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Ecosystem Loss and Fragmentation: Exercise

Author(s): James P. Gibbs

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Forest Fragmentation and its Effects on Biological Diversity: A Mapping Exercise

James P. Gibbs*

*SUNY-ESF, Syracuse, NY, U.S.A., email jpgibbs@esf.edu

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GOALS

This exercise has two goals. The first is to permit you to explore through a mapping exercise what happens to a forested landscape as it undergoes the fragmentation process. The second is to let you predict what will happen to the biota residing within the landscape as a result of these changes. The fundamental question we address is: can landscapes be fragmented in such a way that permits humans and biological diversity to coexist?

OVERVIEW

The first part of the exercise involves measuring changes in a forested landscape as it is fragmented. You begin with a blank grid that represents an undisturbed landscape dominated by forest. Much of the forest is on the upland but some also occurs in wetlands connected by streams that are themselves surrounded by gallery forest. Both wetland forest and gallery forest are considered "seasonally inundated forest" and are indicated on the map by wetland symbols.

Starting with the blank grid, you will mark grid squares in a progression that mimics fragmentation of the landscape associated with colonization by humans, first by adding a major road and the cleared lands associated with it, and then adding secondary roads and tertiary roads and the cleared lands associated with them. "Filled" grid squares will represent areas cleared of forest and converted for agricultural purposes whereas "cross hatched" grid squares will represent edge zones of remaining forest that are directly adjacent to cleared areas. You will then repeat this fragmentation process while invoking some simple land use guidelines to examine how they might influence the outcome in terms of structure of the landscape and the biodiversity within it. You end up with three landscapes to compare: (1) the original landscape, (2) the landscape subjected to uncontrolled fragmentation, and (3) the landscape subject to fragmentation guided by some simple land use regulations and alternatives.

The second part of the exercise enables you to predict what will happen to the biota residing within the landscape as a result of its fragmentation. For each of your mapped scenarios for the same landscape, you will calculate some key biological parameters to make predictions about the state of biological diversity and ecosystem function within the landscape. You will examine how changes in the landscape affect: (1) ecosystem diversity of the landscape, (2) species diversity within the landscape, and (3) ecosystem function in terms of carbon sequestration within the ecosystems present. Advanced students may also want to attempt the remaining steps, which address: (4) population viability of a large herding mammal, (5) foraging energetics of wide-ranging birds, and (6) effective population size and genetic drift in a canopy tree. By contrasting these biological indicators in the three landscapes you generate, you will get a good sense of how fragmentation affects biodiversity and how we can mitigate some of the negative effects through planning and incentives.

PART I

The Forest Fragmentation Process

Becoming Familiar With the Basic Map

First, get oriented to the basic map by noting the cardinal directions. Which way is north? South? East and west? Second, familiarize yourself with the map's scale. Each grid square is 100 m on a side. What is the area of each grid square? What is the width and length of the study landscape? What is the total area of the landscape (in ha and km^2)? If you move horizontally from one grid square to the next, what distance have you moved? If you move diagonally, how far have you moved? Now look at the different cover types. Can you recognize the inundated (wetland and gallery) forests? The upland forests? The streams and other watercourses?

Scenario I: The original landscape with natural small, scattered disturbances and its human population

Scattered disturbances are typical even within the original, unfragmented landscape. These might be due to lightning strikes that have created small openings. Many of these may also have been created by humans who have constructed small, shifting garden plots in certain areas or lit fires in others to generate second growth and attract game. These disturbance patches usually don't comprise a large portion of the landscape (perhaps up to 2% of the area) and are generally well dispersed. To mimic this situation, randomly choose 2% of the grid squares and convert them to open habitats (filled grid squares) and change the grid squares surrounding open habitats to edge habitats (cross-hatched grid squares).

What is the human population being supported within the landscape? Assume that each family (average of five people per family) needs exclusive access to 3 hectares of cleared land for cultivation to meet their needs or 50 hectares of forestland (upland or inundated and not necessarily contiguous) for extraction of natural products and hunting. Often people combine both cultivation and harvest of wild products but we will consider a simple division of livelihoods in this case.

