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## LANDSCAPE ECOLOGY: QUANTIFYING LANDSCAPE PATTERN

### Objectives

- Set up a spreadsheet model of a random landscape.
- Hand-calculate compositional metrics of the landscape.
- Hand-calculate structural metrics of the landscape.

### INTRODUCTION

When ecologists study population processes such as growth, predator-prey relationships, competition, or foraging, they usually consider how these processes operate within a single patch of habitat. That is, most ecological and evolutionary theories assume that local-scale (within-patch) processes drive population processes. But the earth is a patchwork of different habitats, and a mosaic of different patches is called a **landscape**. In recent years, ecologists have come to recognize that, from an ecological and evolutionary perspective, what happens *inside* a patch often depends on what's going on *outside* the patch. For example, when individuals migrate into the patch from an outside location, they affect ecological characteristics such as population size, age and sex structure, and competition. The newcomers also affect evolutionary characteristics such as allele and genotype frequencies. Thus the habitats that surround the patch, as well as their spatial arrangement, can play a very important role in population dynamics.

### Some Definitions

The study of how landscape pattern affects ecological and evolutionary processes is called **landscape ecology**. As Wiens (1995) stated, "The underlying premise of landscape ecology is that the explicit composition and spatial form of a landscape mosaic affect ecological systems in ways that would be different if the mosaic composition or arrangement were different." In other words, if you change the number of patches, types of patches, and/or arrangement of patches in the landscape, the ecology and evolution of a population in a given patch will be affected. Turner et al. (2001) stress that landscape ecology is a subdiscipline of ecology that explicitly addresses the importance of spatial configuration for ecological processes.

At this point you might be wondering, What does a landscape look like?, and Exactly how large is a landscape? If you've ever looked out the window of an airplane, more than likely you saw a collection of different habitats, such as farms, fields, streams, forests, and wetlands—in other words, a mixture of different habi-

tats. A **landscape** consists of two or more habitats or ecosystems that can potentially interact in some way (Urban et al. 1987). How large the landscape of study should be depends on the organism you are studying, how it interacts with its environment, and how processes outside its patch affect its biology. Thus, landscape pattern can affect organisms from a beetle in your backyard (a landscape of a few square meters) to a moose in a northern hardwood forest (a landscape of several square kilometers).

Several terms commonly used in landscape ecology are given in Table 1. Since landscape ecology focuses on spatial patterns of cover types and how they affect ecological processes, it is important to be able to describe a landscape quantitatively. This quantitative information is important for several reasons (Turner et al. 2001). You might be interested in knowing how landscape patterns change over time. You might also be interested in comparing different landscapes and determining how similar or dissimilar they are; the two landscapes in Figure 1, for instance, differ in several ways that can be quantified. And finally, modelers are often interested in determining how a specific change (due to management or development, for example) will affect the biotic and abiotic processes within the landscape. In order to quantitatively study landscape ecology, a means of depicting the various habitat types and their arrangements is needed. In this exercise, we'll use a spreadsheet to depict a landscape in which each cell consists of a given cover (habitat) type.

TABLE 1. Some terms used in landscape ecology

Term	Definition
Configuration	The specific arrangement of spatial elements; often used synonymously with spatial structure or patch structure.
Connectivity	The continuity of a habitat or cover type across a landscape (a measure of how extensively patches of a certain type are connected to each other).
Corridor	A relatively narrow strip of a particular cover type that differs from the areas adjacent on both sides.
Cover type	The category of cover to which a patch belongs. Categories for cover types are defined by the user according to a classification scheme that distinguishes among the different habitats, ecosystems, or vegetation types on a landscape.
Edge	The portion of an ecosystem or cover type near its perimeter and within which environmental conditions may differ from interior locations in the ecosystem; also used as a measure of the length of a boundary between cover types on a landscape.
Fragmentation	The breaking up of a habitat or cover type into smaller, disconnected parcels.
Heterogeneity	The quality or state of consisting of dissimilar elements, as with mixed habitat or cover types occurring on the landscape; opposite of homogeneity, in which elements are the same.
Landscape	An area that is spatially heterogeneous in a least one factor of interest.
Matrix	The background cover type in a landscape, characterized by extensive cover and high connectivity; not all landscapes have a definable matrix.
Patch	A surface area that differs from its surroundings in nature or appearance.
Scale	The spatial or temporal dimension of an object or process, characterized by both grain and extent.

