Chapter 6
Characterizing Categorical Map Patterns Using Neutral Landscape Models

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OBJECTIVES

Spatial patterns of landscapes are the result of numerous biotic, abiotic, and anthropogenic processes, and every landscape is in some way unique. Neutral landscape models—models that lack the explicit consideration of the particular processes generating landscape pattern (Gardner et al. 1987; Gardner and Engelhardt 2008) have proven to be a helpful first step in characterizing pattern in the absence of specific ecological processes and thus serve as a null hypothesis, or baseline, for comparison with actual landscapes. Neutral landscape models have led to new understanding about habitat connectivity thresholds and the influence of landscape composition on spatial configuration (see Gardner and Urban 2007 for a review), and they offer a practical means of generating multiple landscape maps with similar statistical properties. This lab is designed to:

1. Illustrate the methods used for generating neutral landscape models;
2. Explore methods for analyzing patch structure with particular emphasis on the use of different neighborhood rules for identifying patches;
3. Explore the factors influencing connectivity in landscapes as well as threshold effects in connectivity; and
4. Examine the use of neutral models for formulating hypotheses regarding the relationship between pattern and process in actual landscapes.

Before data are collected or experiments are performed, the analysis of landscape pattern requires (at least) two things: (1) a clearly stated, testable question or

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hypothesis, and (2) robust quantitative methods to address that question (Gardner and Urban 2007). Throughout this lab, a variety of neutral models will be generated to create a broad range of landscape patterns. Students will also become familiar with a number of common metrics used to quantify patterns in these landscapes. The concept of connectivity will be addressed, particularly with respect to the neighborhood rules used to define "patches," or "clusters," of habitat in a landscape.

The four exercises of this lab help students develop testable questions and interpret quantitative results. The first exercise provides familiarity with computational methods and can be completed entirely by hand or in Excel. The second investigates the surprising degree of structure present in simple random models and illustrates threshold effects. The third exercise uses multifractal maps to examine contagion effects. The fourth exercise compares metrics of real landscapes with those of a neutral model. You will be using QRULE software for Exercises 2–4, with a series of R files to analyze and display results. All software for this lab is free and can be downloaded from the book website! Some familiarity with R as well as Chapters 4, 5, and 7 is a nice complement to these exercises.

INTRODUCTION

Neutral, or null, models in ecology provide a useful baseline for comparison when examining potential cause-and-effect relationships. In terms of landscape pattern, a **neutral model** is one that exhibits characteristic spatial patterns in the absence of processes that may affect patterns in actual landscapes (e.g., topography, resource gradients, and disturbance regimes; Gardner et al. 1987; With and King 1997; Gardner and Urban 2007). In the neutral models examined here, landscape pattern is an emergent property of either simple random processes or via algorithms derived from fractal geometry that create random but auto-correlated patterns (e.g., multifractal maps). Comparing patterns and landscape indices for real landscapes with those from neutral landscape models can provide insight into the effects of ecological processes on landscape patterns; if a real landscape differs significantly from an appropriate neutral model, it is quite likely that some important ecological process is driving observed patterns. This insight allows the investigators to focus efforts on specific landscape processes and attributes (rather than a broad "shotgun" approach) to possibly reveal pattern–process relationships operating in heterogeneous landscapes.

Landscape pattern analysis usually begins by converting continuous land-cover data (e.g., derived from satellite images) into a gridded map of land-cover categories for analysis by computer programs. Most analysis methods involve identification of habitat patches (or clusters) and description of their sizes, shapes, and spatial arrangements. Although the clustering of habitat into patches may be visually obvious,

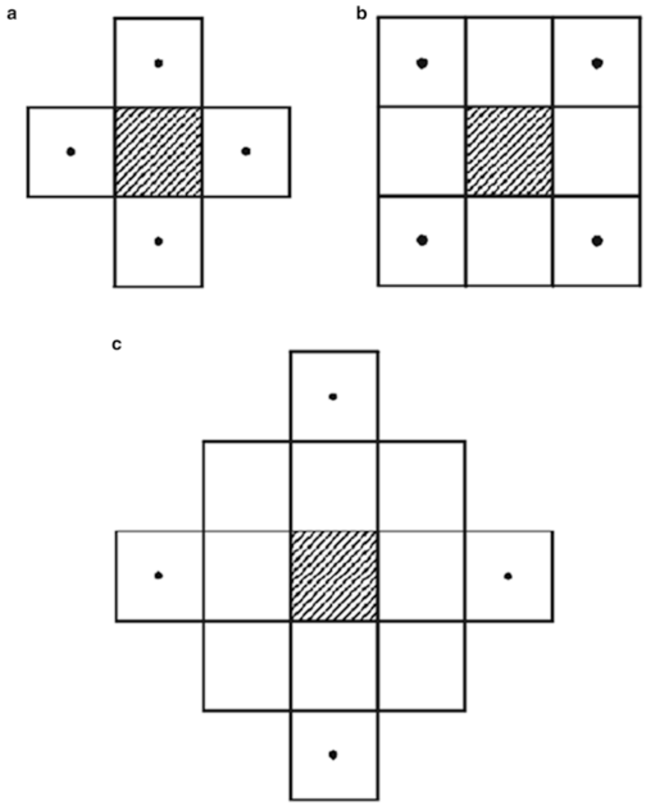

Figure 6.1 Three primary neighborhood rules: (**a**) the nearest (4) neighbor rule; (**b**) the next-nearest (8) neighbor rule; and c. the third-nearest (12) neighbor rule. The additional neighbors added to this sequence of increasing neighborhoods for each shaded pixel are indicated by the dot in the pixel center

clear patch-definition rules are needed for computers to identify habitat patches uniquely and unambiguously.

