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RESERVE DESIGN

In collaboration with Wendy K. Gram

Objectives

- Set up a spreadsheet model of a nature reserve with two different habitats.
- Calculate and compare abundances of species with different habitat requirements in nature reserves.
- Determine the optimal habitat configuration to maximize total abundance of two species with different habitat associations.

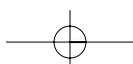
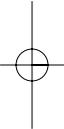
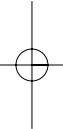
*Suggested Preliminary Exercise: Landscape Ecology:
Quantifying Landscape Pattern*

INTRODUCTION

A major threat to biological diversity is loss of habitat, including fragmentation of large tracts of habitat. Conservation biologists are often responsible for designing nature reserves, or protected areas, that provide different habitats to support a variety of species. Determining the best configuration of habitats requires information about the association of each species with available habitats. Some species may simply require a patch of associated habitat, regardless of the surrounding habitat type or the amount of associated habitat within the reserve. For these species, species density in the landscape will be constant regardless of the amount of associated habitat in the reserve. For example, for the lizard species depicted in Figure 1, as long as the proportion of its habitat is greater than 0, density will be 5 individuals per unit area.

Other species, however, may have densities that are directly related to the total amount of associated habitat in the reserve. Such species, called *landscape-sensitive* species, are sensitive to the amount of total habitat in the reserve, and their densities will vary relative to the proportion of associated habitat available within the reserve. For example, the distribution pattern of the frogs in Figure 2 shows a **threshold effect** because densities are very low until a certain critical level of habitat is reached in the reserve.

If the frog and the lizard species require different habitats and both species are high conservation priorities, how should we manage the reserve to maximize the number of individuals of both species? To determine the best habitat configuration to conserve both species, we need to know the association of each species with



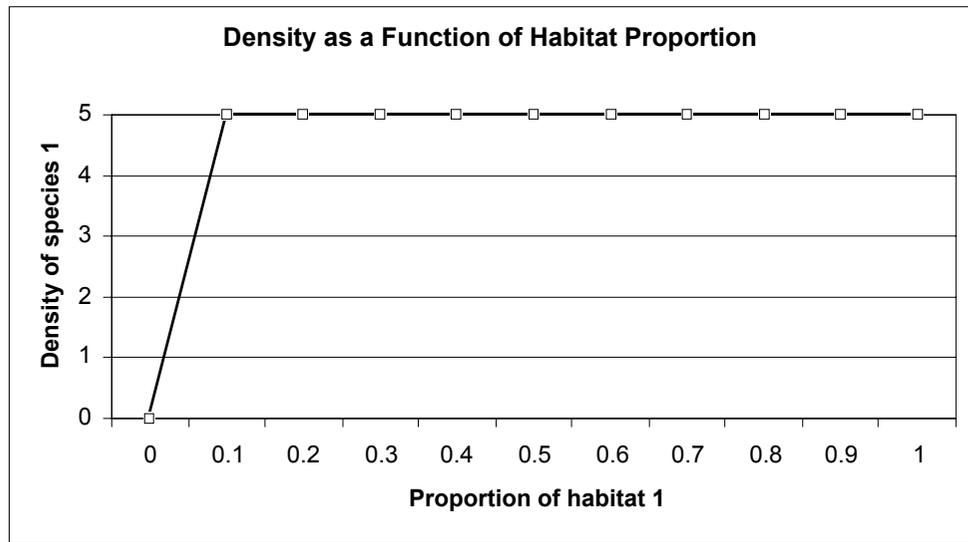


Figure 1 Density of a forest lizard species (numbers of individuals per unit area) that occur when the reserve consists of varying amounts of its preferred habitat.

its required habitat, as shown in the figures, and then compute the total number of individuals that occur for each species under various habitat amounts.

Obviously, to maximize lizards we would manage the reserve so that 100% of the habitat is lizard habitat, and to maximize frogs, we would manage the reserve so that 100% of the habitat is frog habitat. But how can we maximize both species simultaneously? Figure 3 shows how many lizards and frogs will occur in the reserve when the reserve consists of varying amounts of frog and lizard habitat. From curves like these, we can evaluate the best habitat configuration for a specific conservation objective.