Scenario II: The landscape fragmented in an uncontrolled manner
Starting with a blank map of the original landscape, add a road dissecting the region. This road might be the end result of exploration of a remote area for oil or gas or the result of a government effort to access a frontier zone. To make this road, simply draw a heavy line along an east-west axis through the middle of one of the central rows of grid squares. The road width is negligible and can be ignored but it provides immediate access to the grid squares traversed and those immediately adjacent to them (150 m back from the road). These are converted to agriculture. Therefore, fill in all traversed and adjacent grid squares - three rows total.

Note that this initial dissection of the forest also changes the forest that is adjacent to the converted lands into edge habitat. Consider that ecologically important edge effects can extend at least 100 m into a stand, so cross-hatch all the forested grid squares adjacent to cleared land to indicate where forest edge has been created.

Now add more roads. These are the kinds of roads created by people who follow the first major road and now seek to colonize the area and convert more of the forest for agriculture and other uses. Add two such roads by drawing dark lines perpendicular to the initial road that cross it at about 450 m and 1450 m along its length. Extend the secondary roads in both directions right across the landscape. Repeat the process of demarking converted lands 150 m from the roadsides and then the edge habitats adjacent to them.

Calculate the human population supported within the landscape.

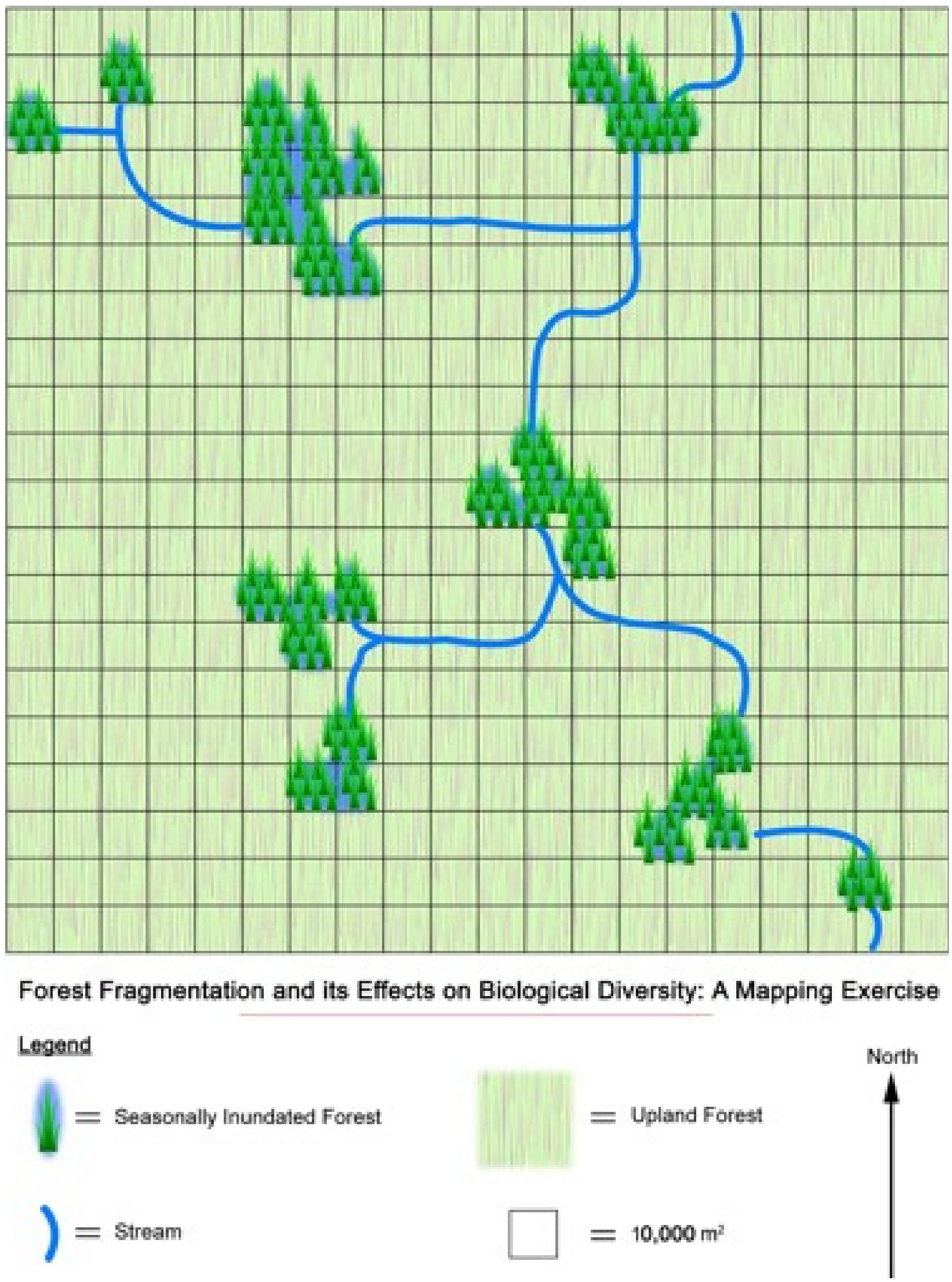
Scenario III. The landscape fragmented following some simple land use guidelines
Starting with a clean map, add roads and cleared lands as you did in Scenario II, with the objective of generating sufficient resources for a comparable number people, but place the roads in any configuration you want that satisfies these simple land use guidelines and land use alternatives (adapted in part from Laurance and Gascon, 1997):

