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Response to G. S. Cumming (2002). "Habitat shape, species invasions, and reserve design: insights from simple models."

Online Publication Enhances Integration of Current Research in the Classroom

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ABSTRACT. Integrating current research materials and issues into graduate courses provides students with exposure to emerging concepts and methods. New online journal formats that allow authors to include raw data and model code provide a unique opportunity to bring current research into the classroom. We developed a graduate-level landscape ecology assignment using data and code provided as appendices to an article in *Conservation Ecology*. Our assignment required students to engage actively with the published material, was positively reviewed by the students, and prompted valuable discussion.

THE SETTING

During the fall 2002 semester, we developed and taught a graduate-level landscape ecology course that introduced the participants to this field by (1) familiarizing them with the jargon, (2) exposing them to the major conceptual foundations of the discipline, (3) relating these foundations to current issues in conservation and natural resources management, and (4) applying these concepts by analyzing landscapes to provide information that could be used to solve conservation and natural resources problems (Hess and Drew 2003). We designed the course using principles of inquiry-guided learning, which are based on the use of teaching techniques that advance learning through independent examination of questions and problems, rather than the presentation of knowledge in a lecture format. Under the guidance of faculty, inquiry-guided approaches promote a range of skills, including the ability to formulate good questions, collect and analyze appropriate data, present results, and formulate conclusions (Boyer Commission 1998, Faculty Center for Teaching and Learning 2003). In our course, lectures were minimal, designed to introduce concepts, and followed by hands-on activities that challenged students to take responsibility for their own learning and interact directly with the concepts that underpin landscape ecology.

The first two thirds of the semester covered the basic tools of landscape ecology, including landscape metrics, spatial statistics, and neutral models. In addition, the students developed an appreciation of connectivity and patchiness from the perspective of individual organisms. At this point, the students demonstrated a basic understanding of landscape pattern, the processes that generate spatial habitat patterns, and the importance of scale. We wanted to help them integrate their new landscape knowledge with their knowledge of population and community ecology and lead them toward an understanding of how landscape ecology provides important data for conservation management decisions. In particular, we wanted them to think beyond the simple "checkerboard" landscapes of earlier exercises.

THE ASSIGNMENT

While ruminating how best to tackle these teaching goals, we encountered Cumming's (2002) publication in *Conservation Ecology*. His article provided an excellent example of how simple models are developed to provide insight into landscape patterns and processes. Cumming used cellular automata models to examine interactions between habitat shape, species invasions, and reserve design. The simulated organisms varied in their mortality rate, number of offspring, and dispersal distance, and dispersed through linear, branching, or square landscapes. The model reported population size at the end of each iteration. Cumming examined the effect of varying habitat shape on the population size of an invasive species at equilibrium and the time to reach equilibrium. Appendices included with the article provided the Matlab model code and landscape files.

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We modified the code to prompt the students for variable values, rather than requiring them to directly read and edit the Matlab code (see Appendix 1 for the edited code). This allowed students untrained in model development or Matlab syntax to experiment with different combinations of variables. Working in groups of three or four, students were required to run the model using their own ranges of variables and critically evaluate two of Cumming's conclusions (see Appendix 2 for details of the assignment). Based on their simulations, we asked the students to explain whether they accepted Cumming's conclusions without reservation, to dissect how and why each biological variable responded to changing landscape patterns, and discuss whether they would trust these model predictions in a real-world setting. They were to support their arguments with up to three graphs displaying the data they generated using the model. The stated objectives of the assignment were to:

- understand how habitat shape can influence species dispersal,
- understand how habitat shape and organism biology (mortality rate, dispersal distance, number of offspring) interact,
- verify published results,
- gain exposure to modeling experiments in landscape ecology, and
- consider model limitations as a predictor of field conditions.

