13:167–186. Hargis et al. examine whether commonly used landscape metrics can distinguish between landscapes that are fragmented and those that are not. This paper can provide a useful basis for a discussion of the behavior of landscape metrics.

LI, H., AND J. F. REYNOLDS. 1993. A new contagion index to quantify spatial patterns of landscapes. *Landscape Ecology* 8:155–162.

LI, H., AND J. F. REYNOLDS. 1994. A simulation experiment to quantify spatial heterogeneity in categorical maps. *Ecology* 75:2446–2455.

*LI, H., AND J. F. REYNOLDS. 1995. On definition and quantification of heterogeneity. *Oikos* 73:280–284. An excellent discussion of what is meant by heterogeneity; it should be read by all those beginning to consider the causes or consequences of spatial pattern.

MCGARIGAL, K., AND B. J. MARKS. 1995. Fragstats: Spatial analysis program for quantifying landscape structure. USDA Forest Service General Technical Report PNW-GTR-351. USDA Forest Service, Pacific Northwest Research Station, Portland, OR.

O'NEILL, R. V., J. R. KRUMMEL, R. H. GARDNER, G. SUGIHARA, B. JACKSON, D. L. DEANGELIS, B. T. MILNE, M. G. TURNER, B. ZYGMUNT, S. CHRISTENSEN, V. H. DALE, AND R. L GRAHAM. 1988. Indices of landscape pattern. *Landscape Ecology* 1: 153–162.

PIELOU, E. C. 1975. *Ecological Diversity*. Wiley-Interscience, New York.

*RIITTERS, K. H., R. V. O'NEILL, C. T. HUNSAKER, J. D. WICKHAM, D. H. YANKEE, S. P. TIMMONS, K. B. JONES, AND B. L. JACKSON. 1995. A factor analysis of landscape pattern and structure metrics. *Landscape Ecology* 10:23–40. Provides the first comprehensive analysis of a wide range of landscape metrics, demonstrating how strongly many of the metrics are correlated and identifying five independent aspects of pattern.

RIITTERS, K. H., R. V. O'NEILL, J. D. WICKHAM, AND K. B. JONES. 1996. A note on contagion indices for landscape analysis. *Landscape Ecology* 11:197–202.

ROMME, W. H. 1982. Fire and landscape diversity in subalpine forests of Yellowstone National Park. *Ecological Monographs* 52:199–221.

ROMME, W. H., AND D. H. KNIGHT. 1982. Landscape diversity: The concept applied to Yellowstone Park. *BioScience* 32:664–670.

TURNER, M. G., R. COSTANZA, AND F. H. SKLAR. 1989. Methods to compare spatial patterns for landscape modeling and analysis. *Ecological Modelling* 48:1–18.

*TURNER, M. G., R. H. GARDNER, AND R. V. O'NEILL. *Pattern and Process: Landscape Ecology in Theory and Practice*. Springer-Verlag, New York, chapter 4.

WICKHAM, J. D., AND D. J. NORTON. 1994. Mapping and analyzing landscape patterns. *Landscape Ecology* 9:7–23.

*WICKHAM, J. D., AND K. H. RIITTERS. 1995. Sensitivity of landscape metrics to pixel size. *International Journal of Remote Sensing* 16:3585–3594.

CHAPTER 8

UNDERSTANDING LANDSCAPE METRICS II

EFFECTS OF CHANGES IN SCALE

JOSHUA D. GREENBERG, SARAH E. GERGEL, AND MONICA G. TURNER

OBJECTIVES

The perceived pattern of a landscape is influenced by the scale at which the landscape is represented, either in an aerial photograph, satellite image, or data in a Geographic Information System (GIS). This effect of scale has serious implications for the analysis and interpretation of landscape metrics. As such, understanding the range of variability in landscape metrics solely due to changes in scale, and why some metrics are more sensitive to these changes than others, is critical to the appropriate use of landscape metrics. The primary goals of this lab are to

1. explore the quantitative effects of changes in scale (grain and extent) and classification scheme on the computation of landscape metrics; and
2. examine the implications of metric scale dependence for the interpretation of landscape metrics.