Maximizing Habitat and Population Sizes

How you “design” this reserve clearly depends on the habitat requirements of species of conservation interest. Assuming that species 1 is only found in habitat 1 and species

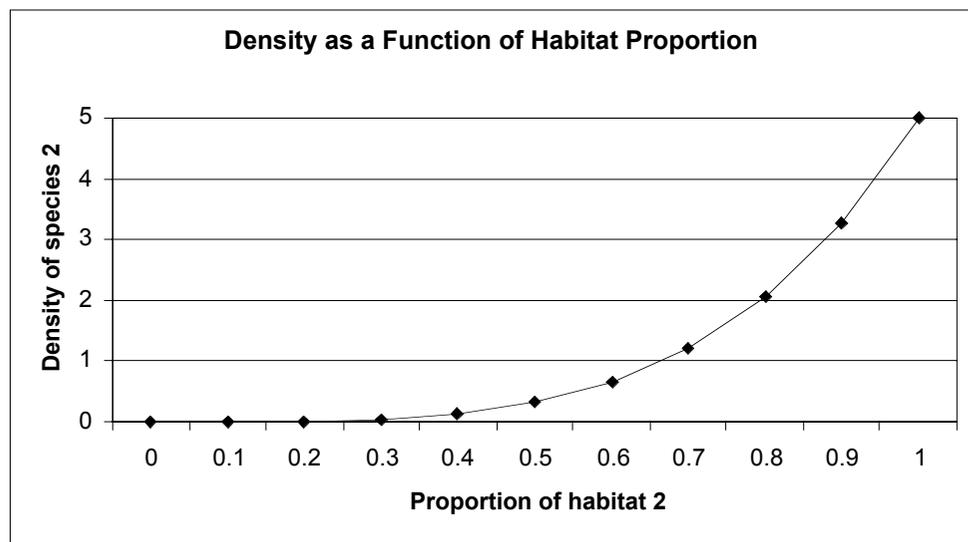


Figure 2 Density of this frog species is approximately 1 individual per ha when 70% of the landscape is bottomland forest habitat, but increases to approximately 3 individuals per ha when 90% of the landscape is bottomland forest.

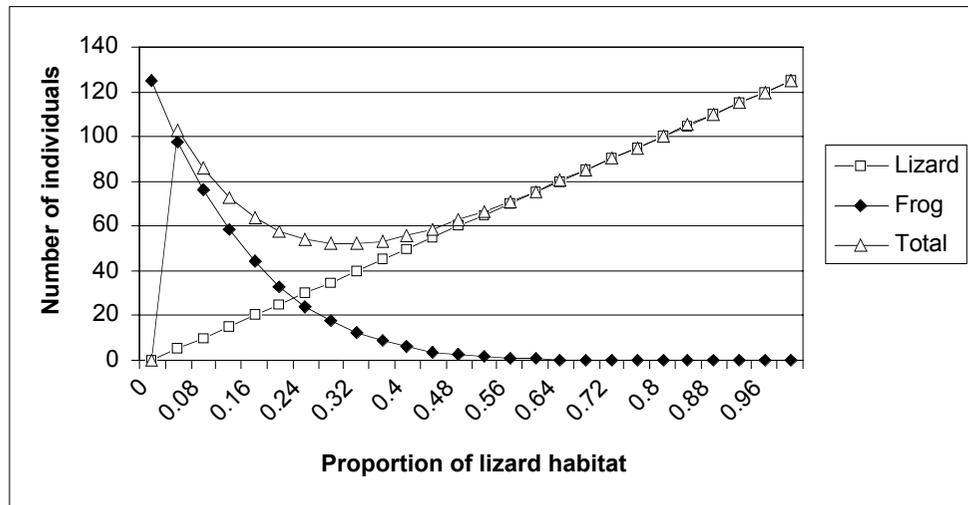


Figure 3 When the reserve consists of 40% lizard habitat and 60% frog habitat, then 50 lizards and about 5 frogs can be supported. Where the two lines intersect (about 24% lizard habitat), both species reach a density that is as high as it can go without compromising the density of the other species.