As a simple reading assignment, this article would have given the students the opportunity to ponder the effects of different habitat shapes and critique the model assumptions. However, such assignments do not fully engage the student. As part of the inquiry-guided learning process, we purposefully left some of the assignment directions open-ended. For example, the students were not told which data to include in the figures or which style of graph to generate. This forced them to sift through the mountains of data that such a model can produce and select the most representative data series. We also did not provide a range for the model parameters, suggesting that the students instead review the paper or run short test simulations to determine the model's limitations. As the students worked on their assignments, different groups selected different variables to test and generated different sets of graphs. As a consequence, the results were not consistent among groups, prompting discussion of how models may be used and abused in landscape ecology.

CLASS RESPONSE

Initial student responses included several requests for clarification of our expectations regarding the final product. As the students began to implement the model, they wanted to know how they should condense the large volume of data into just three graphics. They also wanted to know the "correct" values to input for each model parameter. To meet our inquiry-guided learning goals, we generally asked the students to discuss these concerns within their groups, come to a consensus, and document the decision in their narrative. All groups ultimately selected appropriate parameter values and summarized their results with three graphics.

The students did very well on this assignment, which contributed 15% to their final class grade. We graded according to specific criteria, with a maximum score for each criterion (Table 1). We eliminated two criteria during the course of the assignment. The "Good Graph" criterion was eliminated because of technical problems that prevented the students from accessing the Good Graph reference Website. We eliminated the "reasonable responses" criterion when we realized that the students were being doubly penalized by this question, because those who failed to understand the model or the landscape ecology principles could not provide reasonable responses. Overall, the students demonstrated a good understanding of the model and provided satisfactory graphical and narrative summaries of their observations (see Appendix 3 for sample grade sheets). The lowest scores (3.8/5 ± 0.7 SD) reflected the students' struggle to move beyond a local understanding of ecological processes to the broader landscape perspective.

Class discussion of the results was enriched by our approach because of differences in findings among the teams. It became very clear that research findings, even when everyone is using the same models to answer the same questions, can differ depending on the particular focus taken. It was also gratifying to see the students work to find the consistent patterns among their results. During the rest of the semester, we followed this assignment with other in-class and laboratory exercises that carried us further from the "theoretical model and abstract results," as one anonymous student put it, toward more complex and applied problems in landscape ecology conservation.

Table 1. Grading criteria and grade distribution. The assignment required the students to write a narrative response to the questions, illustrated with a maximum of three graphics to support their arguments. Mean score was calculated based on nine submissions. The questions for this assignment appear in Appendix 2. The assignment was worth 15% of the class grade.

Grading criteria	Maximum possible score	Mean score (SD) (*n*=9)
Graphs		
Did you produce the required graphs?	1	1.0 (0.0)
Did you follow the Good Graph criteria?†	...	...
Did your graphs clearly illustrate the relationships between habitat shape and each variable?	5	4.7 (0.5)
Narrative		
Did you fully respond to each question?	5	4.1 (0.7)
Are your responses reasonable?‡	...	...
Do the responses give evidence of consideration of landscape ecology principles?	5	3.8 (0.7)
Do the responses give evidence of clear understanding of the model?	5	4.1 (0.7)
Is the document well organized with good grammar and sentence structure?	1	1.0 (0.0)
Has the length limit been respected?	1	1.0 (0.0)
Total	23	19.8 (1.7)

†Not scored, because technical problems prevented students from accessing the reference Web site.
‡Eliminated as redundant with next two questions.

In addition to comments and questions received during the course of the assignment, we distributed a survey after the assignments were completed (Table 2). The class response was generally positive. Most students felt the assignment achieved the stated objectives. As seen below, specific positive comments expressed appreciation for the opportunity to experiment with a model and indicated that generating the graphs forced deeper consideration of the hypotheses and results.

"I feel this assignment ... was quite valuable. I found the assignment appropriately challenging. The questions asked in the assignment really made me think about the model and Cumming's conclusions."

"Overall I liked and learned from this assignment. I'd been wanting to gain some experience in modeling, and this was a nice introduction. A little time-consuming for this time of semester, though."

Table 2. Summary of student feedback and critique of Cumming 2002 assignment. Scores were on a 1 to 5 scale, where a 1 indicated strong disagreement and a 5 indicated strong agreement. The mean score was calculated based on responses received from seven out of sixteen students.