In Part 1, to ensure that you fully understand the mechanics behind the different changes in scale, you will change the grain, extent, and classification scheme by hand on a small hypothetical landscape. It is recommended that you work in pairs for this section to divide the workload. In Part 2 you will use the ESRI program ArcExplorer, to examine the effects of changes in scale and classification scheme on landscape metrics by using a large landscape image. In the latter section, the changes in scale and the landscape metric cal-

culations (in FRAGSTATS) have already been performed for you. Your responsibility will be to analyze and interpret the data resulting from the scale changes. Part 1 of this lab requires pencil, paper, calculator, overhead transparencies, and colored markers. Part 2 of this lab requires a PC running ArcExplorer, a spreadsheet program, the Excel file **scale.xls**, and the ArcExplorer files accompanying the laboratory located on the CD. *It is essential that you copy the entire, intact subdirectory for this chapter, including ArcData, to your own PC in order to retain all the necessary files for Part 2.* Familiarity with Chapter 7, Understanding Landscape Metrics I, is required, and familiarity with ArcExplorer as in Chapter 3, Introduction to GIS, or ArcView software is extremely helpful.

INTRODUCTION

Quantification of spatial pattern in landscapes is necessary to evaluate the differences among landscapes and track changes through time. Many factors can influence the results of a pattern analysis, but two extremely important factors are the scale of the data—both its grain and extent—and the way in which the landscape was classified. **Scale** refers to the spatial or temporal dimensions of an object or process, and it is characterized by both grain and extent. Spatial **grain** is the finest level of spatial resolution possible within a given data set. For example, grain refers to the cell size for gridded maps, or the minimum polygon size for vector maps. Spatial **extent** refers to the size of the overall study area. **Classification scheme** refers to the number and type of classes used in grouping the landscape cover types. For example, a landscape might be classified into forested and nonforested categories, or be separated further into forested, urban, agricultural, and prairie categories.

The grain and extent of the data used in any analysis of landscape pattern influence the numerical result obtained for a given metric (Turner et al., 1989; Moody and Woodcock, 1995; Wickham and Riitters, 1995; O'Neill et al., 1996). This sensitivity means that comparison of landscape data represented at different scales may be invalid, or might primarily reflect scale-related differences rather than actual differences in landscape pattern. Moody and Woodcock (1995) changed the grain size of a Landsat image and demonstrated that scale-induced changes in the proportion of the landscape occupied by different cover types influenced landscape metrics such as patch size, patch density, and landscape diversity. However, not all metrics are equally sensitive to changes in grain (Cain et al., 1997). Furthermore, spatial extent can influence landscape metrics independently of grain size. Smaller maps may show the effects of map boundaries, resulting in biased measurements of patch size and shape. As with the long-recognized relationship between the number of species observed in a given location as a function of area (i.e., species-area curves), landscapes of larger extent often contain a greater number of cover types.

Finally, the classification scheme used when a landscape is represented as a map also strongly influences the numerical results of any pattern analysis (Wickham et al., 1997). The categories should be selected for a particular question or purpose. For example, twelve general categories of land cover might be appropriate to study landscape patterns in the Upper Midwest or New England regions of the United States, but the spatial heterogeneity within smaller areas, such as a state park, would require more finely distinguished vegetation classes. In this lab, we will illustrate how the same landscape can look quite different under alternative classification schemes.

EXERCISES

Part 1. Understanding Changes in Scale

To ensure that you understand how the maps you will analyze later were produced, you will first conduct a series of scale changes by hand on a small landscape image. The landscape will be created by you, using Figure 8.1 on the CD. This base map represents a 12 × 12 pixel area and consists of four cover types: (1) forest, (2) wetland, (3) water, and (4) roads. Print a hard copy of Figure 8.1 and follow the simple instructions to create your base map.

EXERCISE 1.1 Changes in Grain

The grain size of spatial data has a profound influence on how a landscape is quantified with metrics. While a finer grain provides more detail, this level of detail must be balanced by the sheer quantity of the resulting data relative to disk storage space.

You will now create two new maps from your original base map, with each successive map at a coarser grain.