After Turner et al. 2001.

0.5	0.85	0.07	0.26	0.07	0.44	0.4	0.05	0.48
0.48	0.79	0.67	0.61	0.01	0.79	0.85	0.63	0.97
0.12	0.96	0.64	0.43	0.99	0.08	0.25	0.05	0.62
0.05	0.84	0.01	0.42	0.89	0.38	0.57	0.86	0.56
0.32	0.94	0.21	0.92	0.31	0.17	0.57	0.33	0.51
0.1	0.49	0.56	0.1	0.57	0.22	0.7	0.52	0.37
0.55	0.94	0.96	0.16	0.83	0.87	0.19	0.89	0.9
0.93	0.62	0.96	0.69	0.06	0.83	0.45	0.05	0.56

0.8	0.52	0.33	0.25	0.78	0.03	0.61	0.33	0.62
0.02	0.96	0.3	0.46	0.47	0.09	0.18	0.91	0.65
0.86	0.37	0.41	0.58	0.48	0.62	0.95	0.97	0.22
0.1	0.99	0.04	0.87	0.63	0.35	0.62	0.94	0.46
0.62	0.11	0.71	0.8	0.1	0.7	0.96	0.89	0.31
0.45	0.27	0.02	0.06	0.86	0.65	0.76	0.64	0.34
0.38	0.22	0.4	0.41	0.58	0.32	0.34	0.21	0.43
0.3	0.86	0.57	0.71	0.38	0.9	0.27	0.97	0.77

**Figure 1** In each the two different landscapes shown, two cover types occur (dark- and light-shaded habitats). Thus, both landscapes are heterogeneous because they contain a mix of cover types. The landscape at the top consists of the dark-shaded habitat type embedded within a matrix that consists of the light-shaded habitat type. The reverse is true for the landscape at the bottom.

**Patch Metrics**

Several “metrics” are used to describe a single patch in the landscape (McGarigal and Marks 1995). These include:

- Patch size
- Amount of edge
- Perimeter-to-area ratio
- Amount of core habitat

Before we can calculate these metrics, we need to know how an organism perceives its environment. If an organism has narrow dispersal abilities and strict habitat requirements, it may “perceive” only those cells in the immediate cardinal directions (north, south, east, and west) from the patch on which it is located. If any of those four cells are of the same habitat type, they are considered to be part of the patch. A more highly mobile organism may be able to range farther afield and its potential patch may be much larger. Figure 2 demonstrates how the patches in a landscape may vary with the organism being considered. *In this exercise, we will use assume that organisms have a limited perception of their landscape and perceive only those cells in the immediate cardinal directions as being part of the same patch.*

Once you have decided what “rule” to use in defining patches, you can then calculate the patch metrics of patch size, amount of edge, perimeter-to-area ratio, and the amount of core habitat. Let’s consider the patterns in Figure 3. Figure 3 depicts a landscape in which cells A26–C30 and cells E26–G30, consist of 10 × 10 meter pixels (cells),

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	<b>Patch "rules"</b>													
2														
3	Species 1				Species 2				Species 3					
4														
5														
6														
7														
8														
9														
10														
11														
12														
13														
14	2 patches				1 patch				1 patch					
15														