2 is only found in habitat 2, a species' **density** (number of individuals per spreadsheet cell) can be related to the landscape by the general model

$$N_i = dp_i^z \quad \text{Equation 1}$$

where

- N_i represents the density of species i (the number per spreadsheet cell)
- d represents the maximum carrying capacity per unit area of habitat i
- p_i represents the proportion of the reserve that is habitat i
- z represents the sensitivity of species i to the total amount of habitat for species i in the reserve. For this exercise, we will let z vary between 0 and 10.

This model describes different species-habitat relationships when the values of the habitat parameters, d and z , are changed. The carrying capacity of a habitat (d) determines the maximum density possible in one cell of habitat. This maximum density is "adjusted" downward by the term z . When z equals zero, there is no downward adjustment and the density of species i equals d . Equation 1 simplifies to

$$N_i = d \quad \text{Equation 2}$$

and each cell on the landscape that is habitat i contains the maximum density of individuals for species i . The species reaches its maximum number of individuals when the reserve consists of 100% habitat i . As z increases, the proportion of associated habitat must reach a critical threshold before density increases sharply (as shown in the density curve for species 2). Species that require more total habitat in the reserve are modeled with larger z values, and thus total abundance remains relatively low until the proportion of habitat reaches the critical threshold. An example of such a species might be a large carnivore that requires a lot of habitat.

Habitat and Patch Sizes

In this exercise, the reserve is represented by a block of 25 cells (5×5) on a spreadsheet (Figure 4.) Different habitats are represented by entering 1 or 2 in each cell.

	B	C	D	E	F
7	Landscape				
8					
9	1	1	1	1	1
10	1	2	1	2	1
11	1	1	2	2	2
12	2	2	2	1	2
13	2	2	2	2	2

Figure 4

As a conservation manager, we will assume that you can “design” your reserve in any way you’d like. You must consider how many cells should consist of habitat 1 or habitat 2, but also must consider the spatial arrangements of the different habitats. For example, Figure 5 shows two potential reserve designs that consist of 48% habitat 1 and 52% habitat 2.

	B	C	D	E	F
9	1	1	1	2	2
10	1	1	1	2	2
11	1	1	2	2	2
12	1	1	2	2	2
13	1	1	2	2	2
14					
15					
16					
17	1	2	1	2	1
18	2	1	2	1	2
19	1	2	1	2	1
20	2	1	2	1	2
21	1	2	1	2	1

Figure 5

Some species are dependent on a minimum size *patch* of habitat to persist; these species are described as **area-sensitive**. For example, some species require not only that the cell be of habitat *i*, but also that any adjoining cell (including diagonals) also consists of habitat *i*. Assume, for example, that the reserve in Figure 6 has two habitats, with each cell representing 1 ha of habitat. The largest patch of habitat 1 in this reserve is 4 ha (counting the number of cells of the same habitat that are adjacent to any one cell, including diagonals; there are two such patches). A species that requires habitat patches of at least 5 ha would not persist in a reserve with this habitat configuration, even if the total amount of habitat in the reserve was large enough for the species to occur. Keeping the proportion of habitats the same, an alternative spatial configuration is necessary for such an area-sensitive species to occur. Clearly, spatial arrangement of habitat patches must be considered in reserve design if conservation objectives are to be achieved.

	B	C	D	E	F
9	1	1	2	2	2
10	1	2	1	2	2
11	2	2	2	2	1
12	1	1	2	2	2
13	1	1	2	1	2

Figure 6

For area- and landscape-sensitive species, conservation managers must overcome two major obstacles: they must ensure both that patch sizes within a reserve are large enough for the species to occur, and that the total amount of habitat in the reserve is enough. This is a crucial element in conservation reserve design: habitat requirements at two or more spatial scales must often be met in order to achieve conservation objectives. As you will see, the solution is not always easy.