1. Use the completed version of Figure 8.1 as (12 × 12 pixels with 144 total pixels, grain = 30 m on a side of each pixel).
2. Aggregate the base map to create a new 6 × 6-pixel map (36 pixels total, grain = 60 m). The total extent of the region stays the same, but fewer pixels are used to represent the area.
3. Assign a cover type category to each new pixel in the new 6 × 6-pixel map based on a majority rule. That is, if the new pixel contains three pixels of forest and one pixel of urban from the base map, the pixel in the new map would be classified as forest. If there is a tie, flip a coin.
4. Repeat this process, but aggregate the 6 × 6-pixel map to a 3 × 3-pixel map (grain = 120 m).
5. Calculate the proportion (p_i) of each cover type in each of the three landscapes. Record your results in Table 8.1, which can be printed from the CD.
6. Calculate mean p_i value for each cover type (across all landscapes) and enter in Table 8.1.
7. Calculate Coefficient of Variation (expressed as a percent; CV%) for each cover type across all landscapes. Enter your results in Table 8.1.

Question 1.1. What happened to the p_i of the rarest and most dominant cover types?

Consider the aggregation rule used in this exercise as you complete the rest of the lab. Think about other possible aggregation rules and when they might be useful.

EXERCISE 1.2 Changes in Extent

Now change the extent of your base map to successively smaller map sizes while keeping the grain size constant. A decision will have to be made about how to reduce the extent of your image—either starting at one corner or reducing the area centered on the middle of the image.

1. Start with Figure 8.1 as your base map (extent = 360 m on a side of image).
2. Reduce the extent of the image to 6 × 6-pixel area (extent = 180 m on a side, with each pixel 30 m in size). Remember that the grain remains the same, and you do not alter any cover type assignments.
3. Reduce the extent of the image to a 3 × 3-pixel area (extent = 90 m).
4. Calculate the proportion (p_i) of each cover type for each landscape extent. Record your results in Table 8.2 on the CD.
5. Calculate mean p_i values for each cover type over all extents and enter in Table 8.2.
6. Calculate CV% for each cover type over all extents and enter in Table 8.2.

Question 1.2. What happened to the total number of cover types in the landscape?

As you work through the rest of the exercises, consider the cover types present in the landscapes of different extent. Think about the possible implications of using maps of different extent.

EXERCISE 1.3 Changes in Classification Scheme

Next, you will enact changes in classification by creating new cover types and/or merging existing cover types.

1. Start with Figure 8.1 (on the CD) as your base map (four cover types). Do not alter the grain or extent of the map.
2. Reclassify this four-cover-type map to a map with three categories. Carefully consider your reasoning for your reclassification.
3. Now reclassify the base map with four cover types to a binary (two-category) map.

Question 1.3. How did you decide which categories to use when reclassifying the map? Was this an arbitrary decision? Why or why not?

Part 2. Effects of Changes in Scale on Landscape Metrics

In this section of the lab, you will examine the effects of changes in scale and classification scheme on a suite of landscape metrics calculated for spatial data from an actual landscape. Much of the laborious work and data collection has already been completed for you; your goal is a synthetic interpretation of the results. The changes in scale and classification scheme that have been performed on the spatial data are virtually identical to the changes you enacted in Part 1 and can be viewed using ArcExplorer. A subset of landscape metrics were calculated for each landscape using FRAGSTATS, and the results were compiled in a spreadsheet file, **scale.xls**. You will be responsible for observing the spatial data (and accompanying scale changes) using ArcExplorer, analyzing and graphing the spreadsheet metric data, and answering a series of question regarding the influence of changes in scale and classification scheme on landscape metrics.

You will analyze the spatial data used in Chapter 3, Introduction to GIS, representing a 25-km^2 area of the Gifford Pinchot National Forest in southwest Washington state (USA). Recall that the Yacolt burn (an extensive fire in 1903) left a mosaic of burned and unburned patches in the area. Patches not burned by the fire are now considered old-growth forests (>200 years old), while burned areas are considered either mature (Age 80–200 years old) or young (Age 41–80 years old) forest. Forest patches less than 80 years old are likely the result of timber harvest. See the metadata file (**metadata.pdf**) included on the disk under the directory of Chapter 3 for a more complete description of the themes. *(NOTE:* In addition to the Excel spreadsheet **scale.xls** and the directory **ArcData** needed for this lab, we have also provided the folder **FragData** on the CD, which provides access to the FRAGSTATS grids and output files on which this lab is based.)