Evaluation questions	Mean score (SD) (*n*=7)
Overall	
This assignment achieved the stated objectives.	4.6 (0.5)
Graphs	
An assignment requiring the creation of publication quality graphics is a good idea.	4.6 (0.8)
Creating the graphs helped me to think more carefully about the model and clarified the relationship between shape and each variable.	4.3 (1.1)
Narrative	
An assignment to critically review a recent landscape ecology publication and model is a good idea.	4.7 (0.5)
The questions were reasonable and fair.	4.3 (1.0)
The questions helped me to better evaluate the strengths and weaknesses of the Cumming model and article.	4.6 (0.5)
The questions helped me to better understand the relationship between habitat shape and organism biology.	4.3 (0.8)
This assignment deepened my understanding of the theory and practice of landscape ecology.	4.5 (0.9)

Criticism of the assignment focused primarily on the intentionally open-ended nature of the questions. Without exact, step-by-step instructions and limits, some students expressed frustration that the assignment was "not always completely clear." Others felt they would have liked to link the assignment to a GIS or other tool to visualize the landscapes and population dispersal patterns.

"It wasn't always clear what we were doing. I think it was confusing for people without [a] modeling background. I think there is still some conceptual connection to do for applications on real-life situations, but I learned a lot from this assignment."

"Would have been good to link actual reserve design (some sort of GIS project) to the results, but that would make the project much longer and more complicated."

CONCLUSIONS AND RECOMMENDATIONS

Overall, we were satisfied that this assignment provided valuable academic and professional development opportunities that could not have been achieved through a simpler "read and critique" assignment. Based on the students' feedback, we will include this assignment in future offerings of our course and be alert for similar opportunities to adapt online publications to classroom exercises. The adaptation and testing of Cumming's model took about two days of effort. This seemed reasonable given the positive response, and matched the time commitment required to prepare more traditional laboratory and homework assignments. The simplicity of the model and the careful documentation accompanying the appendices facilitated the use of these materials and would be important criteria for selecting future publications.

Student comments were helpful for modifying the exercise for future classes. In this version of the assignment, we did not integrate an effective landscape or dispersal visualization tool. Such visualization would have been a valuable aid to understanding the population dynamics for several students. To address concerns of clarity, future versions of this assignment will expressly state the professional development goals to pre-empt confusion about the selection of parameter values and graphics. In particular, we would emphasize the importance of effective data consolidation and presentation, and the need to clarify broad, "unclear" questions by examining and focusing on the objectives.

Responses to this article can be read online at:
http://www.consecol.org/vol7/iss1/resp12/responses/index.html