PROCEDURES

In this exercise, you will use a spreadsheet to design a reserve that provides habitats for two species, each of which requires a different habitat. The goal is to configure the reserve to maximize total abundance across both species while maintaining a predetermined, minimum abundance of each species. As always, save your work frequently to disk.

INSTRUCTIONS

A. Set up the model reserve.

1. Open a spreadsheet and set up the headings as shown in Figure 7.

ANNOTATION

	A	B	C	D	E	F
1	Designing Landscapes for Conservation					
2						
3			Objective:	d	Prop:	z
4		Species 1	20	5		0
5		Species 2	20	5		10
6						
7		Landscape				
8						
9		1	1	1	1	1
10		1	1	1	1	1
11		1	1	2	2	2
12		2	2	2	2	2
13		2	2	2	2	2

Figure 7

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2. In cells C4 and C5, enter the minimum number of individuals of each species that you would like to maintain in the area (your objective).

3. In cells D4 and D5, enter the maximum density per patch for each species.

4. In cells F4 and F5, enter a scaling factor for each species.

5. In cells B9–F13, enter the values 1 or 2 as shown in Figure 7.

6. Conditionally format cells B9–F13 so that a value of 1 is shaded one color and a value of 2 is shaded a different color.

7. In cells E4 and E5, use the **COUNTIF** formula to calculate the proportion of the landscape that is habitat 1 and 2, respectively.

8. Save your work.

B. Examine the sensitivity of each species to the total amount of habitat in the landscape.

Enter the number 20 in cells C4 and C5.

Wildlife and conservation biologists often predetermine their objectives. For example, a conservation objective may be “Maintain a minimum of 20 individuals on the landscape for the next 10 years.” You’ll consider two species (species 1 and species 2) that occur in the region, and would like to maintain *at least* 20 individuals of each species.

Enter the number 5 in cells D4 and D5.

The parameter labeled *d* represents the maximum density that a patch of habitat (a cell in the spreadsheet) can maintain. For now, the maximum density is 5 individuals per spreadsheet cell. You can change this parameter later to model species that are naturally abundant or rare.

Enter the number 0 in cell F4.

Enter the number 10 in cell F5.

The parameter labeled *z* is a **scaling factor** that controls how density per spreadsheet cell is modified depending on the proportion of reserve that consists of habitat 1 and the proportion of the reserve that consists of habitat 2. For this exercise, *z* can take on values between 0 and 10. When *z* = 0, the species’ density (number of individuals per spreadsheet cell) is unaffected by how much habitat in the potential reserve consists of habitat 1 and how much habitat in the potential reserve consists of habitat 2 (the species is landscape insensitive). When *z* = 1, as its proportion of the reserve increases, the density per cell increases linearly. When *z* > 1, density increases very slowly until some critical threshold amount of habitat in the reserve is attained, then densities increase to their full potential (these are landscape-sensitive species). Given *d* and *z* for two species, your job is to determine how much habitat of each type (1 and 2) should be managed to achieve the population sizes listed in cells C4 and C5.

Cells B9–F13 represent the cells of habitat in the reserve. As a biologist, you can manage this landscape within the reserve in any way you choose (by changing the type of habitat associated with a cell). By entering 1s and 2s in cells B9–F13, our initial landscape consists of a mix of habitat 1 (which is good for species 1, but not good for species 2) and habitat 2 (which is good for species 2, but not for species 1). Soon we’ll change some of these habitat cells so that the mix of different habitat types varies.

To better visualize the landscape composition, highlight cells B9–F13, then open **Format | Conditional Formatting**. Format cells equal to 1 as one color, and cells equal to 2 as a second color.

Enter the formula **=COUNTIF(B9:F13,1)/25** in cell E4.

Enter the formula **=COUNTIF(B9:F13,2)/25** in cell E5.

The **COUNTIF** formula counts the number of cells within a range that meet the given criteria. It has the syntax **COUNTIF(range,criteria)**.

Let’s take time now to get a better handle on how *d* is adjusted per cell depending on the proportion of habitat in the landscape and *z*.

