Chapter 9
Simulating Management Actions and Their Effects on Forest Landscape Pattern

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OBJECTIVES

Landscapes are characterized by their structure (the spatial arrangement of landscape elements), their ecological function (how ecological processes operate within that structure), and the dynamics of change (disturbance and recovery). Thus, understanding the dynamic nature of landscapes and predicting their future dynamics are of particular emphasis. Landscape change is difficult to study because controlled experiments at landscape scales often are not feasible for political, economic, social and logistical reasons. Opportunistic studies of change (e.g., after a large fire) are often confounded by uncontrolled factors. For these reasons, changes in landscape pattern are often studied using simulation models. This lab will:

1. Introduce simulation modeling as an important tool of landscape ecology;
2. Show the utility of simulation models for examining landscape change at spatial and temporal scales that are not easily addressed using field methods;
3. Illustrate an applied use of simulation modeling in landscape ecology—examining changes in landscape pattern caused by timber management;
4. Discuss the assumptions and limitations of simulation models; and
5. Show how models can be used to answer questions about landscape pattern and landscape change.

This lab exercise focuses on landscape change produced by forest management, using a timber harvest simulation model. The model you will use is a simplified version of HARVEST (http://www.ncrs.fs.fed.us/4153/Harvest/v61/documentation/), which generates patterns similar to those produced by timber management

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Gustafson and Crow (1999). The model allows you to change the size of timber harvest openings, the total area harvested, and the spatial distribution of harvested areas (whether harvests will be clumped or dispersed). You will determine how different harvest regimes influence the amount of forest interior, amount of forest edge, and the mean patch size of forests. The software and data files needed for this lab can be obtained from the book's website.

INTRODUCTION

Simulation Modeling

Science is a process of ruling out ideas that are *not* true, always leaving some uncertainty about the ideas we think *are* true. The things we accept as scientifically true are actually a collection of conceptual models of how we *believe* the world works and that have withstood multiple attempts to disprove them. When we formalize a conceptual model using mathematical relationships, we have constructed a simulation model capable of generating a prediction based on the initial conditions and the relationships formalized in the model. The utility of simulation models lies in their ability to show the consequences of assumptions as a result of variation in the input parameters. Model assumptions typically are based on an understanding of a process derived from empirical study of the process. Simulation models are built for varying purposes (Karplus 1983). Some are used because they have predictive capabilities (e.g., tree-growth models), some are used to improve our understanding of a newly developed theoretical model (e.g., metapopulation theory), and others illuminate how we might manage an ecological system (e.g., by timber harvest) to produce desired conditions.

Spatial simulation models specifically include the spatial arrangement of key elements of the system being studied. Simulation modeling is especially suited to answer general questions about the spatial implications of interacting processes, especially when manipulative experiments of many combinations of treatments are not feasible. Simulation models also allow control of effects that are difficult to control in empirical experiments. Although stochastic (i.e., based on a random process) spatial models may not be useful to predict the specific location of individual events, they can be used to generate replicate patterns with properties that vary in response to variation in the model inputs. These simulated patterns are assumed to be statistically indistinguishable from those that would be produced in the real world *if the real process behaves as the model has assumed*. Therefore, if comparison of the model results and empirical data reveal a significant difference, we can conclude that our model does not adequately simulate reality. Such a discrepancy also provides an opportunity to reexamine and revise underlying assumptions about the proposed mechanisms for the process that the model represents. Spatial modeling also allows identification of the parameters to which spatial pattern is most sensitive, focusing hypothesis testing and empirical model development. This use provides insight into the implications of the view of reality that is formalized in the model. As such it has heuristic value—that is, it helps clarify our thinking.

When using a simulation model it is critical to understand the sensitivity of model results to changes in the input parameters (Haefner 1996). Large changes in some parameters may have little effect on the model results, whereas small variation in other parameters may induce large effects. Alternatively, model results may be nonlinearly related to the magnitude of the parameter value. An understanding of these model properties is gained by systematically varying input parameters, a process known as **sensitivity analysis**. Here, you will conduct a limited sensitivity analysis of the HARVEST Lite model, and begin to understand the relationship between disturbance (timber management) and landscape pattern.