**Figure 2** Let's suppose an organism of species 1 has narrow dispersal abilities and is situated on the habitat in cell B5. For a study this organism, the landscape in cells A9–C13 consists of two patches, not one, because species 1 perceives this pattern as two patches. Suppose species 2 located on cell F5 is a more highly mobile organism or one with a broader home range. It perceives all adjacent and diagonal pixels as part of a patch. For species 2, the landscape shown in cells E9–G13 consists of a single patch. Finally, species 3 is an organism that is very mobile with very broad perspective of "habitat type." If this organism is situated on cell K5, it perceives not only the cells immediate to it, but also one cell beyond its location. Thus, the habitats in cells J9–M13 consists of a single patch.

and the habitat for our organism of interest is shaded. "Nonhabitat" is not shaded. Thus, we are examining two landscapes, each with a **grain** of 10 m × 10 m = 100 square meters, and each with an **extent** of 30 m × 50 m = 1500 square meters. The figure describes the different metrics in each landscape.

	A	B	C	D	E	F	G	H
25								
26								
27								
28								
29								
30								
31								
32								

**Figure 3** Assuming the patch rules for species 1 in Figure 2, there is one patch in the left landscape. Its **size** is 3 cells (unitless for this example), and it has **8 edges** (borders of the patch that abut nonhabitat), so its **perimeter** is 8. Its **perimeter-to-area ratio** is  $8/3 = 2.67$ . It has no **core habitat** cells (cells that are completely surrounded by habitat). The right landscape has two patches. The larger patch contains 10 cells, and the smaller patch is 1 cell. The small patch has 4 edges, the large patch has 18 edges. The small patch has no core habitat, but the large patch has 1 cell of core habitat (cell F27). Patch 1 in the right landscape has a perimeter-to-area ratio of  $4:1 = 4$ , while the large patch has a perimeter:area ratio of 18:10. Note that if cell F27 were not shaded, the large patch would have a "hole" in it. Edges inside a hole are also counted as edge because they may be biologically significant.

### Landscape Metrics

Several other metrics are used to describe the landscape as a whole (the patch plus the surrounding mosaic of patches), and include both landscape composition metrics and landscape structure metrics. **Landscape composition** metrics describe the amounts and types of different habitats. For example, to say that a landscape contains 49% forest is a compositional metric. The landscape on the left in Figure 3 is composed of 20% habitat and 80% nonhabitat, since 3 of 15 cells are habitat. The landscape on the right is composed of 73% habitat and 27% nonhabitat. Compositional measures do not tell you how this habitat is arranged on the landscape (McGarigal and Marks 1995). Other compositional metrics include proportion of landscape in each habitat type, patch richness (the number of different kinds of habitat in the landscape), and patch diversity (a measure of how heterogeneous a landscape is).

In contrast to landscape composition, **landscape structure** metrics describe the spatial positions of the different habitats in relation to each other. For example, if we state that the average distance between forest patches is 10 kilometers, this gives an indication of how the forest is structured on the landscape. In the right-hand landscape in Figure 3, the distance between the small and large patch is 14.14 meters. This is calculated by measuring the distance between the centers of the closest cell of one patch and the closest cell of the nearest patch. In other words, the center of cell F29 is one column over and one row up from center of cell F30. Think back to geometry and the Pythagorean theorem and recall that you can calculate the distance of any side of a right triangle as long as the distances of two of the sides are known. The Pythagorean theorem has the formula  $c^2$  (the hypotenuse) =  $a^2 + b^2$  (the sum of the squares of the two sides). Since we know that two sides are 10 meters (one cell over and one cell up), the distance of the hypotenuse is the square root of  $10^2 + 10^2$ , or the square root of 200, about 14.14 meters. Other structure metrics include patch isolation, connectivity, and juxtaposition.

### PROCEDURES

In this exercise, you'll set up a spreadsheet to simulate a hypothetical landscape and will learn how to describe the landscape in terms of structure and composition. There are many ways to compute landscape statistics; we will cover only a few of the more commonly used statistics. You'll calculate these metrics by hand so that you learn how the various metrics are computed.

As always, save your work frequently to disk.