EXERCISE 2.1 Effects of Changes in Grain

1. Open ArcExplorer by double-clicking on its icon. (See the Chapter 3, Introduction to GIS, for directions on installing and using ArcExplorer.)
2. Use **File** then **Open Project** on the pull-down menu to open the project file **Grain.AEP** from the ArcData subdirectory. This project contains themes showing grain changes in the spatial data with theme names that correspond to the size of the grain. For example, the Veg50 theme has a grain size of 50 meters (i.e., one side of a pixel is 50 m). The method used to change the grain of these themes was a majority method, which takes the dominant cover class in the finest-scale theme and gives that class to the new, larger cell.

3. Familiarize yourself with the different themes and visually examine the changes in pattern with changes in grain size. When viewing several themes, remember that ArcExplorer displays the themes starting with the ones listed at the bottom of the legend and placing subsequent themes on top. In some cases it may be necessary to uncheck the display box for a theme higher on the legend to see the themes listed lower on the legend. It may be helpful to print these maps if you have access to a color printer.
4. Using a spreadsheet program, open the file **scale.xls**.
5. Be sure you are on the sheet titled **Grain-Summary**. If not, click on the tabs on the bottom of the spreadsheet.
6. Examine the data for dominance in the spreadsheet, which is also shown in the plot in Figure 8.2. Answer Questions 2.1 and 2.2 below.
7. Examine Figure 8.3 as well as the data on which it is based (in the spreadsheet). Answer Quesion 2.3 below.
8. Use the Grain-Summary data sheet to create the following graphs of landscape metrics for classes Age41–80 and AgeOver200 (note that a few additional metrics are also included in the spreadsheet).
   (a) Proportion (p_i) (on the y-axis) vs. grain (on the x-axis)
   (b) Total edge vs. grain
   (c) Mean patch size vs. grain
9. Calculate the CV% for each metric in step 8 for each cover type across all grain changes.
10. Enter your results in Table 8.3 from the CD and answer Question 2.4 below.

Question 2.1. Explain the trend in dominance with increasing grain size. Why does this occur?

Question 2.2. Note the dominance measure calculated for the landscape with a grain size of 200 meters. What do you see? Can you offer an explanation?

Question 2.3. Describe and interpret the trend in contagion with increasing grain size.

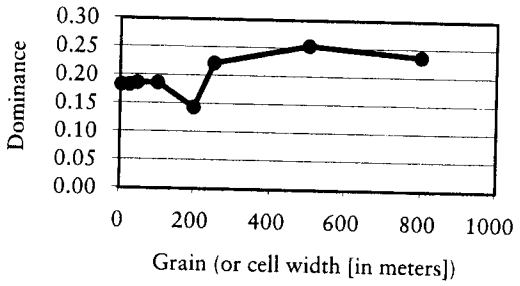


FIGURE 8.2
Changes in the grain (cell size) of an example map and the resulting influence on the dominance value.

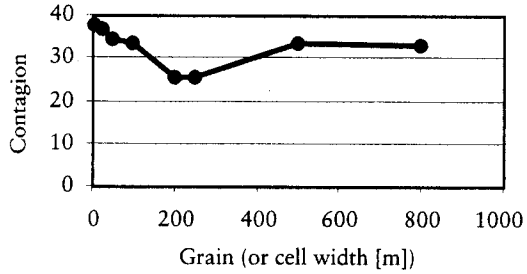


FIGURE 8.3
Changes in the grain (cell size) of an example map and the resulting influence on the contagion value of the landscape.

Question 2.4. For each of the graphs in step 8, describe how the metrics change with grain. Which metrics change the most with increasing grain? Which change the least?

Question 2.5. Which land-cover types are the least affected by changes in grain? Why is this?

Question 2.6. Suggest some principles for how landscapes appear to change when measured with increasing grain sizes.

EXERCISE 2.2
Effects of Changes in Extent

1. Open the file **extent.AEP** using ArcExplorer. In this project, the extent of each theme (measured here as the width of the entire study area) has been changed, centered on the middle of the theme. Use the measuring tool to determine the approximate extent of each theme—see Chapter 3 for a reminder on how. Recall the software bug from Chapter 3—do *not* measure in kilometers. Note how changing the extent changes the visual appearance of the data.
2. Examine the dominance and contagion metrics in the **Extent-Summary** data page in the spreadsheet.
3. Last, examine the plots of dominance versus extent (Figure 8.4) and contagion versus extent (Figure 8.5). Answer Question 2.7 below.
4. Use the **Extent – Summary** sheet to create the following graphs of landscape metrics for classes Age41–80 and AgeOver200.
   (a) Proportion (p_i) (on the y-axis) vs. extent (on the x-axis)
   (b) Total edge vs. extent
   (c) Mean patch size vs. extent
5. Calculate the CV% for each metric in step 4 for both cover types across all extent changes.
6. Enter your results in Table 8.4 and answer Question 2.8 below.