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APPENDIX 1.
Modified Cumming (2002) Code for Student Assignment

```
% cellaut.m
% Cellular automaton model - stochastic dispersal, reproduction and mortality
% Original program written in Matlab 5.3 by Graeme Cumming, November 2000;
% Published in Cumming, G. 2002. Habitat shape, species invasions, and reserve
% design: insights from simple models. Conservation Ecology 6(1): 3
% Modified by Ashton Drew in Matlab Student 6.0, September 2002 to add data entry
% prompts to serve as a teaching tool.
% To run this program in Matlab, simply copy following code then paste and save it as an
% m-file in Matlab.

% These commands read in x,y coords from landscape file
filename = input('What do you want to name the output file? >', 's');
landscape = input ('Select a landscape > ', 's');
fid = fopen (landscape,'r');

[xcoord,ycoord] = textread (landscape,'%f %f');

status = fclose (fid);
count = size (xcoord);

% Initialise the variables for the program
cell = zeros (count);
cell2 = zeros (count);
cell (500) = 1; % Starting value
dispdist = input('How far do organisms disperse in each step? >');
% dispersal distance in m
inc = input('How many offspring do organisms have in each step? >');
```

```
% number of 'offspring' per iteration
mortality = input('What is the mortality rate (x/1000)? >');
% death rate / 1000
area = ceil (3.141592654*(dispdist^2)); %max possible number of neighbours
neighbour = zeros (count(1),area);
reps = input('How many iterations should the model run? >');
% this is the number of iterations, or time steps, that the model runs

% first we write a matrix containing identifiers of all cells in dispersal range
for x = 1:count
match = 1;
for i = 1:count
distance = sqrt(((xcoord(x)-xcoord(i))^2)+((ycoord(x)-ycoord(i))^2));
if distance <= dispdist
match = match + 1;
neighbour(x,1) = neighbour(x,1)+1;
neighbour(x,match) = i;
end;
end;
end;

% now begins the main loop of the program
trials = input ('How many times do you want to run the model? >');
for z = 1:trials %this is the trials, or repetitions, of the model
cell = zeros (count);
cell2 = zeros (count);
cell (500) = 1;
results = zeros (reps,1); % this is the matrix that holds the results
for r = 1:reps % iterations
% disperse
for j = 1:count(1)
if cell(j) == 1
cell2(j) = 1;
for m = 1:inc % remember "inc" is offspring, short for "increase"
rnum = rand * neighbour(j,1);
p = ceil(rnum);
if p==1
p = 2;
end;
plusone_id = neighbour(j,p);
cell2(plusone_id) = 1;
end;
end;
end;
cell = cell2;

cell2 = zeros (count);
for k = 1:count
if round(rand*1000) < mortality
cell(k) = 0;
end;
end;

% results
tally = sum(cell);
results(r,1) = tally;
if tally==0
break
end;
```

```
disp (r);
end;
% ends the main loop

if z == 1
final = results;
end;
if z > 1
final = cat(2,final,results);
end;
end;
save (filename,'final','-ascii');
```

APPENDIX 2.
Assignment Based on Cumming (2002) Article

Habitat Shape, Species Invasions, and Reserve Design Exercise

Read: Cumming, G. 2002. Habitat shape, species invasions, and reserve design: insights from simple models. Conservation Ecology 6(1): 3. [online] URL: http://www.consecol.org/vol6/iss1/art3

Until now, most of our example landscapes have been squares. What happens when our landscapes are arranged in more realistic shapes? In this article, Cumming uses models to explore how habitat shape can influence the dispersal and abundance of invasive populations. We will use the Matlab code provided in this article to modify and reproduce Cumming's cellular automata experiments.

Objectives:

1. Understand how habitat shape can influence species dispersal.
2. Understand how habitat shape and organism biology (mortality rate, dispersal distance, number of offspring) interact.
3. Verify published results.
4. Exposure to modeling experiments in landscape ecology.
5. Consider limitations of model as a predictor of field conditions.

Assignment:

1. Use the Matlab model to evaluate and illustrate the two broad statements by Cummings:
2. The influence of habitat shape on population processes will clearly be less pronounced for populations that ... move *farther* or faster, or have *higher* fecundity.
3. *Lower* mortality rates in the cellular automata model result in more similar colonization rates.
4. **Note: We will only use four landscape shapes: stream0 (linear), strm10c (complex branching with 10 nodes), strm20c (complex branching with 20 nodes), and grd40x40 (square).

1. Based upon your analysis, do you accept Cummings conclusions without reservation? Why or why not?

1. "Invasions in more geometrically complex habitats will occur faster and may ultimately produce a higher abundance of the invasive species." Why? What does it mean to be "more geometrically complex"? Would the statement be true for any metric of complexity?

1. For each variable (number of offspring, movement distance, and mortality rate), comment upon why that variable responds as it does to the change in landscape shape? What ecological mechanism is at work here (or alternatively, you may argue it is a function of the model with no basis in ecology)?

1. "All comparisons were undertaken using identical parameters and habitats of equivalent size that *differed only in shape* ." (1st paragraph in Methods) If they changed the shape, which other landscape metrics also changed?

1. Identify the model assumptions about how animals move, interact with the landscape, and utilize the habitat. How might these influence the applicability of your results (and Cumming's) to real ecological problems?

Products to Turn In for Grading:
Graphs: You should develop three graphs (dispersal distance, number of offspring, mortality rate) that demonstrate the effect of shape on population growth.

Narrative: A review of the model, based upon your observations. The review should incorporate your answers to the above questions. Use the figures to support your arguments where appropriate. Three page absolute maximum, Times font, 1.5 line spacing, 1" margins all around.