The most basic "rule" for patch definition is referred to as the "nearest-neighbor rule" (Figure 6.1a). The **nearest-neighbor rule** states that if two similar sites have one edge along one of the four cardinal directions in common (i.e., adjacent pixels), then they are "joined" and are members of the same patch. Iterative application of this rule to each "joined" site results in the identification of members of a single patch. This rule requires sites to touch along one edge to be members of the same patch, and thus a single row arranged diagonally (along a non-cardinal direction) will *not* be identified as a single continuous patch!

More commonly used in ecology is the **eight-neighbor rule** (Figure 6.1b), also called the next-nearest neighbor rule. It states that similar habitat cells are members of the same patch if they touch along one of their four edges (cardinal directions) *or* four corners (the diagonal directions). While corner sites are not considered members of the same patch with the nearest-neighbor rule, they *are* members of the same patch with the eight-neighbor rule.

Changing the patch-definition rule, such as by increasing the neighborhood that is searched for patch members, alters the metrics used to characterize landscape structure—something we will explore here. The use of different rules for defining patches for a landscape analysis is, in part, how QRULE gets its name. The user may define any rule he/she wishes with three rules conveniently "hard-wired" into QRULE code. The third "hard-wired rule" is the **third-nearest-neighbor rule** (Figure 6.1c) which extends consideration to sites that may not directly touch! Although we do not emphasize the third-nearest-neighbor rule in this lab, it can be useful for identifying habitat patches for an organism that effectively ignores a single cell gap of non-habitat within an otherwise continuous patch.

Once patches are identified, computer analysis quantifies patch attributes including size, shape, and spatial arrangement. Drawing inference from these results is problematic because, since so many metrics may be calculated, some will be statistically significant by chance alone (a Type II statistical error); a theme also explored further in Chapter 7. Neutral models were developed, in part, to avoid this problem by providing a standard against which the patterns of actual landscapes could be compared (Gardner et al. 1987; Gardner and Urban 2007). When hypotheses are clearly stated before the analysis begins, using a limited set of specific metrics helps avoid obtaining spurious, but apparently significant, results.

The simplest **neutral landscape model (NLM)** is a random map generated by assigning to each grid cell a probability of the cell being occupied by "habitat." Such a **simple random map** contains only two land-cover categories (habitat and non-habitat) and the proportion of the landscape occupied by habitat is similar to the probability of the cell being occupied by habitat. Before embarking on the computer-based generation and analysis of neutral landscape models, we begin with an exercise that demonstrates the basic procedure used by the computer algorithm.

EXERCISE 1: Simple Random Map(s) Analyzed with Three Different Neighborhood Rules

The purpose of this exercise is to become familiar with the method for generating and analyzing patch structure in random maps and the effect of changing neighborhood rules for defining patches. Your first step is to generate "by-hand" a simple random map with rows and columns equal to ten and the proportion of a cell being occupied, $\boldsymbol{p}=0.5$. This exercise should be done with paper and pencil according to the following steps (Alternatively, see the instructions for using spreadsheet software, listed *after* the "by-hand" instructions).

Instructions for Generating and Analyzing a Simple Random Map "By-Hand"

1. Use graph paper to create a grid with ten rows and columns.
2. Repeatedly flip a coin to determine the habitat type of each cell. If heads, then the habitat type equals 0. If tails, then the habitat type equals 1.
3. Analyze the map by coloring in all sites with habitat type = 1.
4. Count the total number of colored cells, the total amount of edge, the number of clusters as defined by the nearest-neighbor rule, and the size of the largest cluster.
5. Using the next-nearest-neighbor rule, recalculate the number of clusters and the size of the largest cluster. (*NOTE:* the total number of colored cells and the total amount of edge will not be affected by this change in neighborhood rule.)
6. Record your results in tabular form.

Instructions for Using a Spreadsheet to Generate a Matrix of Random Numbers

Open Excel and then:

1. Open a new worksheet
2. Type this equation in the first cell: "`=rand()`" (this produces a single random number between the interval 0.0–1.0).
3. Copy this cell to a 10×10 grid of cells
4. Analyze the map by coloring all sites with random numbers ≤ 0.5
5. Print the resulting matrix and go to step 4 of the "by-hand" directions

Q1 The generation of maps by hand is a tedious exercise that results in a small, inadequate sample size. Does the number of habitat sites of type 1 equal exactly 50% of the map? How many sites with habitat of type 1 touched the edge of the map? How many of these sites that touched the edge of the map would have adjoined another site of habitat type 1 if the map size was increased? (*HINT*: See Gardner et al. 1987, for a discussion of cluster truncation effects.) How big would clusters be if the map size were increased?