#### INSTRUCTIONS

##### A. Set up the landscape model.

1. Open a new spreadsheet and set up column headings as shown in Figure 4.

#### ANNOTATION

	A	B	C	D	E	F	G	H	I	J
1	<b>Introduction to Landscape Ecology</b>									
2										
3										
4	0.1631	0.4508	0.5682	0.2302	0.9776	0.3677	0.0742	0.1355	0.0698	0.103
5	0.2921	0.1699	0.9612	0.6314	0.0277	0.849	0.1439	0.8589	0.5483	0.9084
6	0.5429	0.098	0.8119	0.4506	0.6031	0.3347	0.8126	0.447	0.5056	0.9367
7	0.9818	0.6908	0.8018	0.0009	0.905	0.9679	0.8104	0.4215	0.2531	0.9104
8	0.7391	0.8307	0.592	0.8579	0.2154	0.29	0.0993	0.4353	0.3283	0.9592
9	0.4216	0.8416	0.887	0.5977	0.912	0.7651	0.6775	0.1763	0.326	0.9189
10	0.4755	0.46	0.6538	0.3328	0.5675	0.475	0.5947	0.5843	0.9761	0.6065
11	0.169	0.6097	0.8339	0.2717	0.656	0.9126	0.6463	0.1211	0.8555	0.3289
12	0.9707	0.2197	0.9718	0.8265	0.975	0.6303	0.1984	0.0753	0.1479	0.5283
13	0.2357	0.7301	0.8224	0.015	0.3199	0.6415	0.2775	0.6757	0.7031	0.6149

Figure 4

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2. In cell A4, enter the formula `=RAND()`, and copy this formula over and down to cell J13.

3. Conditionally format cells A4–J13.

4. Press F9 until you generate a hypothetical landscape of your choice.

5. Paste the *values* (instead of the functions) into the spreadsheet to “fix” your landscape in the arrangement you selected in step 4.

**B. Calculate landscape and patch metrics.**

1. Open a new spreadsheet and set up column headings as shown in Figure 5 (facing page).

2. In cell M3, calculate the **grain** of your landscape as the size of the individual units of observation.

3. In cell O3, calculate the **extent** of your landscape as the overall area of investigation.

4. In column M, calculate patch metrics by hand.

We’ll consider a random landscape that consists of several cells (100 to be exact), where each cell is a kind of habitat. The cells can be of size or resolution that you want. For example, if the landscape “photo” was taken from outer space by a satellite, the cells might be 50m × 50m. If the “photo” was taken from a low-flying airplane, the cells might be 10m × 10m. This is called the **map resolution** or **map grain**. The grain or resolution of the landscape can affect how you interpret your landscape.

Imagine for now that your spreadsheet consists of squares rather than rectangles and that each cell on your spreadsheet represents a 50m × 50m cell. We’ll suppose that the habitat that best describes a cell of land is either forest (green), field (yellow), or other (white). To conditionally format a cell, select cells A4–J13, then go to Format | Conditional Format. A dialog box will appear. For condition 1, if a cell value is between 0 and 0.3, format the pattern as yellow (for field habitat). For condition 2, if a cell value is between 0.3 and 0.7, format the pattern of the cell as green (for forest habitat). Click OK and your cells will be formatted according to the random number associated with it.

Because the **RAND** function was used, every time F9 is pressed, the spreadsheet will generate a new random number between 0 and 1. Your conditional formats will then change as the random numbers change. (If your calculation key is set to automatic, the program will automatically recalculate any functions when you hit the return key. If you wish to set your calculate key to manual, go to Tools | Options | Calculation and select Manual calculation.)

Select cells A4–J13, then copy the cells and paste their values directly onto the landscape. Now you can calculate the metrics that describe your landscape.

You may want to get out a scratch sheet of paper so that you can keep track of each patch on the landscape more effectively.

For example, if a cell is 50 m × 50 m, the grain is 2500 m<sup>2</sup>.

For example, if your landscape is 9 cells × 20 cells, the extent is 180 cells squared. You will need to convert this to an appropriate unit, which will depend on the grain size.