Because replicated landscape studies involving extensive removal of trees are generally not feasible, the study of how forest spatial pattern is affected by harvesting strategies is facilitated by spatial simulation models. The conceptual basis for landscape-scale simulation of harvest patterns can be traced back at least to the coarse-grid model developed by Franklin and Forman (1987). Other harvest pattern-generation models include LSPA (Li et al 1993), CASCADE (Wallin et al. 1994), HARVEST (Gustafson and Crow 1996), SIMPPLLE (Chew et al 2004), and LANDIS (Gustafson et al. 2000). These models differ in the input data required, and the sophistication of the scenarios they can simulate.

The model you will use is a simplified version of HARVEST (Gustafson and Rasmussen 2005). HARVEST was designed to simulate even-aged timber harvest techniques that regenerate a stand of trees of the same age (e.g., clear-cutting, shelterwood, seed-tree techniques), generating patterns similar to timber management (Gustafson and Crow 1999). HARVEST has been used to predict the effect of alternatives management strategies on forest fragmentation (Gustafson and Crow 1996) and animal habitat (Gustafson and Crow 1994; Gustafson et al. 2001), and evaluate effects of diverse owner management strategies on landscape sustainability (Gustafson et al. 2007). For this exercise, the model was simplified to minimize the input data required and allow the user to experiment with the most interesting and important parameters while minimizing confusion caused by too much complexity. The model enables one to change the size of timber harvest openings, the total area harvested, and the spatial distribution of harvested areas (whether harvests will be clumped or dispersed).

Change in Spatial Pattern

An important spatial consequence of intense disturbance (including even-age timber management techniques) or disease in forested ecosystems is the increased production of edge and reduction of **forest interior habitat**. Although a number of species appear to be sensitive to **edge habitat** (forest that is in proximity to a forest edge), it is not entirely understood why this sensitivity exists. One possible explanation is that the amount of forest habitat found within a given radius of a nest located adjacent to an open area is less than a nest surrounded by forest (King et al. 1997). Another might be the increased predation or brood parasitism rates observed in edge habitats (Brittingham and Temple 1983; Andren and Angelstam 1988). It is also unclear how far negative edge effects permeate into the forest. Effects of light and microclimate on vegetation may extend only a few tens of meters into the forest (Chen et al. 1992). For some forest interior birds, the effect may extend 100–500 m (Andren and Angelstam 1988; DellaSalla and Rabe 1987; Van Horn et al. 1995) although the strongest evidence suggests an effect of only about 50 m (Paton 1994). Conversely, some species prefer edge habitat, and their numbers respond positively to the creation of edge habitat (Litvaitis 1993; Hewison et al. 2001). Likewise, it is not known how far from an edge that the habitat will still be suitable for edge species. Because of these uncertainties, it is useful to quantify the amount of edge and interior habitat using a range of edge-buffer widths. The amount of interior present is quite sensitive to the width of the edge-buffer under certain patterns of forest openings, as you will discover.

The patch structure of landscapes is thought to have a significant effect on ecological communities (Turner 1989). Disturbance usually produces **patches** (i.e., an area with habitat conditions that are different from those surrounding it). The patchiness of a landscape mosaic is the result of the interaction of past disturbance and the heterogeneity of the abiotic environment. Disturbance has the potential to significantly alter the scale of patchiness of the landscape mosaic (Levin 1992). Consequently, monitoring change in patch-based measures of spatial pattern is an important way to assess landscape change, and spatial models provide a tool to investigate how disturbance may affect patchiness (Gustafson 1998).

Change in spatial pattern is also related to the rate of recovery after disturbance. When recovery is quick, disturbance effects are more transient. Timber harvest openings are generally ephemeral—succession occurs and forests regrow. However, the rate of recovery may vary widely depending on a number of factors, most notably climate (precipitation and temperature) and soil conditions, where colder, dryer or unproductive sites may take decades longer to recover than warmer, wetter, or productive sites. For this reason, the persistence of disturbance effects may vary markedly between different parts of the world.

