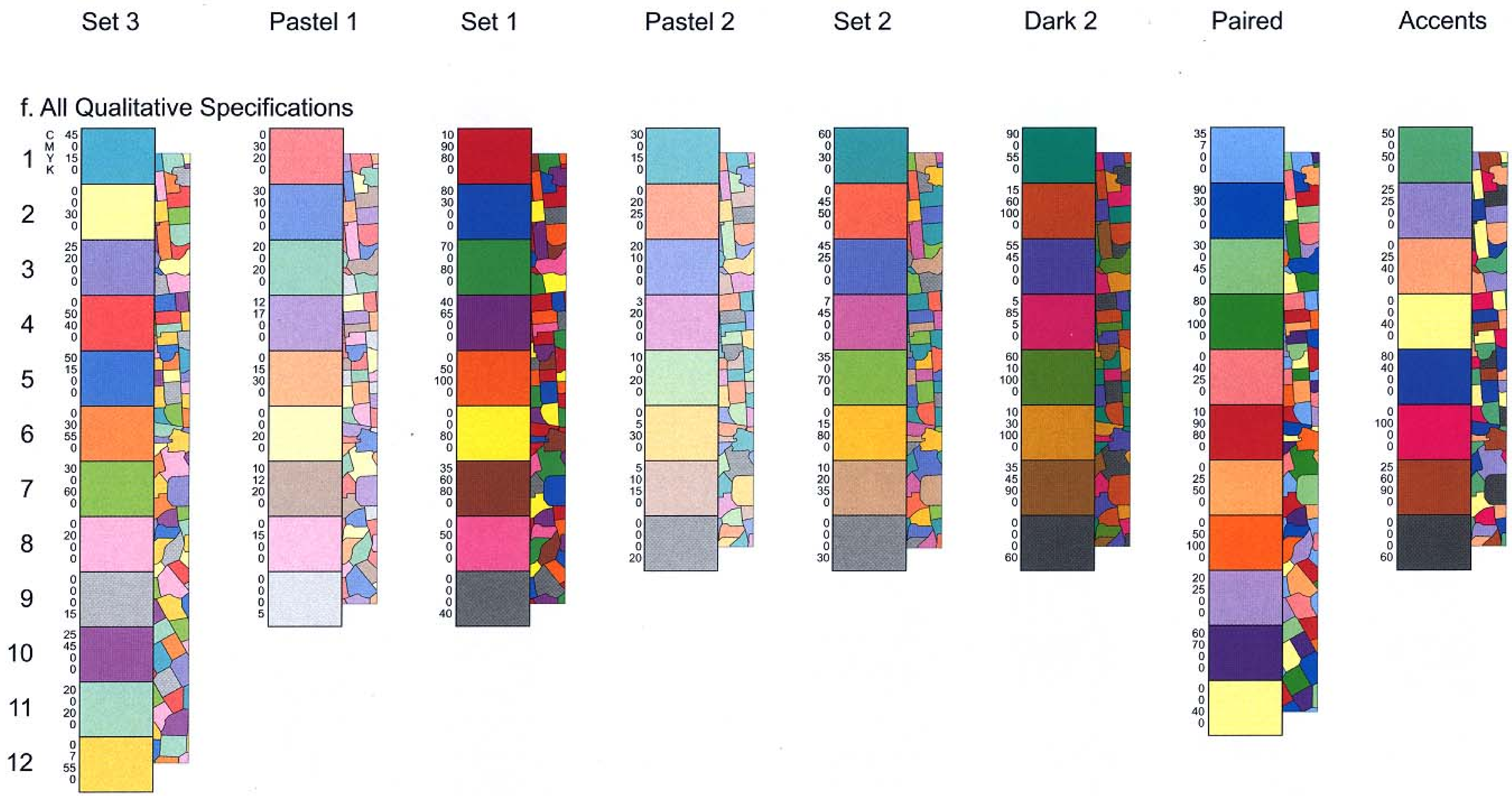

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