FIGURE 8.4
Changes in the extent of an example map and the impact on the dominance value.

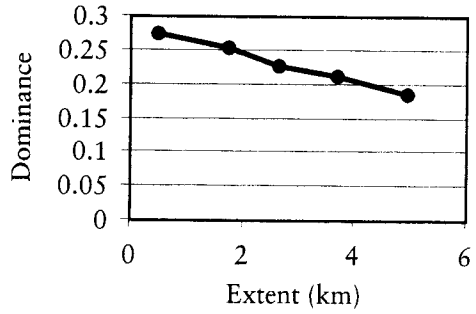


FIGURE 8.5
Changes in the extent (or total area) of an example map and the impact on the contagion value of the landscape.

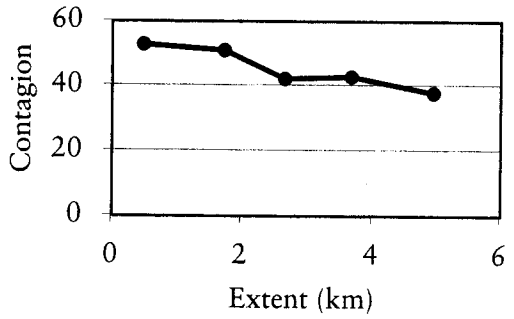
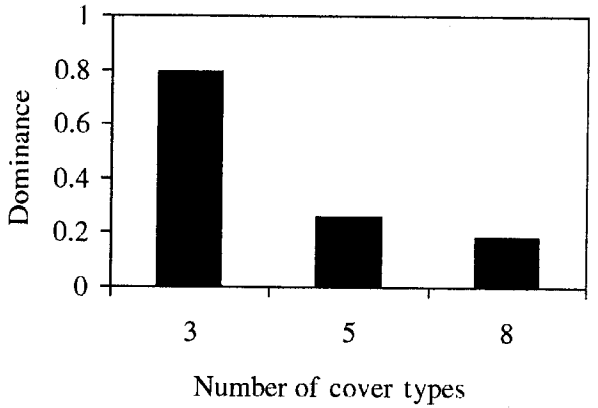


FIGURE 8.6
The influence of changes in classification scheme (from eight to five to three classes) on the dominance value of the landscape.



Question 2.7. Examine the value of dominance for the smallest extent. What do you see and why is this so? Does contagion vary with extent? Interpret the trend that you observe.

Question 2.8. For each of the graphs in step 6, describe how the measures change with extent. Which metrics change the most with increasing extent? Which change the least?

Question 2.9. Which land-cover types are the least affected by changes in extent? Why is this?

Question 2.10. Explain how changes in extent alter the patches on the edge of the extent, and what could be done to help remedy that effect in pattern analysis.

EXERCISE 2.3
Changes in Classification Scheme

The number of classes used in a GIS theme (or any map) is often a subjective decision made by the map creator. In this exercise, you will examine changes in landscape patterns due to changes in the classification scheme of the vegetation.

1. Open the file **class.AEP**. In each reclassification, the bare ground and hardwood classes have been maintained, while the six age classes of the evergreens have been reduced from six classes to three classes to one class. The theme names, **veg3class, veg5class,** and **veg8class,** refer to the total of number of classes used in the classification. Answer Question 2.11 below.
2. Examine the Class-Summary sheet for both dominance and contagion.
3. Compare these data to the plots in Figures 8.6 and 8.7.

Question 2.11. Visually, give a qualitative estimate of how this landscape changes with the different classification schemes.

Question 2.12. Explain the changes in dominance and contagion when the number of classes are changed.