The HARVEST Lite Model

HARVEST Lite is a simple, yet powerful harvest simulator that allows control of the most important determinants of spatial pattern in managed forests. HARVEST Lite allows the user to specify the definition of forest interior and the rate at which harvested areas recover to a closed canopy condition. This requires you to specify the width of the edge-buffer used to calculate forest interior, and how long harvest openings will function as openings, perforating the forest interior. You will find this useful to investigate how changes in these definitions affect spatial pattern. The patch structure of the forest age map is also analyzed by HARVEST LITE. Patches are identified using an 8-neighbor rule, meaning that cells of the same age that share a common edge or are adjacent in a diagonal direction are considered part of the same patch. The model parameters are as follows:

MODEL INPUT

- **Forest age map of initial conditions**. Managed forests are typically divided into stands. A stand is an area with a common history and is relatively homogeneous with respect to forest composition and age. The age of a stand usually reflects the time (yrs) since harvest or other disturbance such as fire or windthrow. Two forest age (stand) maps representing different disturbance histories are supplied for this exercise.
- **Mean harvest size**. This is the average size of harvests (ha) that HARVEST LITE will apply to the landscape. The model will generate harvests from a distribution with this mean size and a standard deviation 10% of this value. In real-world management, values may range from <1.0 ha to more than 300 ha, depending on the ecosystem and the management goals.
- **Percent of forested area to cut**. This is the percent of the forested area in the input map cut by the model each decade. For example, if 10% of the forest is cut each decade, 80% of the forest will have been harvested by the end of the eight-decade simulation.
- **Dispersion method**. Two spatial dispersion methods for harvests are available—dispersed (harvests openings are placed independently), or clumped (harvests are placed in clusters of nine openings.) In both cases, harvests are only permitted in forest stands older than 80 years of age.

Two additional parameters are specified for the analysis of forest interior and edge:

- **Edge-buffer width**. This is the maximum distance (m) from a forest opening that edge conditions permeate into the forest. Interior conditions are assumed to exist at distances greater than this value. HARVEST LITE must use a value that is a multiple of the map grid cell width (in this case 30 m). Other values will be converted to the nearest multiple of the cell width. A proposed definition of edge habitat for forest interior birds ranges between 50 and 500 m, which would be represented as 60–490 m in the model.
- **Opening persistence time**. This is the average time (yrs) that it takes for harvest openings to regrow to closed canopy conditions. Harvested cells younger than this value are assumed to be an opening, whereas cells exceeding this value are assumed to have a closed canopy. HARVEST LITE will round values to the nearest decade.

MODEL OUTPUT

Each simulation represents eight decades of harvest activity. Model outputs take the form of maps and map analysis reports including:

- **Forest age map.** Displayed upon completion of the simulation, this map reflects the cells harvested during the simulation, and the aging of unharvested cells. This map may be saved and used as input for other simulations.
- **Area of forest interior.** This is the area (ha) of forest interior conditions based on the input forest age map using the defined edge-buffer width described above. Forest interior habitat is shown in red.
- **Area of forest edge.** This is the area (ha) of forest edge conditions calculated based on the forest age map with interior conditions defined by the edge-buffer width. Forest edge habitat is shown as a gradient of colors other than red. A measure of linear edge (boundary) between patches of different ages is calculated as part of patch analysis, and this is different than the area of forest edge habitat calculated as part of interior analysis.
- **Mean size of patches.** This is the average size (ha) of forest patches, where patches are defined as contiguous cells of the same forest age. Some patches will be the result of simulated harvests and other remnants of uncut forest. Consequently, the mean size of patches *will not likely equal* the mean harvest size you used to simulate harvest activity.

ASSUMPTIONS

A number of simplifying assumptions were made in the development of HARVEST Lite to reduce input data requirements, and enable quick simulations over relatively large areas. The first assumption is that unless forest managers are intentionally trying to manage spatial pattern, harvest openings within areas managed for timber typically take a spatially random distribution when accumulated over the course of a decade. This assumption is based on an analysis of harvest activity on the Hoosier National Forest (Gustafson and Crow 1996). However, HARVEST Lite does include the constraint that harvests cannot be placed where the forest is younger than a specified age. This minimum age of forest that may be harvested has been fixed at 80 years in HARVEST Lite, and all simulations run for eight decades. Several other simplifications have been made to reduce model complexity for this exercise. The standard deviation around the user-specified mean harvest size has been fixed at 10%. HARVEST Lite includes an option to manage spatial pattern by producing clumped distributions of harvest openings. The nucleus of each clump is randomly placed, and then eight other harvest units are placed randomly around the initial harvest. HARVEST Lite always leaves a 1-cell buffer between harvests allocated in the same decade and adjacent to any non-forested land uses. HARVEST Lite ignores specific forest types, assuming that forest types are harvested in proportion to their availability. HARVEST Lite uses stand age as a surrogate for merchantability and ignores the density of trees and tree size class. The proximity of roads and the feasibility of conducting logging operations are assumed to be uniform across the land base.