1. Set up new headings as shown in Figure 8.

	H	I	J
1	Density - Proportion Relationships		
2		Species 1	Species 2
3	z =	0	10
4	d =	5	5
5	Proportion of habitat 1	Density	Density
6	0		
7	0.1		
8	0.2		
9	0.3		
10	0.4		
11	0.5		
12	0.6		
13	0.7		
14	0.8		
15	0.9		
16	1		

Figure 8

2. Set up a linear series from 0 to 1 by units of 0.1 in cells H6–H16.

3. Enter formulae in cells I3–J4 to link z and d for each species back to cells D4–D5 and F4–F5.

4. In cells I6–I16, enter a formula to compute the density for species 1 as the proportion of habitat 1 changes.

5. In cells J6–J16, enter a formula to compute the density for species 2 as the proportion of habitat 2 changes.

6. Graph density as a function of the proportion of habitat 1 in the landscape.

Enter 0 in cell H6.

Enter = **H6 + 0.1** in cell H7. Copy this formula down to cell H16.

Enter the following formulae:

- I3 =F4
- I4 =D4
- J3 =F5
- J4 =D5

Enter the formula =**I\$4*(H6^I\$3)** in cell I6. Copy the formula down to row I16.

This is simply the base density multiplied by the proportion of habitat 1 raised to the power of z .

Enter the formula =**J\$4*(1-H6)^J\$3** in cell J6. Copy the formula down to row J16.

This is simply the base density for species 2 multiplied by the proportion of habitat 2 (which is 1 minus the proportion of habitat 1), raised to the power of z for species 2. Remember that the landscape can be composed only of two habitat types, and as the proportion of habitat 1 decreases, the proportion of habitat 2 increases.

Use the scatter graph option and label your axes fully. Your graph should resemble Figure 9.

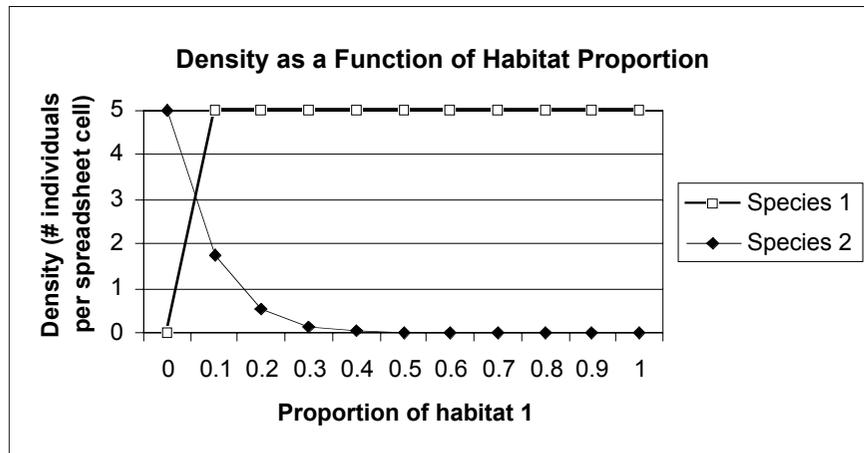


Figure 9

7. Interpret your graph.

8. Examine how changes in z and d affect your graph.

9. Save your work.

C. Populate the reserve with species 1 and 2.

1. Set up new headings as shown in Figure 10.

Change cells D4–D5 and F4–F5 and examine your updated graph. When you feel that you have a handle on how d and z work, return their values to their original entries ($d = 5, z = 0$ for species 1 and $d = 5, z = 10$ for species 2).

	B	C	D	E	F
16	Species 1				
17					
18					
19					
20					
21					
22				total =>	
23					
24	Species 2				
25					
26					
27					
28					
29					
30				total =>	

Figure 10

2. In cells B17–F21, enter a formula to compute the number of individuals of species 1 that live in each cell.

3. In cell F22, enter a formula to sum the total number of individuals of species 1 occupying the landscape.

4. Enter the formula in cells B25–F29 to compute the number of individuals of species 2 occupying each cell of the landscape.