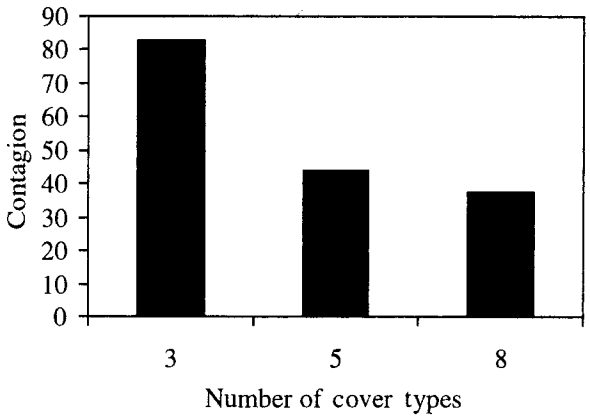


FIGURE 8.7
The influence of changes in classification scheme (from eight to five to three classes) on the contagion value of the landscape.

Question 2.13. Will dominance and contagion always change in the same way as classes change, or will variations in the metrics be specific to the landscape?

CONCLUSIONS

Quantitative measures of landscape pattern are useful for a variety of purposes. However, when analyzing or interpreting landscape metrics, one must pay close attention to the scale of the data and the classification scheme used. Differences in scale among two data sets (e.g., between time periods or for different landscapes) can obscure or augment the actual amount of landscape change and limit the comparability of many landscape metrics. Research into the behavior of metrics must identify the relative sensitivity of various metrics to scale differences and work toward developing scaling rules for extrapolating across different scales.

DISCUSSION QUESTIONS

1. The aggregation rule used to change grain size for this lab was a majority rule. What are two other rules that could have been used? Explain the advantages and disadvantages of each and the conditions under which one might choose to apply each.
2. Compare the CV% of dominance across grain, extent, and classification scheme changes.
   (a) Which alteration resulted in the most variance in dominance? Why?
   (b) Which alteration resulted in the least variance in dominance? Why?
3. Compare mean patch size for each landscape (regardless of cover type). Does grain, extent, or classification scheme have the greatest influence on mean patch size? Why?
4. Compare the relative impact of changes in grain versus changes in extent for the metrics you examined (refer to your answers for Questions 2.4 and 2.8). Are any metrics insensitive to changes in both grain and extent? What attributes of a metric might reduce its sensitivity?
5. The amount of edge habitat in a landscape is often quantified for wildlife-related research because many species respond very differently to edge habitats. If quantifying edge habitat for white-tailed deer, what considerations would you suggest regarding selection of grain, extent, and number of classes for the study landscape?
6. Should spatial pattern analyses be conducted across multiple scales? What is the utility of conducting a spatial pattern analysis at only one scale? What is the utility of conducting a pattern analysis at more than one scale?

BIBLIOGRAPHY

Note. An asterisk preceding the entry indicates that it is a suggested reading.

CAIN, D. H., K. RIITTERS, AND K. ORVIS. 1997. A multi-scale analysis of landscape statistics. *Landscape Ecology* 12:199–212.

*MEENTEMEYER, V., AND E. O. BOX. 1987. Scale effects in landscape studies. In M. G. Turner, ed. *Landscape Heterogeneity and Disturbance*. Springer-Verlag, New York, pp. 15–34. One of the earlier papers addressing scale effects in landscape studies; it lays out a variety of ways in which scale is important.

MOODY, A., AND C. E. WOODCOCK. 1995. The influence of scale and the spatial characteristics of landscapes on land-cover mapping using remote sensing. *Landscape Ecology* 10:363–379.

O'NEILL, R. V., C. T. HUNSAKER, S. P. TIMMINS, B. L. JACKSON, K. B. JONES, K. H. RITTERS, AND J. D. WICKHAM. 1996. Scale problems in reporting landscape pattern at the regional scale. *Landscape Ecology* 11:169–180.

TURNER, M. G., R. V. O'NEILL, R. H. GARDNER, AND B. T. MILNE. 1989. Effects of changing spatial scale on the analysis of landscape pattern. *Landscape Ecology* 3: 153–162.

*WICKHAM, J. D., R. V. O'NEILL, K. H. RIITTERS, T. G. WADE, AND K. B. JONES. 1997. Sensitivity of selected landscape pattern metrics to land-cover misclassification and differences in land-cover composition. *Photogrammetric Engineering and Remote Sensing* 63:397–402. A useful investigation of the effects of classification scheme on resulting landscape metrics.

*WICKHAM, J. D., AND K. H. RIITTERS. 1995. Sensitivity of landscape metrics to pixel size. *International Journal of Remote Sensing* 16:3585–3594. This paper empirically demonstrates the sensitivity of different landscape metrics to changes in grain, which is relevant to using satellite imagery.