Grading Criteria:
As we grade this assignment, we are primarily looking for evidence that you evaluated the landscape – organism biology interactions and thoughtfully evaluated the observed trends within the context of landscape ecology principles. We will also be grading your ability to present a clear analysis of the observed trends both in graphical and written format.

Graphs:
Did you produce the required graphs?
Did you follow the Good Graph criteria?
Did your graphs clearly illustrate the relationships between habitat shape and each variable?
Narrative:
Did you fully respond to each question?
Are your responses reasonable?
Do the responses give evidence of consideration of landscape ecology principles?
Do the responses give evidence of clear understanding of the model?
Is the document well organized with good grammar and sentence structure?
Has the length limit been respected?

How to run the model:
Copy the **cellaut.zip** file from the class calendar to the desktop. Unzip this file to obtain a folder named **Cellaut** which contains five files. (Matlab works from one working directory – if you move files around, Matlab will no longer be able to find them.)

Open Matlab. Reset the Current Directory to be the **Cellaut** folder by clicking the "..." key near the top right. You can now run the model simply by typing **cellaut** at the Matlab command prompt.

You will be prompted to enter the following information:

What do you want to name the output file?
Create a unique name for the output file. The output file will be an ascii text file that you can open in Excel. (e.g. stream0_off2 or stream0_mort3)

Select a landscape.

Input the name of a landscape shape file. (e.g. stream0.txt). Your landscape files are: **stream0** (linear), **strm10c** (complex branching with 10 nodes), **strm20c** (complex branching with 20 nodes), and **grd40x40** (square)

How far do organisms disperse in each step?
Always enter **3**, unless you are evaluating the effect of this parameter.

How many offspring do organisms have in each step?
Always enter **2**, unless you are evaluating the effect of this parameter.

What is the mortality rate (x/1000)?
Always use **300**, unless you are evaluating the effect of this parameter. (This is equivalent to a mortality rate of 0.3).

How many iterations should the model run?
You can use the figures in Cumming's article to gauge how many iterations you will need to allow for the model to reach equilibrium. **** After you enter this value, you will need to wait patiently for a few minutes while Matlab runs through some functions. *****

How many times do you want to run the model?
Enter **1**. Since this is a homework activity, you will only run each model once. If you were interested in a thorough evaluation of these questions, you would run many trials of each model and use the average. After you enter this value you will watch numbers scroll by on the screen. These show the iteration numbers so you can gage how long it will take the model to run and ensure that it is in fact running.

When the model finishes running (the numbers stop scrolling by and command prompt returns), open the output file in Excel. In Excel you can graph the results to observe how the population behaved under the conditions you specified and verify that your model did reach equilibrium.

If at anytime you want to interrupt the model, just hit **Ctrl-C**. This will give you an error message that tells you where you interrupted the program, which you can ignore.

It may help you to create a chart similar to this for each variable (offspring, movement, and mortality) to keep track of your data:

Effect of Number of Offspring:												
Offspring	1	1	1	1	**2**	**2**	**2**	**2**	3	3	3	3
Landscape	grd40x40	stream0	strm10c	strm20c	grd40x40	stream0	strm10c	strm20c	grd40x40	stream0	strm10c	strm20c
Time to Equilibrium												
Pop Size at Equilibrium												

APPENDIX 3.
Samples of Instructors' Grade Sheet with Comments

Reserve design assignment

The following sample grade sheets provide insight into the strengths and weaknesses of the students' responses and the level of our expectations. As instructors, we first graded each submission separately. We then met together to discuss inconsistencies between our scores and comments to establish a consensus on a fair final score.