- Triple the production rates on cultivated land through provision of fertilizer and perhaps alternative crops so that local people now need to clear only a third as much forest to meet their needs. Note that under the land use alternatives scenario, however, each family can meet its needs on just one hectare of cultivated land because productivity has been tripled. In other words, now you only convert the lands up to 50 m from roadsides, so fill in only the blocks directly intersected by the road.
- Prohibit forest clearing of any habitat block that supports a watercourse. Note that roads can traverse watercourses but the forest blocks that include water courses are not cleared.

- Protect all rare ecosystems -- no conversion of inundated forests.
- Allocate half of the landscape to production purposes and human use while allocating the other half to reserve status.

Recalculate the human population supported within the landscape.

Figure 1. Map for Exercise.



PART II

Biological Implications of Fragmentation Scenarios

Step 1. Landscape Analysis and Ecosystem Diversity

For each of the maps that you produce from the three fragmentation scenarios above, tally the area of the landscape that is upland forest interior, upland forest edge, inundated forest interior, inundated forest edge, and land converted from forest to agriculture. Note that riparian zones of the watercourses are natural "edges" or ecotones, but we are concerned here with forest edges adjacent to open habitats. Calculate the fraction of the landscape composed of each habitat. Last, estimate ecosystem diversity within each of these landscapes using the Shannon-Weiner index of diversity, which is

$-\sum pi*\log(pi)$,

where pi = the fraction of the landscape represented by ecosystem$_i$. For example, if interior forest occupied 900 of the total 1000 grid squares and inundated forest occupied the rest of the landscape, then Simpson's index of diversity would = (0.9*log(0.9))+(0.1*log(0.1)). Your calculations will be similar but made across all ecosystem types.

Step 2: Changes in Ecosystem Function – Carbon Sequestration

Based on the estimates of Laurance et al. (1998) for Amazonian moist forest near Manaus, Brazil, forest biomass averages 300 tons/ha with carbon comprising 50% of that amount. Forest clearing commits 95% of forest biomass to carbon emissions from burning and decay with 5% remaining as relict living trees in pastures or inert as charcoal. Forest edges lose 10% of their biomass as mortality of trees is higher on the edges. Do not distinguish inundated from upland forests for this exercise. Based on these relationships, estimate the tons of carbon sequestered by the landscape in above-ground woody biomass under the three different landscape scenarios.

Step 3: Changes in Faunal Diversity

Estimate the faunal diversity of an average habitat block within the landscape under the different scenarios of fragmentation (undisturbed, uncontrolled fragmentation, fragmentation with some land use guidelines and alternatives). This can be done with information on birds, mammals, frogs, and ants gathered by Gascon et al. (1999). These researchers worked over several decades to determine which species near Manaus, Brazil, primarily used forest interior, forest edge, and "matrix" or open lands near fragments. Note that some of the forest species listed below use the matrix but still rely on the primary forests.

Approximating from the Gascon et al. (1999) report (Figures 2 & 3), for birds there are locally some 123 species, 31 of which use the matrix (converted lands) versus 92 that use the forest edge and 92 that use forest interior. Note that no birds were restricted to the forest interior, so the same 92 occur in both edge and interior areas. For frogs, there are 62 species, 16 of which use only the matrix, 52 of which occur in the forest interior, and 51 of which use the forest edge. Of 15 mammals in the area, 4 use the matrix only, 15 use the forest interior, and 10 use the forest edge. For the 127 ant species, 32 use the matrix only, 104 use the primary forest, and 44 use the forest edge. Do not distinguish inundated from upland forests for this exercise.