Q2 Combine your results with those of other students and statistically summarize (e.g., mean, standard deviation, minimum, maximum) the number of cells of habitat, total amount of edge, number of clusters, and the size of the largest cluster. What are the most reliable statistics (i.e., which ones have the lowest coefficient of variation)?

Q3 Do you expect the results from actual landscapes to be more or less variable than random maps? Explain your rationale.

Using QRULE to Generate and Analyze Neutral Landscape Models

The remainder of this lab will be performed using QRULE, a program written in Fortran with separate versions that run in either DOS or Linux. The latest version of QRULE makes several improvements over older versions, including the output of statistics in metric units rather than pixel units. See documentation, *Qdocumentation.pdf* for details. QRULE was developed to be a research tool—and it still is used as such! Consequently only minimal attention has been devoted to making QRULE "user friendly." QRULE does not have a GUI (graphical user interface); nor does it produce instant graphical output or data displays. It may "crash" if you input conflicting or incorrect information (i.e., a file name that does not exist in the directory specified). The good news is that a few simple "tricks" detailed below will allow you to run QRULE in a remarkably efficient and flexible manner.

Several types of maps can be generated by QRULE. The ones of interest for this exercise are simple random maps and multifractal maps (Figure 6.2). Maps created by other programs—especially those developed from remotely sensed images—may also be read into QRULE for analysis of spatial patterns. The algorithms are explained briefly below.

Simple random maps (Figure 6.2a) may be created by specifying the number of rows and columns in the map, the number of habitat types to be generated, and the probabilities, ***pi***, associated with each habitat type ***i***—including the probability, ***p0***, for areas lacking any habitat at all. Table 6.1 provides a sample dialog for QRULE execution producing a random map with 128 rows and columns and two habitat types. A uniform random number (URN, a computer-generated random number ranging from 0.0 to 1.0) is iteratively used to randomly and independently assign a habitat type to each grid site.

In Table 6.1, the example specifies the value of ***p0*** = 0.1, ***p1*** = 0.3, and ***p2*** = 0.6. If URN ≤ ***p0***, then the site is set to "non-habitat"; if URN is between 0.1 and 0.4, the site is set to habitat type 1; and if the UNR > 0.4, it is set to habitat type 2 (also notice the cumulative probability distribution, ***CumP*** in Table 6.1 and the realized probabilities for habitat types 1 and 2 were 0.301 and 0.5991, respectively. The definitions for each landscape statistic calculated by QRULE are given in Table 6.2.

Multifractal maps produce patterns that are quite realistic (Figure 6.2b–d) because a fractal algorithm is used to produce spatially correlated patterns of land cover. Fractal maps have been frequently used by investigators wishing to use random but more realistic maps to simulate biological and physical processes (e.g., With 1994; Plotnick and Prestegaard 1995; Wiens et al. 1995). Multifractal maps (Figure 6.2b–d) are generated in QRULE by the midpoint displacement algorithm (MidPointFM2d, Saupe 1988). This algorithm creates a map of real numbers by iterative interpolation to locate the midpoint of a line, followed by perturbation of the line's midpoint by a Gaussian random value (GRV). Successive reductions of the variance of the GRV as the distance between points becomes finer and finer produces correlated patterns. Two parameters are used by QRULE to control this process:

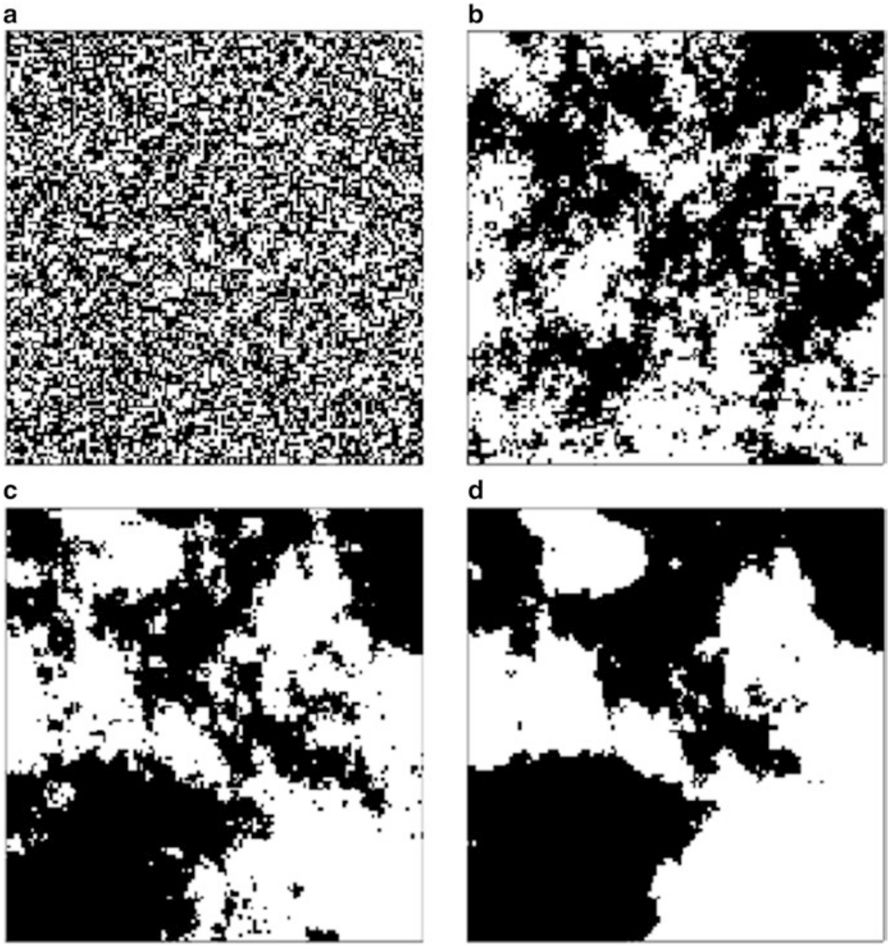

Figure 6.2 Sample maps produced in RULE: (**a**) a simple random map, and multifractal maps with (**b**) $H=0.1$, (**c**) $H=0.5$, and (**d**) $H=0.9$. In each instance, the value of p, the proportion of black cells within the map, is equal to 0.5

- ***L***, the "number of levels" or iterations of the midpoint displacement algorithm. The size of the map will always equal to 2^L. For instance when L=4, then the dimensions of the map (number of rows and columns)=16; when L=6, map dimensions=64, etc.
- ***H***, the parameter that controls the rate of reduction of the GRV in successive iterations of the midpoint displacement method (H may range in value from 0.0 to 1.0).

The generation of successive finer Gaussian increments results in the variance between points separated by distance $\boldsymbol{x}$ that is approximately equal to $\boldsymbol{x^{2H}}$ (assuming

Table 6.1 Sample QRULE dialog producing a Simple Random Map with two habitat types
User response to questions by QRULE are given in *Bold Italic*. All Output by QRULE is also written to a disk file: *rulerun.log*

./Qrule.exe

```
    Qrule (v 4.1) Landscape Pattern Analysis   20131113

    Enter map type to be analyzed:

       <I> Input existing map file

       <R> Generate a random map (with replacement)

       <S> Generate a simple random map

       <M> Generate a multifractal random map

       <G> Generate a multifractal random map with a gradient

       <X> Use input map as mask, generate "seeded" map

       <Y> Use input map as mask, generate siple random map
```

s

```
    Map choice: S

    Enter number of map rows and columns (max = 20000 ea.)
```

128 128

```
    Rows x Columns =  128 x  128

    Enter a negative random number seed
```

-191827

```
    Random number seed:    -191827

    Enter the neighborhood rule

       1 - nearest neighbor (N_nb = 4)

       2 - next nearest neighbor (N_nb = 8)

       3 - 3rd nearest neighbor (N_nb = 12)

       4 - user defined
```

(continued)

Table 6.1 (continued)

1

```
Rule choice is: 1

Enter the number of map classes
```

2

```
Map classes =     2

Enter the   3 probabilities, starting with p(0)
```

0.1

0.3

0.6

```
The normalized probabilities are:

   P          CumP

 0    0.1000     0.1000

 1    0.3000     0.4000

 2    0.6000     1.0000

Enter the number of replications
```

10

```
N_Reps =     10

Create an output maps?

 N = None

 G = generated map

 S = cluster Size map

 C = cluster ID map
```

(continued)

Table 6.1 (continued)

n

```
Map output choice = N

Perform map analysis?

   <N>o analysis

   <L>acunarity analysis

   <R>ule analysis

   <A>ll (both Rule and Lacunarity)
```

r

```
Analysis method: RULE

What is the resolution of each grid element?

  (length of the side of a grid element, in meters)
```

30

```
 Resolution:  30.0000     meters

          Mean Association Matrix

   Avg ChiX = 8.35187 w/ 4 df (FXceed (9.4480= 0.3000)

      0        1        2

  0   0.010298 0.030043 0.059652

  1   0.030043 0.090493 0.180387

  2   0.059652 0.180387 0.359046

 p's  0.099992 0.300923 0.599085
```

(continued)

Table 6.1 (continued)

STATISTICAL SUMMARY (N= 10; Resolution= 30.0000 meters)

--Cover Type 0 (non habitat)-- [p = 0.1000 Cum. p = 0.1000]

--Land Cover Type 1-- [p = 0.3010 Cum. p = 0.4009]