5. Enter a formula in cell F30 to compute the total number of individuals of species 2 on the landscape.

6. Save your work.

D. Determine optimal amounts of habitat 1 and 2.

1. Set up new column headings as shown in Figure 11.

Enter the formula `=IF(B9=1,D4*E4^F4,0)` in cell B17, and copy this formula across and down to cell F21. The formula in cell B17 computes the number of individuals of species 1 that occupies the upper-left corner of our initial landscape (cell B9), based on d , z , and the proportion of the landscape that consists of habitat 1. The formula tells the spreadsheet to evaluate cell B9. **IF** cell B9 is species 1’s habitat (**B9=1**), the program calculates a density of species 1 with the formula `D4*E4^F4`, which is d times the proportion of landscape consisting of habitat 1 raised to the power of z for species 1. If the value does not equal 1, then a 0 is returned, indicating 0 individuals from species 1 occur there.

Enter the formula `=SUM(B17:F21)` in cell F22.

Enter the formula `=IF(B9=2,D5*E5^F5,0)` in cell B25. Copy the formula down and across to cell F29.

The formula in cell B25 is written to compute the number of individuals of species 2 that occupies the upper-left corner of our initial landscape. You’ll notice that the density of species 2 is calculated with the formula `D5*E5^F5`, which are the d , proportion, and z parameters for species 2. How do species 1 and 2 differ in habitat use?

Enter the formula `=SUM(B25:F29)` in cell F30.

Now we will compute the total number of individuals of species 1 and 2 under varying landscape configurations. Cells M4–M29 represent the number of cells in the landscape that consist of a particular habitat type (say, for example, habitat 1). Enter 0 in cell L4.

	L	M	N	O	P	Q
2		Proportion of habitat		Number of individuals		
3		Habitat 1	Habitat 2	Species 1	Species 2	Total
4	0	0	1			
5	1	0.04	0.96			
6	2	0.08	0.92			
7	3	0.12	0.88			
8	4	0.16	0.84			
9	5	0.2	0.8			

Figure 11

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2. In cells L4–L29, set up a linear series from 0 to 25.

3. In cells M4–M29 and N4–N29, enter formulae to calculate proportions of habitats for each value in column L.

4. In cell O4, enter a formula to compute the total number of individuals of species 1 on the landscape when the landscape is composed of the proportion of habitat given in cell M4.

5. In cell P4, enter a formula to compute the total number of individuals of species 2 on the landscape when the landscape is composed of the proportion of habitat given in cell N4.

6. Sum the total number of individuals (species 1 + species 2) in cell Q4.

7. Select cells O4–Q4, and copy them down to cells O29–Q29.

8. Graph the number of individuals of species 1 and 2, as well as the total number of individuals combined, as a function of the proportion of habitat 1.

Enter $=1+L4$ in cell L5. Copy this formula down to cell L29.

Enter the formula $=L4/25$ in cell M4. Copy the formula down to row M29.

Enter the formula $=1-M4$ in cell N4. Copy the formula down to row N29.

The landscape will now consist of varying proportions of habitat 1 and habitat 2, starting with 100% habitat 2 and 0% habitat 1.

Enter the formula $=D\$4*M4^F\$4*L4$ in cell O4.

This is the base density multiplied by the proportion of habitat 1 raised to the z for species 1. This result is multiplied by the number of cells in the reserve that consist of habitat 1 to generate a total number of individuals of species 1.

Enter the formula $=D\$5*N4^F\$5*(25-L4)$ in cell P4.

This is the base density for species 2 multiplied by the proportion of habitat 2 raised to the z for species 2. This result is multiplied by the number of cells in the reserve that consist of habitat 2 to generate a total number of individuals of species 2.

Enter the formula $=SUM(O4:P4)$ in cell Q4.

Your spreadsheet should now look like Figure 12.

	M	N	O	P	Q
2	Proportion of habitat		Number of individuals		
3	Habitat 1	Habitat 2	Species 1	Species 2	Total
4	0	1	#NUM!	125	#NUM!
5	0.04	0.96	5	79.7799163	84.7799163
6	0.08	0.92	10	49.9546722	59.9546722
7	0.12	0.88	15	30.6351074	45.6351074
8	0.16	0.84	20	18.364629	38.364629
9	0.2	0.8	25	10.7374182	35.7374182

Figure 12

Use the line graph option and label your axes fully. Your graph should resemble Figure 13.

