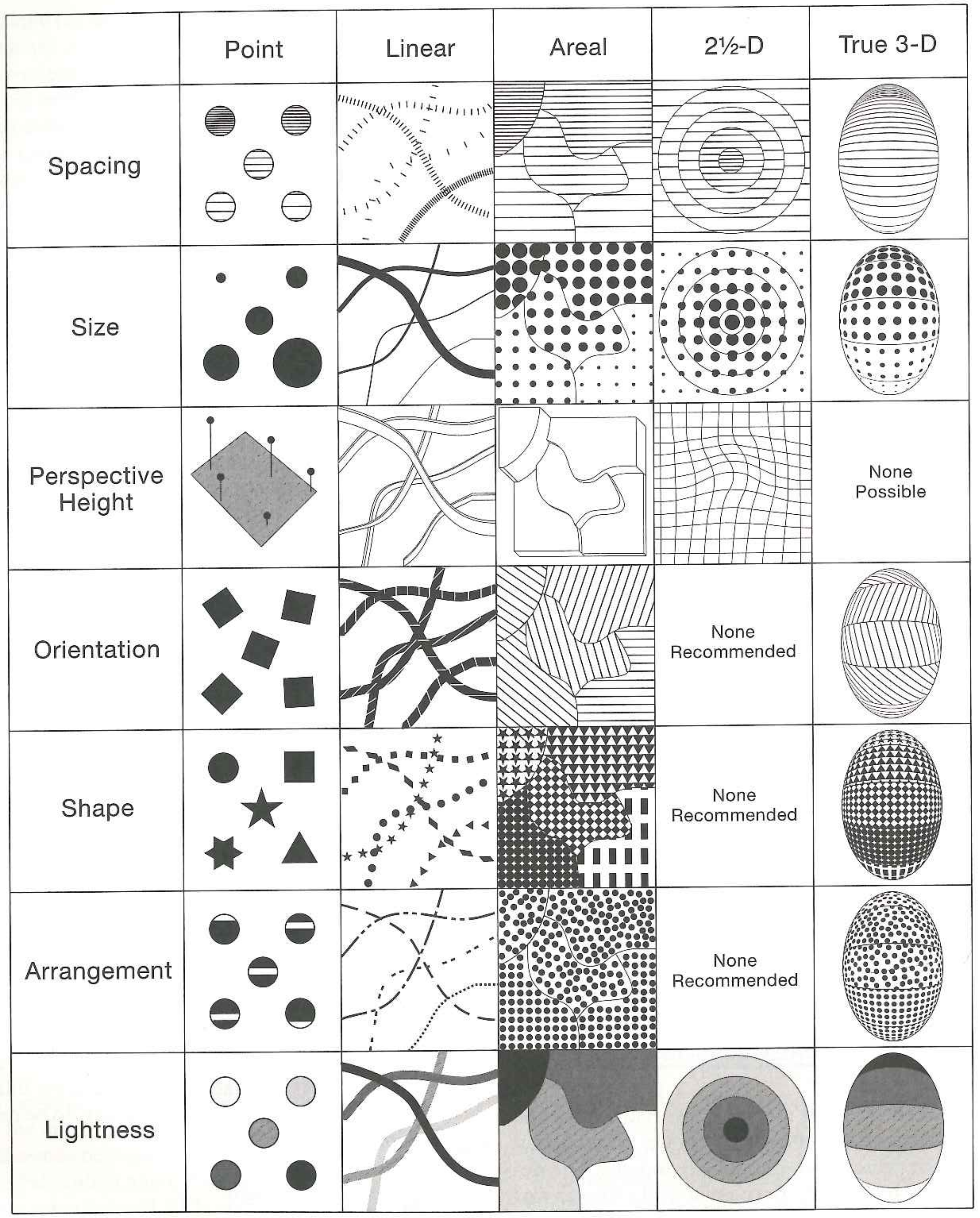

FIGURE 4.3 Visual variables for black-and-white maps. For visual variables for color maps, see Color Plate 4.2.

could be represented by a fencelike structure above each roadway, with the height of the "fence" proportional to traffic flow. In the case of areal and $2^1/_2$-D phenomena, we have already discussed examples for the forest cover data in South Carolina (Figure 4.2). Perspective height cannot be used for true 3-D phenomena because three dimensions are needed to locate the phenomenon being mapped.