Variable	Units	Mean	St.Dev.	C. V.	Minimum	Maximum
L.C.size	ha	2.44800	0.510529	20.8549	1.89000	3.51000
L.C.edge	m	1566.00	286.287	18.2814	1260.00	2160.00
L.C.fract	-	1.51835	0.710262E-01	4.67785	1.41497	1.66736
L.C._rms	m	119.670	12.6254	10.5502	96.9325	134.728
TTL clstr	N	2118.20	46.5422	2.19725	2048.00	2210.00
TTL edgs	m	415206.	5080.47	1.22360	404580.	423300.
Sav size	ha	0.451091	0.201442E-01	4.46567	0.424208	0.485755
S_Freq	N	4931.10	50.0132	1.01424	4833.00	4989.00
Cor_len	m	73.7511	3.46446	4.69750	68.6342	79.3984
Perc	%	0.00000	0.00000	0.00000	0.00000	0.00000

--Land Cover Type 2-- [p = 0.5991 Cum. p = 1.0000]

Variable	Units	Mean	St.Dev.	C. V.	Minimum	Maximum
L.C.size	ha	367.317	140.730	38.3128	212.310	655.110
L.C.edge	m	178968.	68017.9	38.0056	102360.	317880.
L.C.fract	-	1.75286	0.437641E-01	2.49672	1.68642	1.83279
L.C._rms	m	1270.99	169.286	13.3192	976.709	1483.23
TTL clstr	N	463.000	36.6667	7.91937	386.000	512.000
TTL edgs	m	477390.	3784.05	0.792653	469200.	482160.
Sav size	ha	220.843	111.444	50.4632	129.076	487.170
S_Freq	N	9814.90	50.0354	0.509791	9757.00	9913.00
Cor_len	m	1193.55	196.669	16.4776	869.864	1480.94
Perc	%	0.500000	0.527046	105.409	0.00000	1.00000

Table 6.2 Indices of spatial patterns produced by QRULE for each habitat type

Index	Definition
L.C.size	The size of largest cluster (total number of grid units making up the largest cluster)
L.C.edge	Number of edges of largest cluster sites adjacent to a different habitat type
L.C.fractal	Fractal index of largest cluster estimated as *ln*(L.C.edge) / *ln*(average diameter of the cluster)
L.C._rms	Mean squared radius of largest cluster (also known as the radius of gyration, Stauffer and Aharony 1992). If r_i is the i[th] of *s* sites in the cluster, then L.C._rms = $\sum(r_i - r_j)^2 / s^2$. Diffuse sites of size *s* will have a larger L.C._rms than more compact sites
TTL clusters	Total number of clusters on the map
TTL edges	Total edge of all clusters
Sav size	Area weighted average cluster size. If S_i is the size of the i^{th} cluster, then $S_{av} = \frac{\sum s_i^2}{\sum s_j}$
S_Freq	Total number of sites of current habitat type. ***P***, the fraction of sites of the current habitat type are estimated as: ***P*** = S_Freq/(***nr*** * ***nc***), where ***nr*** and ***nc*** are the number of rows and number of columns of the map, respectively
Cor_len	Average mean squared radii of all clusters
Perc/freq	Frequency (percent of all maps) with a cluster large enough to span the dimensions of the map

NOTE: Units for each index are indicated in program output and Table 6.1. See Gardner (1999) for additional details concerning the calculation of each index

that σ^2, the variance of the Gaussian process, is equal to 1.0). Thus, extremely fragmented patterns are produced when caused by a fractal algorithm that causes negative correlations among sites (i.e., *H less than 0.5*; Figure 6.2b) while positive correlations of differences produce highly aggregated patterns (i.e., *H greater than 0.5*; Figure 6.2d). For further details regarding the use of multifractal maps, see Plotnick and Gardner (1993), Pearson and Gardner (1997), and With and King (1997).

Analyzing real landscapes with QRULE simply requires that the map type be defined as **I** indicating that a map will be **input** rather than generated. Then, the full name of the map file (e.g., "C:/foldername/mapname") is entered and then the number of rows and columns and the number of habitat types is specified. The landscape map file must be a space delimited sequence of ASCII integers representing each habitat type. An example input map file, ***anti_128.map***, is provided with this exercise.

Instructions for Using QRULE

Acquiring software. All exercises require QRULE. A text editor will also be needed for handling scripts (see explanation and example below) and examining output. There are many good choices for a text editor, but a particularly useful one is **Notepad++**. Statistical and graphical analysis may be performed either with **R** or using Excel. The current version of QRULE (V4) may be acquired at either the website for this book or the QRULE website (http://www.umces.edu/al/program/gardner/qrule). The current version of Notepad++ can be downloaded at www.notepad.todownload.com and R (R Development Core Team 2010) from www.r-project.org. Excel is, of course, part of the Office software distributed by Microsoft.

(*NOTE*: An important word on operating systems. There are hundreds of operating systems (and multiple versions of each OS), but QRULE runs on only two: DOS (**D**isk **O**perating **S**ystem, a part of Microsoft Windows distributions more correctly referred to as MS-DOS), and Linux. We provide here descriptions for running QRULE under DOS. Those using Linux will have little difficulty adapting the following instructions for this OS.)

Unpacking Qrule. Download QRULE into a directory you have created—ideally, one at the top of your directory tree (e.g., c:/Qlab). Extract all files from the zip file (see Table 6.3 for a list of files contained in this zip file). This action will create a series of subdirectories. Next, go through the following steps.