9. Save your work.
Answer questions 1–3 at the end of the exercise before proceeding.

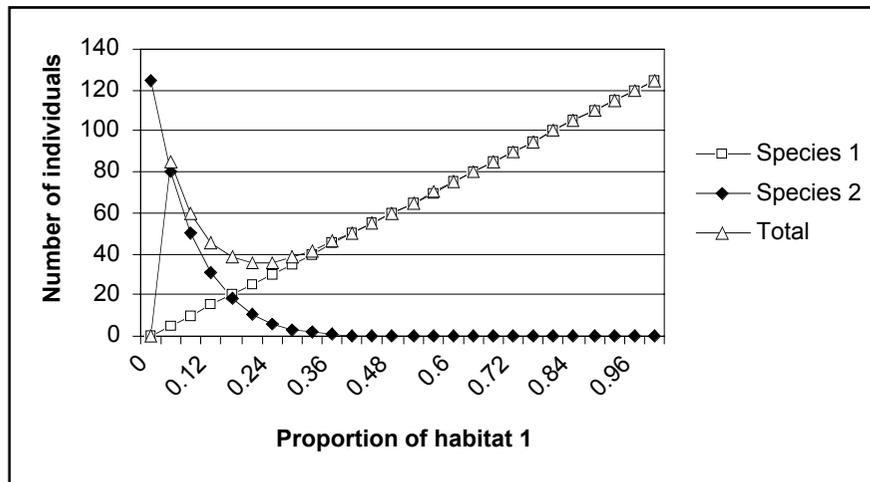


Figure 13

E. Incorporate patch size and spatial configuration in the model.

Up to this point, we have not considered patch size or the spatial arrangement of patches on species distribution. In this section we will incorporate patch size and spatial configuration into the model by letting densities depend on the number of cells that surround a given habitat patch. When this more local-scale habitat importance is included, the configuration (arrangement) of habitat patches in the landscape becomes critical if we are to achieve our conservation goals.

1. Copy columns A–F into a new spreadsheet as shown in Figure 14, and modify your conservation objectives (cells C4–C5), the landscape composition (cells B9–F13), z values (cells F4–F5), and minimum patch size.

	A	B	C	D	E	F	G
1	Designing Landscapes for Conservation						
2							Minimum #
3			Objective:	d	Prop:	z	patch size
4		Species 1	80	5	0.4	1	1
5		Species 2	80	5	0.6	10	2
6							
7		Landscape					
8							
9		1	1	1	1	1	1
10		1	1	1	1	1	1
11		2	2	2	2	2	2
12		2	2	2	2	2	2
13		2	2	2	2	2	2
14							
15							
16		Species 1					
17		2	2	2	2	2	2
18		2	2	2	2	2	2
19		0	0	0	0	0	0
20		0	0	0	0	0	0
21		0	0	0	0	0	0
22					total =>	20	
23							
24		Species 2					
25		0	0	0	0	0	0
26		0	0	0	0	0	0
27		0.03023309	0.030233088	0.030233	0.030233	0.030233	
28		0.03023309	0.030233088	0.030233	0.030233	0.030233	
29		0.03023309	0.030233088	0.030233	0.030233	0.030233	
30					total =>	0.453496	

Figure 14

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2. Enter the values 1 and 2 into cells G4 and G5, respectively.

3. Adjust the formula in cell B17 so that species 1 is present on cell B9 only if it consists of habitat 1 *and* it meets the minimum patch size requirements for species 1. Copy your new formula down and across to cell F21.

4. Adjust the formula in cell F25 so that species 2 is present on cell B9 only if it consists of habitat 2 *and* it meets the minimum patch size requirements for species 2. Copy your new formula down and across to cell F29.