Now calculate the average diversity per hectare for each of these faunal groups. To do so, for each landscape multiply the number of hectares of each habitat type by the expected diversity within it. Next sum these values across habitat types. Last, divide by the sum of the weights, which is the same as the total area of the landscape. For example, if the landscape was composed of 1000 grid squares, of which 500 were primary forest, 250 were forest edge, and 250 were matrix, then ant diversity on average in that landscape would = ((500*104)+(250*44)+(250*32))/100. This "weighted average" will indicate how many species are likely to occur, on average, per hectare in each landscape.

[Optional exercises for advanced students]

Step 4: Population Viability of a Herding Species With a Large Home-Range

Assume that one km^2 of forest (interior and edge) can support five white-lipped peccaries and that these animals live in herds (Fragoso, 1998) that roam in a fairly predictable fashion about the landscape. Also assume that the peccaries are reluctant to cross roads and cleared areas because they will be shot and therefore restrict their movements to individual forest remnants. Therefore, forest blocks support isolated populations.

What is the total peccary population among all the remaining viable populations? To answer this, you will first have to tackle the following questions: How many peccaries can each of the remaining forest patches support? What fraction of patches contains both the upland and wetland forest that are required to meet the annual needs of these animals during the wet and dry seasons? Note that if both wetland and upland forest are not available within a forest patch, then a population cannot be supported.

Step 5: Mobile Species and Foraging Energetics

Let's consider a wide-ranging, large-bodied frugivorous bird that must visit many sites every day to harvest newly ripened fruit. A hornbill, quetzal, or large parrot are good examples. Let's assume the tree species whose fruits it needs occur only in inundated forests, that is, in the highly clumped distributions that are typical of many tropical trees. How far must these birds travel on average each day to meet their daily needs? Assume that a pair of these birds must visit five such patches (one hectare blocks of inundated forest) each day.

To answer these questions, first trace the shortest path possible between all patches of inundated forest in the landscape. Start with an isolated patch in one of the corners of the landscape. It's virtually impossible to find the exact shortest path so just try to link all patches together as might a foraging bird that was trying to save energy flying between all the patches. As you move to the next nearest patch of inundated forest not yet visited, sum up the distance of each sequential move. The total distance traveled divided by the total number of patches visited equals the average cost of accessing a foraging site. Recall that the birds must visit five patches per day to meet their needs.

Step 6: Genetic Diversity in a Canopy Tree

Consider a rare tree species with mature individuals distributed evenly through the upland forest at a density of only one per hectare. A good example is *Pithecellobium elegans* (Chase et al., 1996; Hall et al., 1996). Any trees within 250 m of any other trees represent part of the same breeding population (can exchange gene flow). More distant individuals are unable to exchange pollen effectively and are therefore considered to be members of a different population. First, mark the individuals linked through potential gene flow by drawing a line that includes all collections of individuals within 500 m of another individual.

Next, assuming that the genetically effective population size in this species equals the census population size (only breeding adults in this long-lived species are considered), what average fraction of heterozygosity will be lost over the next 100 generations from each of the remaining breeding populations? Recall that the formula for estimating the amount of genetic variation (heterozygosity) in a population of size Ne retained after t generations = [1 - (1/(2*Ne))]t

Repeat these calculations for each *Pithecellobium elegans* population under each of the three landscape fragmentation scenarios. What is the least amount of genetic diversity lost by any single population under each scenario?

PART III

Synthesis

Construct a table that summarizes, for each of the three fragmentation scenarios, the (1) human population supported in the landscape, (2) characteristics of the landscape (fraction of land in different habitat types), (3) estimates for the key biological indicators:

fraction of land in different habitat types, ecosystem diversity, carbon emissions from the landscape, average faunal diversity per habitat block, population size and viability for white-lipped peccaries, foraging energetics for the frugivorous bird, and genetic diversity in the tree *Pithecellobium elegans*. To indicate how sensitive each parameter is to the fragmentation process, calculate the proportional change in each parameter relative to its value in the original landscape (Scenario I). Can you conclude that biodiversity and substantial human populations can co-exist despite fragmentation to the landscape? What social incentives and political means are available to actually achieve a landscape like that in scenario III?

TERMS OF USE

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