1. Assuming you are running Windows software, open the **start** menu in the lower left corner of the screen (a separate application in Windows 8 titled "Command prompt" provides this functionality). Next click on the **run** icon and then type **cmd** in the window that opens and check **OK**. This action has opened a DOS window (see Table 6.4 for some useful DOS commands).

Table 6.3 Overview of files for this lab exercise

File Name	Function	Location
QruleV4.exe	Executable file for QRULE	Qlab
sample.scr	Script file for generating random map	Qlab
sample.scr	Copy of above script file	Qlab/Ex1
multifract.scr	Script file for generating multifractal map	Qlab/Ex2
Qcfd.R	R program for generating cumulative frequency distributions	Qlab/Ex2
Qcfdfun.R	Function called by Qcfd.R	Qlab/Ex2
anti_128.map	Actual map for analysis	Qlab/Ex3
anti_128.scr	Script file for analysis of the anti_128.map	Qlab/Ex3
Zview.R	R program for map display	Qlab/Ex3
mapview.R	Function called by Zview.R	Qlab/Ex3

Table 6.4 Useful DOS Commands

Command	Definition	Example
Cd	change directory	cd C:/Qlab/Ex1
Dir	list directory	dir
Copy	copy file	copy rulerun.log rulerun.abc.log
Del	delete file	del rulerun.log
Edit	simple editor	edit sample.scr

2. Navigate in the DOS window to the directory where you have placed the QRULE files. If you created a directory called C:/Qlab in your user area, then simply type `cd C:/Qlab` to reach that directory. Then, use `cd` to navigate to the appropriate subdirectory (e.g., cd Ex1 will take you to the Ex1 subdirectory under *Qlab*). The executable QRULE (file name is QruleV4.exe) exists under C:/Qlab. It will be easiest if you copy QruleV4.exe into each subdirectory.
3. Then, to execute, type `QruleV4.exe` and answer the questions that the program asks (if you can! Explanations for each input are provided subsequently.)

A test run using a script file. The program executable file for DOS is QruleV4.exe. The series of interactive questions required to run QRULE is tedious and error-prone. Many errors in input may cause QRULE to crash. No harm is done when it crashes (I told you it isn't user friendly), but you do have to start over. A more efficient, error-free method of running QRULE is to assemble all required inputs into a **script file** and run all analyses in batch mode. A sample script file, ***sample.scr***, is provided to illustrate running QRULE in batch mode (this is not part of the lab—just a practice run to see how script files are used). To run in batch mode:

1. Open the sample script file (sample.scr) with a text editor such as Notepad++. See **Qdocumentation.pdf** for description of the contents of *sample.scr* which has all the interactive answers to a QRULE run. Examine this file. You also may want to use this as a base from which to make modifications for future runs by changing and resaving the file.
2. Run QRULE using *sample.scr* by typing in the DOS window:

```
QruleV4.exe < sample.scr
```

Program results and output. Once QRULE executes, the screen output has a lot of valuable information, which is difficult to print and save. Therefore, all output is automatically written to a text file in the directory from which you have been running QRULE. The name of the output "log" file is ***rulerun.log***. You can look at this file in Notepad++ and print it if you like. [*IMPORTANT*: You should save it to a unique name before running Qrule a second time because each execution of Qrule will overwrite this file. Type `copy rulerun.log yourpreferredname.log`].

In the test run example, the screen and logfile contain the statistics for 10 landscape metrics for each of the land-cover types simulated (in this case, there are two—the habitat and non-habitat). The meaning of these metrics is given in Table 6.2. Because ten map iterations were performed, QRULE provides a statistical summary of each metric—its mean, standard deviation, C.V. (coefficient of variation), minimum and maximum values. The statistical results are also saved in a separate disk file, *stats.csv* in the directory in which the Qrule is located. This file may be viewed in Notepad++ or Excel. The file contents are described in Qdocumentation.pdf.

In addition to *rulerun.log*, five other files are created each time QRULE is executed: *assmat.dat*, *stats.csv*, *patch_cfd.dat*, *sample.map*, and *arcgrid.map* (descriptions of each file can be found in Qdocumentation.pdf.). We ignore *assmat.dat* for now but will use the other files with R programs to illustrate and examine the QRULE results.

EXERCISE 2: Random Maps and Critical Thresholds

A central concept to emerge from neutral landscape models (which were themselves derived initially from a branch of physics called percolation theory; Stauffer and Aharony 1992) is that of **critical thresholds**. In short, small changes in ***p*** can result in sudden changes in spatial patterns, and in particular, whether habitat is connected from one edge of the map or not. The value of ***p*** at which spatial patterns on a random map change qualitatively is called the **percolation threshold**, typically abbreviated as $\boldsymbol{p_c}$ or $\boldsymbol{p_{crit}}$. In this exercise, we use QRULE to generate and analyze a series of simple random maps as a function of ***p,*** which will range from 0.1 to 0.9. The results of four landscape metrics (total number of patches, total edge, area-weighted mean patch size, and frequency of percolation among the map replicates) will be examined to determine if and at what values of ***p*** a percolation threshold may exist.