You should perform these calculations manually (with the help of a calculator if you wish) and enter the values in the appropriate cells

- Count the number of patches of each habitat type in cells M8, M19, and M30.
- Calculate the area of the largest and smallest patches in the landscape.
- Calculate the mean patch size and standard deviation of patch sizes for each habitat type.

	K	L	M	N	O	P
1	<b>LANDSCAPE METRICS</b>					
2						
3		<b>Grain =</b>		<b>Extent =</b>		
4						
5	<b>Patch composition</b>			<b>Landscape composition and structure</b>		
6						
7	<b>Forest habitat</b>					
8		Number of patches =			Total forest =	
9		Largest patch =			Total field =	
10		Smallest patch =			Total other =	
11		Average patch size =			Total other =	
12		Std patch size =				
13		Number of edges of largest patch =			Percent forest =	
14		Perimeter of largest patch =			Percent field =	
15		Fractal dimension of largest patch =			Percent other =	
16		Nearest neighbor to largest patch =				
17					Forest total core =	
18	<b>Field habitat</b>					
19		Number of patches =			Field total core =	
20		Largest patch =			Other total core =	
21		Smallest patch =			Patch richness =	
22		Average patch size =			Patch diversity =	
23		Std patch size =				
24		Number of edges of largest patch =				
25		Perimeter of largest patch =			Total forest edge =	
26		Fractal dimension of largest patch =			Total field edge =	
27		Nearest neighbor to largest patch =			Total other edge =	
28						
29	<b>Other habitat</b>					
30		Number of patches =				
31		Largest patch =				
32		Smallest patch =				
33		Average patch size =				
34		Std patch size =				
35		Number of edges of largest patch =				
36		Perimeter of largest patch =				
37		Fractal dimension of largest patch =				
38		Nearest neighbor to largest patch =				

Figure 5

- For the largest patch only, count the number of edges in the patch.
- For the largest patch only, calculate perimeters as the number of edges × the number of meters per side per cell. For example, if a cell is 10 m × 10 m, and there are 4 edges, the perimeter is 4 × 10 m = 40 m.
- Calculate the fractal dimension of the largest patch.

The **fractal dimension** ranges between 1 and 2, and gives some indication of how complex a patch is. When the fractal dimension is 1, the patch has a simple shape, such as square. When the fractal dimension is 2, the patch has a more complex structure that is convoluted in shape. The formula for calculating the fractal dimension of a patch is 2 times the log of the patch perimeter divided by the log of patch area. A small correction factor 0.25 is incorporated due to the nature of the “pixels” or cells in your spreadsheet:

$$fractal = \frac{2 \ln(0.25 \times perimeter)}{\ln(area)}$$

- For the largest patch only, calculate the distance to the nearest patch of the same habitat type. Find the closest cell in the closest patch to the closest cell in

5. In column P, calculate landscape metrics.

the largest patch. Once you have identified the two cells of interest, you can calculate the distance using the Pythagorean theorem.

Landscape metrics simply describe the collection of patch matrixes taken together.

- Calculate the total area of forest, field, and other habitat in cells P9–P11.
- Calculate the percent forest, field, and other habitat as the total area of the habitat of interest/extent.
- Calculate the total area of core habitat for forest, field, and other habitat in cells P17–P19.
- Calculate the patch richness as the total number of habitat types on the landscape. You should have a patch richness of 3. However, it is possible that due to the random assignment of habitats to cells that richness is less than 3!
- Calculate patch diversity using the Shannon-Weiner diversity index.

The **Shannon-Weiner diversity index** gets larger when the patch richness is high and/or when the proportion of the various habitats are equitable across the landscape. First, you will calculate the proportion ( $P_i$ ) of each habitat type in the landscape (e.g., forest is 0.40 of the landscape, field is 0.30 of the landscape, and other is 0.30 of the landscape). Next, take the log of each proportion, and multiply it by the original proportion (e.g., forest is 0.40 of the landscape,  $\ln(0.40) = -0.916$ , and  $-0.916 \times 0.40 = -0.366$ ). Repeat for the other habitat types, and sum the total values. Finally, take the negative of that the sum. The Shannon-Weiner formula is

$$diversity = -\sum_{i=1}^n (P_i \times \ln P_i)$$

- Calculate the total forest edge, total field edge, and total other edge in cells P25–P27.