...tion and Shape

... size visual variable, the character of the ... isual variable is a function of the kind of ... mena. For linear, areal, and true 3-D phe... ntation refers to the direction of individual ... up the symbol. In contrast, for point phe... ntation refers to the direction of the entire ... (Figure 4.3). (Marks of differing direction could be applied to point symbols, but the small size of point symbols often makes it difficult to see the marks.) Because orientation is most appropriate for representing nominal data, we do not recommend using it for $2^1/_2$-D phenomena, which are inherently numerical. Note that the **shape** visual variable is handled in a fashion similar to orientation.

4.3.5 Arrangement

Understanding the **arrangement** visual variable requires a careful examination of Figure 4.3. For areal and true 3-D phenomena, note that arrangement refers to how marks making up the symbol are distributed; marks for some areas are part of a square arrangement, whereas marks for other areas appear to be randomly placed. For linear phenomena, arrangement refers to splitting lines into a series of dots and dashes, as might be found on a map of political boundaries. Finally, for point phenomena, arrangement refers to changing the position of the white marker within the black symbol.

4.3.6 Hue, Lightness, and Saturation

The visual variables hue, lightness, and saturation are commonly recognized as basic components of color.* **Hue** is the dominant wavelength of light making up a color (the notion of wavelengths of light and the associated electromagnetic spectrum will be considered in detail in Chapter 10). In everyday life, hue is the parameter of color most often used; for example, you might note that one person has on a red shirt and another a blue shirt. Color Plate 4.2 illustrates how various hues can be used to depict spatial phenomena.

Lightness (or **value**) refers to how dark or light a particular color is, while holding hue constant; for example, in Color Plate 4.2, different lightnesses of a green hue are shown. Lightness also can be shown as shades of gray (in the absence of what we commonly would call color), as in Figure 4.3.

Saturation (or **chroma**) can be thought of as a mixture of gray and a pure hue. It is the intensity of a color; for instance, we might speak of different intensities of colorful shirts. This concept is illustrated in Color Plate 4.3, where the areal symbols shown for saturation in Color Plate 4.2 are arranged along a continuum from a desaturated red (grayish red) to a fully saturated red (while holding lightness constant).

* See Brewer (1994a) for a discussion of terminology associated with color.

4.3.7 Some Considerations in Working with Visual Variables

You should bear in mind that Figure 4.3 and Color Plate 4.2 depict only a fraction of the many symbols that could be used to depict the visual variables; for example, either circles or squares might be used to depict point phenomena for the size visual variable. A major group of symbols not shown in the figures are **pictographic symbols**, which are intended to look like the phenomenon being mapped (as opposed to **geometric symbols** such as circles). For instance, Figure 4.4 illustrates the use of different-sized beer mugs to represent the number of microbreweries and brewpubs in each U.S. state. Pictographic symbols are often used in children's atlases.

Also keep in mind that the visual variables can serve as basic building blocks of more complex representations. For example, Figure 4.5 illustrates how the visual