1. You and/or your team will generate a series of random maps using a specific neighborhood rule.
   a. If your last name begins with a letter in the range A–L then use **neighborhood rule 1** (nearest-neighbor); M–O then use **neighborhood rule 2** (next nearest-neighbor); P–W then use **neighborhood rule 3** (third nearest-neighbor).
   b. If you do not have a last name you are excused from this exercise.

2. Open a command window and navigate to the Qlab directory. Under the subdirectory **Ex1** you will find a script file, *sample.scr*, which is set to generate a random map with two habitat types. Each habitat type will have a value of ***p*** of 0.5. Run this file by typing:

```
QruleV4.exe<sample.scr
```

3. Save the *rulerun.log* file in Windows Explorer or by typing in the command window:

```
copyrulerun.logrulerun.ran55.log
```

4. Save the *patch_cfd.dat* and *stats.csv* files in a similar manner producing files named *patch_cfd.ran55.dat* and *stats.ran55.csv* by typing:

```
copypatch_cfd.datpatch_cfd.ran55.dat
copystats.csvstats.ran55.csv
```

5. Now open *sample.scr* in Notepad++ (or another suitable editor) for a series of changes. First, change the two probabilities (i.e., habitat, non-habitat) for land-cover generation from 0.5 to 0.1 and 0.9 (but leave ***p0*** unchanged). Save the edited file to *sample.91.scr*. Edit again, changing probabilities to 0.2 and 0.8, saving the script file as *sample.82.scr.* And a third time with probabilities of 0.3 and 0.7, saving as *sample.73.scr.* One last time changing to 0.4 and 0.6, saving as *sample.64.scr.* You will now have four new script files.

6. Repeat the above process outlined in steps 2–4, running QRULE separately for each script file and then renaming the log files and the *patch_cfd.dat* and *stats.csv* files after each run (and before the next sequence of runs begins!).

```
QruleV4.exe<sample.91.scr
copyrulerun.logrulerun.ran91.log
copypatch_cfd.datpatch_cfd.ran91.dat
copystats.csvstats.ran91.csv
```

7. When you have finished you will have five log files and five corresponding data sets, which contain the results from QRULE for ten different values of ***p*** analyzed using one of the three neighborhood rules. You may use a text editor (e.g., Notepad++) to print and examine the results of each log file. The details of each simulation have been preserved in the csv files, which may be opened with Excel directly (or R which isn't quite as simple).
8. Using separate graph windows, plot the values from "TTL clstr", "TTL edgs", "Sav size", and "Perc" on the *Y*-axis as a function of ***p*** on the X-axis.

Q4 Were the resulting fractions of each land-cover type in the results (see the log files) equal to what was specified in the script files? If not, why not?

Q5 What is the meaning of ***po***? And why is it always set to zero in the above sequence?

Q6 Inspect the plots of "Sav size" and "TTL edge" versus ***p*** and describe the resulting relationships.

Q7 Plot "Sav size" against "L.C. size". What does this relationship show?

Q8 Inspect the histogram of "Perc" as a function of ***p***. What do these results indicate?

Q9 Compare your results with the other class teams that used a different neighborhood rule. How does the neighborhood rule affect the location (i.e., ***p***) of a critical threshold changes in metric values? Explain why you observe such changes?

EXERCISE 3: Spatial Contagion

In real landscapes, habitats are seldom (if ever) distributed in a completely random manner. Instead, land-cover categories have some degree of **spatial autocorrelation**, or contagion, in which nearby locations are likely to be similar to one another. Hopefully you explored this concept already in Chapter 5. Autocorrelated patterns also can be represented using neutral landscape models, but a more complex algorithm is required to produce the spatial contagion. The patterns with autocorrelation are still neutral landscape models because no particular generating process besides spatial autocorrelation is specified. However, they produce patterns that appear more realistic and allow the user to control the amount of spatial autocorrelation in the habitat. Neutral landscape models with spatial contagion have been used for a variety of studies, including landscape–genetics relationships (Graves et al. 2012), nitrogen cycling (Gergel et al. 2005), and animal movement (With et al. 1999).

This exercise will compare the distribution of patch sizes produced from simple random maps with those generated with a significant degree of spatial autocorrelation. The maps are produced using the multifractal algorithm described above in which the parameter **H** controls the level of autocorrelation. Higher values producing greater spatial autocorrelation, i.e., a more clumped distribution of the habitat. The instructions below will allow you to run QRULE once to a single map for your selected values of *p* and H. Your simulations will comprise only one combination of *p* and H, but comparisons with the results of other class members will allow an evaluation of the full factorial experiment for multiple values of *p* and H.