For this exercise, two forest age maps have been provided. These maps were derived from stand maps of the Hoosier National Forest, and represent an area of almost 4000 ha, with a cell size of 30 m (0.09 ha). Non-forested areas appear black on the forest age maps; a lake occurs in the right-center of the input maps provided, and a small agricultural area in the lower right corner. One represents a managed landscape, where stands range in age from <10 to 140 years old (**managed.gis**). The other (**undistbd.gis**) contains a map with the same spatial characteristics, yet with no young stands, suggesting a lack of disturbance. Because none of the stands in the undisturbed map are too young to be harvested, there are initially no constraints on harvest.

Instructions for Using the HARVEST Lite Model

Start HARVEST Lite by double clicking on its icon (or HarvLite.exe). A help document is available from the **Help** menu.

1. Specify a base forest age map to use for simulations by selecting **Choose base map** from the **Model** menu. This will load the map into memory and allow you to analyze the initial pattern, or alternatively, immediately begin a simulation.
2. The spatial pattern of patches may be analyzed at any time using the **Analyze** menu. Analysis of forest interior requires specification of an **edge-buffer width** and an **opening persistence time**. HARVEST Lite will display a map of forest interior and edge and calculate the amount of interior and edge habitat based on these values, with results printed to the screen and written to a running log file that can be saved as a record. You may conduct multiple analyses of interior on the same forest age map using various values for interior definition.
3. Similarly, an analysis of patches calculates the **mean size of forest patches** (defined by their age) with results also written to the running log file.
4. The **running log** can be saved to a text file at any time using the **Save log file** option under the **Save** menu. The running log is cleared when you load a new base map (and when you save the log file), so if you wish to save any analyses, do so prior to loading a base map.
5. The map of interior may also be saved using the **Save** menu. Map files are saved in ERDAS 7.4 format, and may be loaded into many common GIS systems, or used as input maps for other HARVEST Lite simulations.
6. To conduct a harvest simulation, select **Execute** from the **Model** menu. A dialog will allow you to set the parameters controlling the allocation of harvests on the landscape. When the simulation is finished, an updated forest age map is displayed.
7. You may now analyze the pattern of this changed landscape using the same analysis functions described above in steps 2 and 3. Analyses will be appended

to those conducted previously. You may also wish to save the new maps for later analysis or to use as input for further simulations (as in step 5).

8. To conduct a new simulation using different parameters, reload a base map by selecting **Choose base map** under the **Model** menu. This will clear all prior maps, analyses, and parameter settings from memory.
9. To quit HARVEST LITE, choose **Exit** from the **Model** menu.

EXERCISES

Forest Harvest Simulation Scenarios

Complete the simulations for all assigned exercises before answering discussion questions to ensure you complete the simulations in the allotted time. An excel spreadsheet is provided to record and graph your results (**HarvLite.xlsx**). This is a stochastic simulation model (i.e., simulations are based on random number sequences). Thus, the model will not produce the same results on successive runs, and results will differ slightly among users. When asked to describe the relationship between a model parameter and a measure of landscape pattern, consider the possibility that they are not related.

EXERCISE 1: Effects of Mean Harvest Size on Forest Pattern

Forest managers are being compelled (either by regulation or public opinion) to reduce the size of clear-cuts and other timber harvest activities. For example, in the USA there is a 16 ha limit on the size of clear-cuts on most National Forests. In preparation for this exercise, propose hypotheses (circle options below) about how clear-cut size is related to the amount of forest interior and forest edge remaining on a landscape, given a constant area of timber harvest.

- *Hypothesis 1*: The amount of forest interior will (increase/decrease) as clearcut size increases.
- *Hypothesis 2*: The amount of forest edge habitat will (increase/decrease) as clearcut size increases.