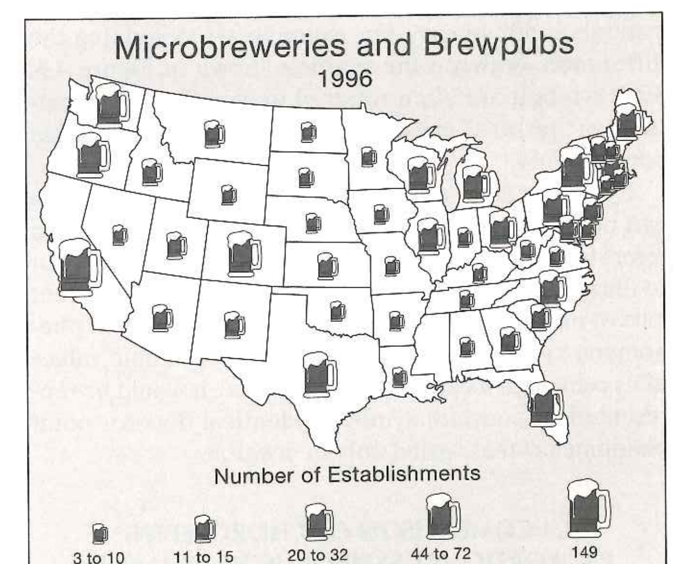

FIGURE 4.4 Using a pictographic visual variable (beer mugs) to represent the number of microbreweries and brewpubs in each U.S. state. (For similar data, see *http://brewpubzone.com.*)

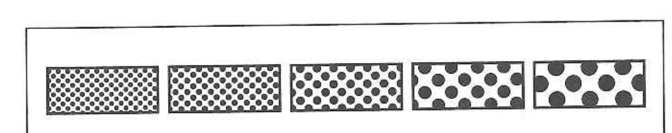

FIGURE 4.5 Combining the visual variables spacing and size. (After MacEachren 1994a, p. 26.)