6. Interpret your results. Then compare and contrast your results with a partner (who presumably analyzed a different landscape).

### QUESTIONS

1. In this exercise, you defined a patch as a series of cells or pixels that are connected by a common side in any of the four cardinal directions. How does changing the definition of a patch affect your landscape statistics? How should a patch be defined so that it has biological meaning to a particular organism or unit of management?
2. Each pixel or cell in the landscape you measured consists of a certain kind of habitat. If a pixel is 50 m × 50 m, how is that “piece” of land assigned a habitat value, when it may in fact be comprised of many different habitat types? What sort of “errors” might be made in categorically assigning a habitat to each pixel?
3. Consider the two landscapes shown at the top of the next page. Landscape A has an extent of 81 cells; landscape B has an extent of 121 cells. Note that the interior cells of landscape B are identical to those in landscape A. How does the extent of your map influence your landscape analysis? Consider average patch size for both landscapes and how map extent affects this metric. In general, how does the landscape composition *beyond your landscape boundaries* affect your metrics?



**Landscape A: Extent = 81 cells**

1	0	0	0	1	0	1	1	0
0	0	0	1	0	0	0	1	0
1	0	0	0	1	0	1	0	1
0	1	1	0	0	0	1	1	1
1	0	0	1	1	1	0	1	0
0	0	1	0	1	0	0	0	0
1	0	1	1	1	0	0	0	1
1	0	1	1	1	0	0	1	0
0	0	1	1	1	1	0	0	1

**Landscape B: Extent = 121 cells**

0	0	0	1	0	0	0	1	1	1	1
1	1	0	0	0	1	0	1	1	0	0
1	0	0	0	1	0	0	0	1	0	1
0	1	0	0	0	1	0	1	0	1	1
1	0	1	1	0	0	0	1	1	1	1
0	1	0	0	1	1	1	0	1	0	0
0	0	0	1	0	1	0	0	0	0	0
1	1	0	1	1	1	0	0	0	1	0
0	1	0	1	1	1	0	0	1	0	1
1	0	0	1	1	1	1	0	0	1	0
1	1	1	1	0	0	0	1	0	1	1

4. How does grain influence your landscape analysis? Examine the landscape below, which consists of two habitat types. Both landscapes consists of  $10 \text{ m}^2$  pixels, so the extent of the landscape is  $90 \text{ m} \times 90 \text{ m} = 8100 \text{ m}^2$ . The landscape on the left has a fine resolution—each pixel is a  $10 \text{ m}^2$  habitat type (1 cell represents  $10 \text{ m}^2$  of habitat, so the grain =  $10 \text{ m}^2$ ). The landscape on the right has a broad resolution; each large  $3 \times 3$  square represents a single habitat type, so the grain = 9 cells =  $90 \text{ m}^2$ . How would you “reassign” each  $3 \times 3$  cell to a specific habitat type in the right-hand landscape? How does a change in grain size affect a landscape metric, such as number of patches?

<i>n</i> = 1						<i>n</i> = 9								
0	1	0	1	1	0	1	0	0	0	1	1	0		
1	0	0	0	1	0	0	0	1	0	0	0	1	0	
0	1	0	1	0	1	1	0	0	1	0	1	0	1	
0	0	0	1	1	1	0	1	1	0	0	1	1	1	
1	1	1	0	1	0	1	0	0	1	1	1	0	1	0
0	1	0	0	0	0	0	0	1	0	1	0	0	0	0
1	1	0	0	0	0	1	1	0	1	1	0	0	0	1
1	1	0	0	1	0	1	0	1	1	1	0	0	1	0
1	1	1	0	0	1	0	0	1	1	1	1	0	0	1

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