The following exercise will allow you to test your hypotheses by simulating four different management scenarios in which mean harvest size differs. To do so, follow the sequence of steps below.

1. From the Model menu, select **Choose base map**. Use the input file **managed.gis**, found in the same directory as the HARVEST Lite program itself.
2. Use HARVEST Lite to simulate four forest management scenarios in which mean harvest sizes vary (use sizes of 1, 10, 20, and 30 ha). To do this, select **Execute** from the Model menu. Enter a **harvest size** of 1.0. The values for the

other two simulation parameters (% forest area to cut and dispersion method) will be held constant across simulation runs. For **Percent of forested area to cut**, enter a value of 3.0, and select the **Dispersed** dispersion method. Click on the **OK** button to start the simulation.
3. When each simulation run has completed, calculate the amount of forest interior by selecting **Interior (after harvest)** from the **Analyze** menu. Enter an **Edge-buffer distance** of 180 m and an **Opening persistence time** of 20 years. Be sure to use these values for each simulation in this exercise. Also conduct a patch analysis by selecting **Patches (after harvest)** from the **Analyze** menu.
4. Use spreadsheet provided (see the tab for Exercise 1) to record the mean harvest size, area of forest interior, area of forest edge, and mean patch size (all age classes) for each run. These values can be found in the **Progress and Results** window after each analysis is completed. If you wish to save the log file after each simulation, be sure to do so (select **Save log file** under **Save** menu) prior to reloading the base map.
5. Repeat steps 1–4 for the other three harvest sizes (10.0, 20.0, and 30.0 ha).
6. Recalling that Harvest Lite is a stochastic model, replicate your data two more times, and record those results in the appropriate tables in the spreadsheet. The purpose of replication is to provide a sense of the variability among model runs and to provide mean values that are more accurate than those from a single model run.
7. Examine the graphs of the area of forest interior, forest edge, and mean patch size plotted against mean harvest size. Answer the following questions:

Q1 Is there a threshold effect of mean harvest size (i.e., a small range of values where the effect changes markedly)? If so, at approximately what mean harvest size does the threshold occur?

Q2 If you were advising a forest manager who was under pressure to both minimize harvest size and to maximize forest interior habitat, what would you recommend as a policy for mean harvest size?

Q3 Would you say the variability among model runs is high or low?

Q4 Based on the graphs, would you say your hypotheses were supported or discredited?

EXERCISE 2: Effects of Percent of Forest Cut Each Decade on Forest Pattern

Timber production levels are declining on many publicly owned forests in the USA, primarily to enhance biodiversity and other non-commodity values of forests. This is implemented primarily by reducing the percentage of the land over which timber harvest is allowed. In this exercise, we will examine the effect of changing the percent of forest cut each decade. In preparation, propose a hypothesis about how the percent of forest cut each decade is related to the amount of forest interior and forest edge remaining on a landscape, given a constant timber harvest size. Upon reflection, you might likely hypothesize that increasing the area cut will decrease the amount of interior. Thus instead, consider a more subtle hypothesis about whether the relationship is linear (straight line) or nonlinear (curve) by circling an option below:

- *Hypothesis:* The amount of forest interior will decrease (linearly/nonlinearly) as clearcut size increases.

To explore your hypothesis, follow these steps:

1. From the Model menu, select **Choose base map**. Use the input file **managed.gis**.
2. Use HARVEST Lite to simulate four other forest management scenarios in which the **Percent of forested area to cut** varies, from 1 to 7% of the landscape each decade in 2% increments. Hold the other parameters constant for each of these runs. Use a **Mean harvest size** of 5.0 ha, and the **Dispersed** dispersion method.
3. Calculate the amount of forest interior using an **Edge-buffer distance** of 180 m and an **Opening persistence time** of 20 years. Be sure to use these values for each simulation in this exercise. Also conduct a **patch analysis**.
4. Record data in the Exercise 2 tab of the spreadsheet.
5. Repeat steps 1–4 for each **Percent of forested area to cut** (1, 3, 5, 7%) and replicate two more times.
6. Examine the graphs and answer the following questions:

Q5 What is different about the shape of these plots compared to those generated for the effects of mean harvest size? Was your hypothesis supported?