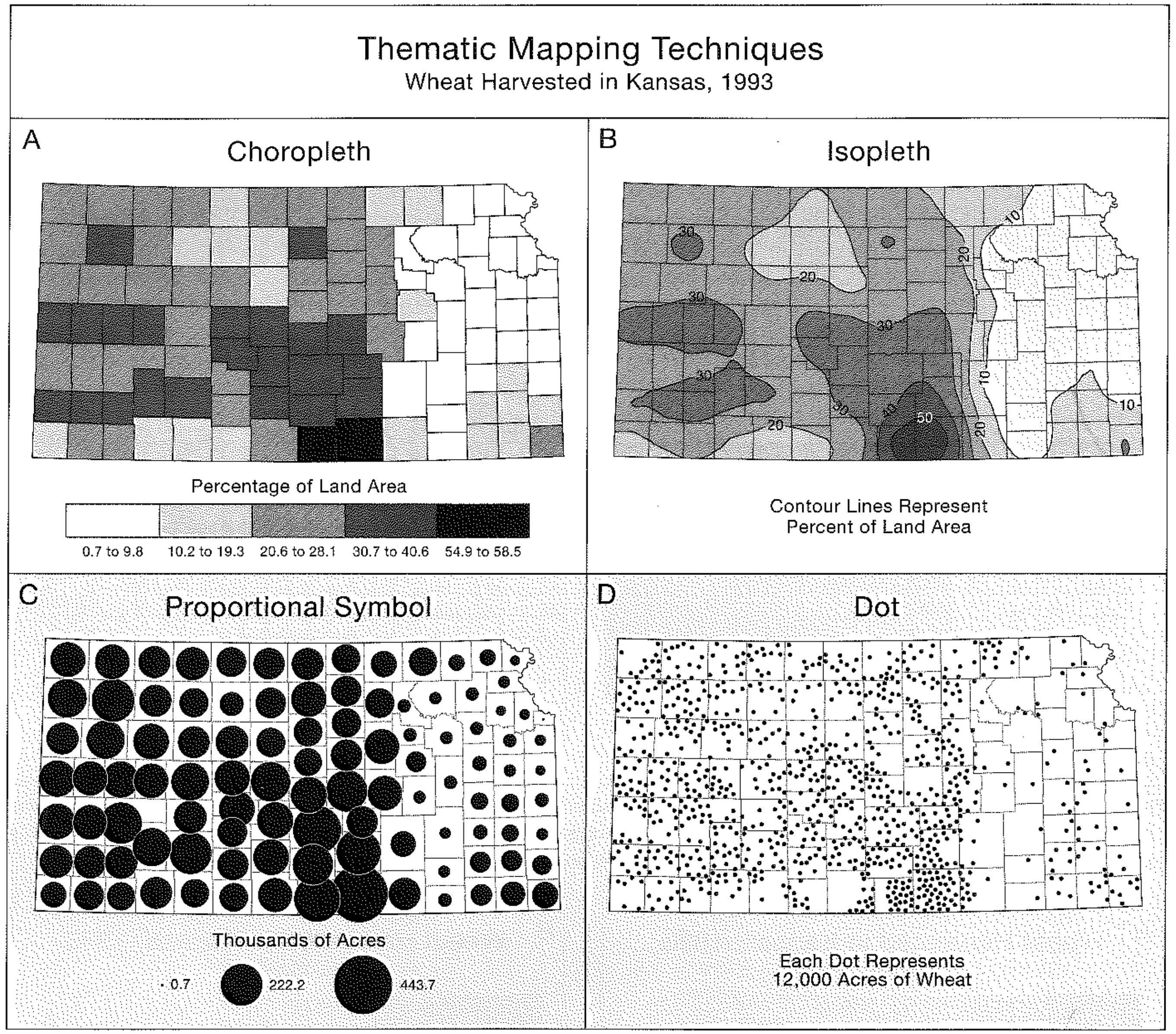

FIGURE 4.9 A comparison of basic thematic mapping techniques: (A) choropleth, (B) isopleth, (C) proportional symbol, and (D) dot maps. The choropleth and isopleth maps are based on the percentage of land area from which wheat was harvested, whereas the proportional symbol and dot maps are based on the total acres of wheat harvested.

point locations. These locations can be *true points,* such as an oil well, or *conceptual points,* such as the center of an enumeration unit for which data have been collected; the latter is the case with the wheat harvested data. In contrast to the standardized data depicted on choropleth maps, proportional symbol maps are normally used to display raw totals. Thus, the magnitudes for acres of wheat harvested are depicted as proportional circles in Figure 4.9C. (Note that the visual variable used here is *size.*)

The raw totals depicted on proportional symbol maps provide a useful complement to the standardized data shown on choropleth maps. Raw totals are important because a high proportion or rate might not be meaningful if there is not also a high raw total. As an example, consider counties of the same size having populations of 100 and 100,000, in which 1 and 1,000 people, respectively, have some rare form of cancer. Dividing the number of cancer cases by the population yields the same proportion of people suffering from cancer (0.01), but the rate for the less populous county would be of lesser interest to the epidemiologist.

Although the proportional symbol map is a better choice than the choropleth map for depicting raw totals, care should be taken in using it. To illustrate, consider map D of Figure 4.7, which displays the hypothetical wheat data using proportional circles. Note that all circles in region U are larger than those in region T. This could lead to the mistaken impression that counties in region U are more important in terms of wheat production than those in region T. Counties in region U might be more important to a politician in assigning tax dollars (more wheat harvested indicates a greater tax is appropriate), but in terms of the density of wheat harvested, regions T and U are identical.

4.4.3 Isopleth Map

An **isarithmic map** (or **contour map**) is created by interpolating a set of isolines between sample points of known values; for example, we might draw isolines between temperatures recorded for individual weather stations. The **isopleth map** is a specialized type of isarithmic map in which the sample points are associated with enumeration units. It is an appropriate alternative to the choropleth map when one can assume that the data collected for enumeration units are part of a smooth continuous ($2\frac{1}{2}$-D) phenomenon. For example, in the case of the wheat data, it might be argued that the proportion of land in wheat changes in a relatively gradual (smooth) fashion, as opposed to changing just at county boundaries (as on the choropleth map).