5. Save your work, and answer questions 4–7 at the end of the exercise.

Cells G4 and G5 give the minimum patch size needed for a species to occur. In this way, we are modeling area sensitivity (as opposed to landscape sensitivity). As an example, if cell J11 = habitat 1, and the remaining cells consist of nonhabitat (Figure 15), species 1 will occur on cell J11 only if its minimum patch size is equal to 1. If it requires larger patches, then some of the adjacent cells, including diagonals, must also be habitat 1 for the species to occur on cell J11.

	I	J	K
10			
11		1	
12			

Figure 15

We entered the formula `=IF(AND(B9=1,COUNTIF(A8:C10,1)>=G4),D4*E4^F4,0)` into cell B17. You may have come up with another solution.

Our formula is a nested **IF** formula with **AND** and **COUNTIF** functions embedded within it. The **IF** function requires that *two criteria*, not just one, be met in order for the second portion of the **IF** function to be computed—thus the nesting of the **AND** function within the **IF** function. If both criteria are met, the spreadsheet will compute the equation $D4 \times E4^F4$. *If either criterion is not met, the program will return a 0.* The **AND** function returns the word **TRUE** if all of the conditions in it are true, and the word **FALSE** if any of the conditions are not true. For species 1 to occur on cell B9, cell B9 must equal 1, and the number of 1s in cell B9 and all of its surrounding cells (A8–C10) must be greater than or equal to (\geq) the minimum patch size listed in cell G4. In this way, a species occurrence depends not only on whether a given cell consists of the appropriate habitat, but also on whether that cell has enough adjoining habitat patches to meet the minimum patch size requirement.

We entered the formula `=IF(AND(B9=2,COUNTIF(A8:C11,2)>=G5),D5*E5^F5,0)`.

This formula is conceptually identical to the formula in cell B17, except that our focus is now on species 2 rather than species 1.

QUESTIONS

1. Keeping the parameters as you set them at the beginning of the exercise, and examining the table and graph that you created in section C, determine the optimal habitat proportions to maximize total abundance across the two species while maintaining minimum abundances of 20 for each species. Can you achieve your conservation goals?
2. Keeping the parameters as you set them at the beginning of the exercise, what habitat proportion is optimal to maximize total abundance across the two species while maintaining minimum abundances of 5 for each species? Does

this proportion differ from the optimal proportion that you found when the minimum abundance per species was 20 individuals? Explain your answer.

3. You can change the habitat association of the species by changing the parameters d and z .
 - What happens to total abundance if you increase d ?
 - What happens to total abundance if you increase z ?
 - Generally speaking, what kinds of species “drive” your options for reserve design?
4. Which of the following habitat configurations maximizes total abundance across the two species while maintaining minimum abundances of 5 individuals for each species, using the following parameters:

	B	C	D	E	F	G
2						Minimum #
3		Objective:	d	Prop:	z	patch size
4	Species 1	5	5		1	3
5	Species 2	5	5		3	1

Habitat configuration A

1	2	1	2	1
2	1	2	1	2
1	2	1	2	1
2	1	2	1	2
1	2	1	2	1

Habitat configuration B

2	2	2	1	1
2	2	2	1	1
2	2	1	1	1
2	2	1	1	1
2	2	1	1	1

Habitat configuration C

2	1	2	1	2
2	1	2	1	2
1	2	1	2	1
1	2	1	2	1
1	2	1	2	1

Habitat configuration D

2	2	1	1	1
2	2	1	1	1
2	2	2	2	1
1	1	2	2	1
1	1	2	2	1

5. For species 1, change the minimum patch size to 5 and reevaluate the four habitat configurations in question 3. Does the same habitat configuration maximize total abundance? How does changing the minimum patch size for one species affect the total abundances for each habitat configuration?
6. Set up habitat configuration as follows, with patch size = 2 and $d = 5$ for both species:

2	1	2	1	2
1	2	1	2	1
2	1	2	1	2
1	2	1	2	1
2	1	2	1	2

What values of z (and hence, sensitivity to amount of habitat on the reserve, are possible to maintain an abundance of 5 individuals per species in the reserve?

7. Explore your model. Ask a question pertaining to habitat amount, habitat arrangement, species distribution, and sensitivity, and answer it with your model.