Q6 Does there appear to be a threshold effect of percent of forest area cut each decade? If so, at approximately what percent does the threshold occur?

OPTIONAL: You may wish to produce a 3-D surface plot combining the results of this and the previous exercise. Additional simulations will be necessary to complete the plot. Compare your results to those in Gustafson and Crow (1994).

EXERCISE 3: Effects of Spatial Dispersion on Forest Pattern

Landscape ecologists have argued that intentionally managing the spatial pattern of landscapes can improve habitat conditions. One option available to forest managers is clustering harvest activity. This exercise will examine the effects of clustering of harvests on area of forest interior, area of forest edge, and mean patch size.

1. Select the input file **undistbd.gis**.
2. Choose a **mean harvest size** between 5 and 30 ha, and a **percent of the forest area to be cut** between 1 and 7%. Run three replicate (parameters unchanged) simulations each for dispersed and clustered harvests.

3. Calculate the amount of forest interior using an **Edge-buffer distance** of 180 m and an **Opening persistence time** of 20 years. Also conduct a **patch analysis**. Record data in the tab for Exercise 3.
4. Examine the graphs and answer the following questions:

Q7 In statistics, a significant difference between groups indicates that values observed in one group are highly unlikely to be also observed in a different group. Would you say that clustering harvests significantly changes the area of forest interior habitat when compared to dispersed harvests? What about forest edge habitat? Mean patch size?

Q8 How did you judge significance from these plots? (*HINT:* look at the error bars.)

EXERCISE 4: Effects of Edge-Buffer Width and Opening Persistence Time on Forest Pattern

There is some debate about how far into the forest the effects of edge are evident. The effects related to reduced nesting bird densities and increased nest predation may extend much further into the forest than do microclimate effects. Forests also recover from harvesting at different rates in different ecosystems. Forests on good soils in moist climates may recover more quickly than forests on poor sites or in relatively dry climates. This exercise will examine how the spatial pattern of forest interior depends on how interior habitat is defined.

1. Select the input file **managed.gis**.
2. Simulate harvests with a **mean harvest size** of 1.0 ha and 4% of the **forest area cut each decade**. Use the **Dispersed** dispersion method. This will be the only simulation run for this exercise.
3. Calculate area of forest interior using no edge-width buffer (**0 m**), a **150 m** edge-buffer width, and a **300 m** edge-buffer width. Assume that openings persist for two decades. Do not conduct a new simulation between interior calculations for each edge-buffer width.
4. Record data in the tab for Exercise 4 in the spreadsheet.
5. Without running another simulation, repeat the three calculations in step c, this time using an **Opening persistence time** of three decades. Record your data.
6. Examine the graphs and answer the following questions:

Q9 Does an increase in edge-buffer width have a disproportionate effect on the area of forest interior habitat? Why or why not?

Q10 Some species are highly sensitive to the presence of edge in their habitat, and therefore a large edge buffer width would be used to calculate suitable habitat for them. What is the consequence of timber cutting for such species relative to less sensitive species?

Q11 What is the effect of a longer opening persistence time?

Q12 To maintain interior habitat in a forest with slow-growing species (i.e., openings persist longer), make recommendations about timber cutting strategies to achieve this goal based on what you have learned in this lab exercise.

SYNTHESIS

Q13 Is forest interior more sensitive to variation in "Harvest size" or "Percent of forest area cut?" To which is forest edge more sensitive? To which is patch size more sensitive? Can you think of a situation where a forest manager would find this information useful?

Q14 How did this exercise change your thinking about the spatial aspects of timber harvesting? How might the results of your simulations be used to develop a research project or advise a forest management debate about trade-offs?

Q15 Review the assumptions made by the HARVEST Lite model. Under what scenarios might they be reasonable or unreasonable? How might you test these assumptions? How does knowledge of the assumptions influence interpretation of the results?

Q16 Was there a parameter missing from the model with which you wanted to be able to experiment? What was it, and how might that parameter be related to the habitat requirements of a forest species?

Q17 Consider the process and impacts of landscape change represented by each of the parameters that can be manipulated by HARVEST Lite (mean size of harvests, % of forest cut, dispersion). How are these processes and impacts similar to disturbances in non-forested landscapes? How are they different? Do you think the principles you learned today can be applied to other ecological systems?

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