In a fashion similar to a choropleth map, an isopleth map also requires standardized data. Referring again to the hypothetical raw totals shown in Figure 4.7A, imagine drawing contours through such data. High-valued contour lines would tend to occur in region U, where there are high values in the data; but as has already been shown for the choropleth case, region U is really no different from region T. Dividing the raw totals by the area of each enumeration unit would result in standardized data that could be appropriately contoured.

The isopleth map resulting from contouring the standardized Kansas wheat data is shown in Figure 4.9B. (Again, note that the visual variable lightness has been used.) Although this map might be more representative of the general distribution of wheat harvested than the choropleth map, the assumption of continuity and the use of county-level data produce some questionable results. For example, note the island of higher value near the center of the extreme southeastern county (Cherokee). In reality, it seems unlikely that you would find a higher value here; the high value is more likely a function of the fact that the centers of counties were used as a basis for contouring and Cherokee's value was higher than any of the surrounding counties. Note that a similar problem occurs within two northern counties (Figure 4.9B). The dot map could be a solution to this type of problem.

4.4.4 Dot Mapping

To create a **dot map**, one dot is set equal to a certain amount of a phenomenon, and dots are placed where that phenomenon is most likely to occur. The phenomenon might actually cover an area or areas (e.g, a field or fields of wheat), but for the sake of mapping, the phenomenon is represented as located at points. Constructing an accurate dot map requires collecting ancillary information that indicates where the phenomenon of interest (wheat, in our case) is likely found. For the wheat data, this was accomplished using the cropland category of a land use/land cover map (the detailed procedures are described in Chapter 17). The resulting dot map is shown in Figure 4.9D. (In this case, the visual variable *location* is used.) Clearly, the dot map is able to represent the underlying phenomenon with much more accuracy than any of the other methods we have discussed. Also note that parts of the distribution exhibit sharp discontinuities that would be difficult to show with the isopleth method (which presumes smooth changes).

4.4.5 Discussion

An examination of Figure 4.9 reveals that each of the four maps provides a quite different picture of wheat harvested in the state of Kansas. Which method is used should depend on the purpose of the map. If the purpose is to focus on "typical" county-level information, then the choropleth and proportional symbol maps are appropriate. The choropleth map provides standardized information, whereas the proportional symbol map provides raw total information. It must be emphasized that neither map depicts the detail of the underlying phenomenon, which is unlikely to follow enumeration unit boundaries.

When data are collected in the form of enumeration units, the dot and isopleth methods should be considered as two possible solutions for representing an underlying phenomenon that is not coincident with enumeration unit boundaries. In the case of the wheat data, the dot method is probably the more appropriate approach because it can capture some of the discontinuities in the phenomenon. The isopleth method, however, could probably be improved on with a finer grid of enumeration units (e.g., townships);* of course, this would also be true of the choropleth and proportional symbol maps.

It must be noted that we have only considered four of the more common methods of thematic mapping. One alternative would be a **dasymetric map**, which, like the dot map, can show very detailed information, but uses standardized data. We will cover the dasymetric map in

* Data at the township level are not released to the general public to protect the confidentiality of individual farm production.

Chapter 17. Another alternative would be to modify the proportional symbol map by making the area of the circle that is filled in proportional to the percent of land area from which wheat is harvested—this creates what is called a **pie chart**. Finally, we should keep in mind that if maps are to be viewed in an interactive graphics environment, the mapmaker will have the option of showing several of them, thus providing the user with various perspectives on the distribution of wheat harvested in Kansas.

4.5 SELECTING VISUAL VARIABLES FOR CHOROPLETH MAPS

In the preceding section, the visual variable lightness was utilized for the choropleth map. An examination of Figure 4.3 and Color Plate 4.2 reveals that there are a number of other visual variables that might be used to represent a phenomenon that is treated as areal in nature. This section considers how we might select among these visual variables. The basic solution is to select a visual variable that appears to "match" the level of measurement of the data. For illustrative purposes, we again use the Kansas wheat data.