1. The files needed for this exercise are in the subdirectory **Exercise 3**, including a script file for generating a multifractal map (see *multifract.scr* for map parameters used in this simulation). Open this script file and change the neighborhood rule to the one assigned by your last name in the above exercise. Save this modified file. Only a single execution of QRULE is needed using the *multifract.scr* script file.
2. Use your version of *multifract.scr* to generate a multifractal map with QRULE (*HINT:* it will be very convenient to copy QruleV4.exe to this subdirectory).
3. Rename all resulting files from QRULE (e.g., *rulerun.log to rulerun.mf.log,* etc.) before running QRULE again.
4. We'll next use R to compare results of this map with a random map with the same probabilities. Copy the patch file from the previous exercise, *patch_cfd.ran55.dat*, to this directory.
5. Open R, then open the file *Qcfd.R* in the **New script** dropdown option under **File** menu. Reset to the proper directory in the **setwd** command of Qcfd.R, and run the first part of this program in R (through to the "STOP" comment). The subsequent statistical tests listed in this script (which you may wish to run, but are not required to do) will only work for data sets with one iteration.
6. Copy the plot of the cumulative frequency distributions here.

Q10 What is the value of "Sav" for the random and multifractal case? What differences do you see in the cumulative frequency distributions (CFDs) for the random and mulitfractal maps? (*HINT:* Compare values on the X-axis for the 1, 5, 50, 95, and 99 percentiles shown on the Y-axis)

Q11 What effect does the H parameter have on the patterns produced in the multifractal maps? (*HINT:* multiple runs of Qrule will be necessary to answer this question).

Q12 What will happen if you rerun the mulitfractal case with H = 0.9? (Those that are ambitious might try it).

Q13 What is the advantage of using the cumulative frequency distribution over simple landscape metrics?

Q14 How does the neighborhood rule affect the differences between random and multifractal maps (*HINT:* this requires comparison of your results with those from the other end of the alphabet)?

EXERCISE 4: Neutral Models and Actual Landscapes

One use of neutral landscape models is to produce multiple maps that capture spatial attributes of a real landscape so that the effect of patterns on processes of interest can be evaluated. For example, one may wish to generate spatially neutral maps that have a particular habitat amount and level of spatial autocorrelation that is based on an actual landscape. Gergel (2002) used this approach to generate replicate floodplain landscapes that had set proportions and spatial autocorrelation in different elevation classes. These neutral landscapes then provided the foundation for modeling effects of flooding on nitrogen processing (Gergel et al. 2005). This exercise will compare an actual landscape with random and multifractal neutral landscape models.

1. The "actual landscape" is an image derived from Landsat (30 m resolution) of Antietam, Maryland and rescaled to 120 m resolution to reduce map size and computational expense. This map (***anti_128.map***) has 128 rows and columns and 4 land-cover types. The script file for map analysis (***anti_128.scr***) provides the necessary input to QRULE. Run this script file by typing:

```
QruleV4.exe < anti_128.scr
```

2. Rename files as you have done before.
3. We would like to compare the patterns in this map with a simple random map and with a multifractal map. If your last name begins with letters in the range A–L, then you will make a random vs. actual landscape comparison. Otherwise, you will compare a multifractal map with the actual landscape.
4. The maps you will generate should have the same number of habitat types and values of ***p*** as the actual landscape. For the random map, this means you must

specify ***p*** for each habitat type based on the QRULE analysis of the Antietam map (step 1). For the multifractal maps, you must also select values of H such that your neutral landscape maps have similar levels of habitat clumping. Create the appropriate script file for your case, using the same values of ***p*** that are in the *runrule.anti.log* file. Save the files produced by appropriately renaming of each.

5. You decide how best to compare your neutral maps with the actual landscape.

Q15 List the script file that you used to generate a neutral model for this exercise.

Q16 What metrics are the same, what metrics differ? What differences are statistically significant (i.e., the metric value for the actual landscape lies outside the range in the neutral landscape model) or would be ecologically important?

Q17 Given what you have learned about simple random maps and multifractal maps, are there particular situations in which one or the other might be the most appropriate neutral model? Would you ever expect a real landscape to have random spatial patterns? Explain your reasoning.

Q18 Develop a question from your own research that could be answered by using QRULE and an NLM approach. Provide the rationale for your question (why is it interesting and important?), explain how you would use QRULE to answer your question (i.e., design your simulation experiment), and describe how you would evaluate the results. If you have more time for the assignment, you can even carry out your study!

CONCLUSIONS

Neutral landscape models will continue to play an important role in ecological studies that seek to understand the effects of landscape composition and configuration on ecological processes. NLMs are useful for determining the extent to which landscape metrics deviate from some theoretical expectation and for studies of how ecological processes respond to variation in landscape structure (With and King 1997). NLMs are also important for evaluating the statistical behavior and interpretability of landscape metrics (e.g., Wang and Malanson 2007); any newly introduced metric should be fully evaluated by applying it to a suite of neutral landscape models in which ***p*** and ***H*** are varied. The tools introduced here can be used in a variety of different contexts. However, it is important to remember that NLMs do not represent actual landscapes (and were never expected to do so), rather, they provide a standard against which actual landscapes may be compared, and provide a baseline against which the effects on processes can be evaluated.

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[1] *NOTE:* An asterisk preceding the entry indicates that it is a suggested reading.

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