Sample one

Sample one graphs	
Score	Question
1/1	**1. Did you produce the required graphs?** Your graphs looked good overall. The figures were well explained by the legends and key. You selected three graphs that well illustrated key points made in your narrative section. For your posters, I would suggest you review the good graph criteria and the comments on your graphs.
...	**2. Did you follow the Good Graph criteria?** We did not grade for this criteria, since we failed to provide the Good Graph criteria from the start of the assignment.
4/5	**3. Did your graphs clearly illustrate the relationships between habitat shape and each variable?** You did not provide a graph illustrating the effect of changing the number of offspring (-2 points) However, I felt your third graph was well chosen to illustrate how pop size is more sensitive to mortality than habitat shape. (+1 point)

Sample one narrative	
Score	Question
3/5	**1. Did you fully respond to each question?** You addressed most of the questions. I did not see a discussion of the effect of changing the number of offspring (part of question 3). You had extra room to write and you had some good ideas, it would have been nice to see you use the extra space to develop them more fully. Also, although you addressed several issues related to the methods, you did not take the next step of specifying which results you felt might be invalidated by these assumptions. Also, although you discussed the issue of population size, you did not discuss the influence of the habitat shape and biological rates on TIME to equilibrium. Time was much more responsive to shape than the population size, which could have important implications for how we manage invasive species.
...	**2. Are your responses reasonable?** We eliminated this question from the grade calculation because if you did not understand the model or the ecological processes, then your answers were not reasonable. We were deducting points for the same omissions in two places.
4/5	**3. Do the responses give evidence of consideration of landscape ecology principles?** You identified several landscape ecology issues that were overlooked or ignored by the model (considering scale, edge effects etc). However, although you identified these as important, you did not hypothesize how incorporation of these factors might influence the model's outcome or its application to real world problems with invasive species.
4/5	**4. Do the responses give evidence of clear understanding of the model?** I was concerned by your confusion of carrying capacity versus population equilibrium size. I emailed Dr. Cumming to verify that my interpretation of the model is correct (and will change your score if I am wrong). Also, in this model there is no direct ecological link between a species Carrying Capacity and its mortality rate. Changing the mortality would only change how quickly a species reached equilibrium (or extinction) - it would not influence the habitat's carrying capacity for that species.
1/1	**5. Is the document well organized with good grammar and sentence structure?** This report was well written.

1/1	**6. Has the length limit been respected? (Three page max at 1.5 line spacing)** The report was completed within three pages.

TOTAL SCORE : 18/23 points

Sample two

Sample two graphs

Score	Question
1/1	**1. Did you produce the required graphs?** You presented graphs illustrating the effects of varying dispersal distance, number of offspring, and mortality rate.
...	**2. Did you follow the Good Graph criteria?** We did not grade for this criteria, since we failed to provide the Good Graph criteria from the start of the assignment.
4/5	**3. Did your graphs clearly illustrate the relationships between habitat shape and each variable?** Your graphs were not very neatly organized or labeled. In the future, your graphs should also have some sort of legend that summarizes the conclusions from each set of graphs.

Sample two narrative

Score	Question
4/5	**1. Did you fully respond to each question?** I felt you did not directly answer question 2. Did you accept all of Cumming's conclusions without reservation? Overall the responses were adequate, but could have used a little more development, particularly with regards to ecological processes.
...	**2. Are your responses reasonable?** We eliminated this question from the grade calculation because if you did not understand the model or the ecological processes, then your answers were not reasonable. We were deducting points for the same omissions in two places.
3/5	**3. Do the responses give evidence of consideration of landscape ecology principles?** I would have liked to see evidence that you recognized the interplay between structural (in the habitat shape) and functional (in how the model represented dispersal, reproduction and mortality) connectivity. This was a key concept from this exercise. Another possible mechanism explaining some of the processes are metapopulation dynamics resulting from the interactions between empty patches created by mortality and recolonization by dispersal. The different structures place different limitations on these dynamics.
3/5	**4. Do the responses give evidence of clear understanding of the model?** I liked your observation and explanation of the "humps" in the stream colonization process. You were the only group to comment upon these. I was concerned that you did not identify three of the major model assumptions and consider their implications: constant rates, homogeneous habitat, and random dispersal.
1/1	**5. Is the document well organized with good grammar and sentence structure?**

The written style met the assignment criteria.

1/1 **6. Has the length limit been respected?**

The report was completed in three pages.

TOTAL SCORE : 17/23 points

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