The specific visual variables we discuss are illustrated in Figure 4.10 and Color Plate 4.4. In examining these figures, note that they depict classed maps using *maximum-contrast symbolization,* which means that symbols for classes have been selected so that they are maximally differentiated from one another. An alternative approach would be to create an unclassed map in which symbols are directly proportional to the value for each enumeration unit (as in Figure 1.6B). The maximum-contrast approach is used here because it is common and more easily constructed (particularly in the case of the size visual variable).

In addition to discussing Figure 4.10 and Color Plate 4.4, we also consider Figure 4.11, which summarizes the use of visual variables for various levels of measurement. Note that the body of this figure is shaded and labeled to indicate various levels of acceptability: Poor (P), Marginally effective (M), and Good (G). MacEachren (1994a, 33) developed a similar figure, which he appeared to apply to all kinds of spatial phenomena. We use Figure 4.11 only for areal phenomena; as an exercise, you might consider developing such a figure for other kinds of phenomena.

We'll consider the perspective height and size visual variables first because they have the greatest potential for logically representing the numerical data depicted on choropleth maps. Use of perspective height produces what is commonly termed a *prism map* (Figure 4.10A). In Figure 4.11, note that perspective height is the only visual variable receiving a "good" rating for numerical data. The justification is that an unclassed map based on perspective height can portray ratios correctly (a data value twice as large as another will be represented by a prism twice as high), and that readers perceive the height of resulting prisms as ratios (Cuff and Bieri 1979).

There are two problems, however, that complicate the extraction of numerical information from prism maps. One is that tall prisms sometimes block smaller prisms. A solution to this problem is to rotate the map so that blockage is minimized; for example, the map in Figure 4.10A has been rotated so that the view is from the lower valued northeast. A second solution to the blockage problem is to manipulate the map in an interactive graphics environment. If a flexible program is available, it might even be possible to suppress selected portions of the distribution so that other portions can be seen. A third solution is to use the perspective height variable but also symbolize the distribution with another visual variable; for example, Figure 4.10D might be displayed in addition to Figure 4.10A.

Another problem with prism maps is that rotation might produce a view that is unfamiliar to readers who normally see maps with north at the top. This problem can be handled by showing a second map (as suggested earlier) or by using an overlay of the base to show the amount of rotation (as in Figure 4.2C).

The size visual variable is illustrated in Figure 4.10B; note that here the size of individual marks making up the areal symbol has been varied. Size can be considered appropriate for representing numerical relations because circles can be constructed in direct proportion to the data (a data value twice another can be represented by a circle twice as large in area). Furthermore, readers should see the circles in approximately the correct relations. (However, we will see in Chapter 16 that a correction factor might have to be implemented to account for underestimation of larger circles.)

Although some cartographers (most notably Bertin) have used this sort of argument to promote the use of the visual variable size on choropleth maps, two problems are apparent. First, it is questionable whether map users actually consider the sizes of circles when used as part of an areal symbol. Users might analyze circle size when trying to acquire specific information, but it seems unlikely that they would do so when analyzing the overall map pattern. Rather, it is more likely that they would perceive areas of light and dark, in a fashion similar to the lightness visual variable. Second, many cartographers (and presumably map users) find the coarseness of the resulting symbols unacceptable—they would prefer the fine tones shown in Figure 4.10D. The latter problem in particular caused us to give the size variable only a moderate rating for portraying numerical data (Figure 4.11).

Note also that we have given both perspective height and size only moderate ratings for portraying ordinal data. The logic is that if such variables are used to illustrate numerical relations, users might perceive such relations when only ordinal relations are intended.

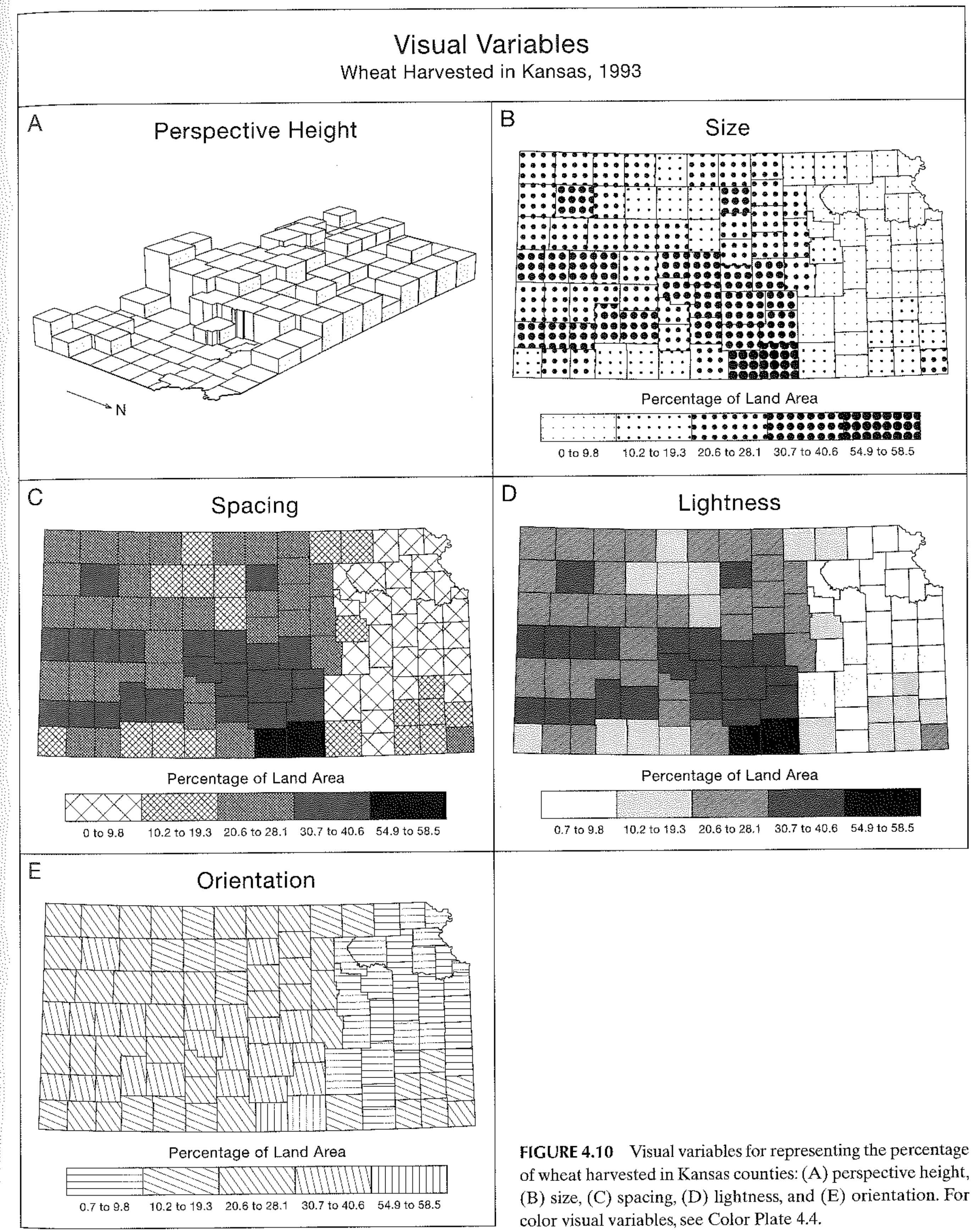

FIGURE 4.10 Visual variables for representing the percentage of wheat harvested in Kansas counties: (A) perspective height, (B) size, (C) spacing, (D) lightness, and (E) orientation. For color visual variables, see Color Plate 4.4.