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Island Biogeography and Geographic Information Systems

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Summary of Activity:

This four- or five-week long lab module introduces students to the basic concepts of Geographic Information Systems (GIS), mathematical modeling, and landscape ecology. In the classroom, students learn about the Equilibrium Theory of Island Biogeography, a classic model that attempts to explain patterns of species richness (number of species) on oceanic islands as a function of the spatial configuration of the islands, with the assumption that all species originated on the mainland. This simple model predicts species richness on islands based on the size of the island, the distance from the mainland, and the total species pool. The Island Biogeography Theory has often been applied to non-island systems in which smaller “islands” of habitat are isolated from a larger “mainland” by an inhospitable matrix. We use a terrestrial system of forested preserves in a “sea” of human habitation for this exercise.

In Exercise 1 of the module, students complete a published exercise in which they create a mathematical model in Excel that predicts species richness for islands of known size and distance from the mainland. In Exercise 2, students are introduced to GIS using the ESRI software ArcView. They are given an orthophoto of the study site, a large forest fragment (the “mainland”) surrounded by a series of smaller fragments (the “islands”), and they use ArcView to determine the sizes of the various forest fragments and distances between them. These data, along with an estimate of species richness, are then plugged into their Excel model to generate an expected species richness for each island. Finally, students measure the actual species richness of mammals, reptiles and amphibians in the fragments and compare the model predictions to their observations.

Integration of Disciplines:

This laboratory module integrates three disciplines: geography/spatial statistics, mathematics, and biology. These fields are not completely distinct, as they are often integrated in the biological sub-field of ecology, but undergraduates are not commonly

exposed to the techniques and concepts in introductory ecology classes and are rarely given hands-on experience in spatial modeling and GIS.

Students are first introduced to the mathematical model, which they recreate in Excel and manipulate so that they understand its functionality, if not the specifics of the computations. They are then introduced to ArcGIS, a technology first developed for the field of geography, which gives them an understanding of the importance of spatial relationships and an introduction to relational databases. These two exercises are then integrated with the study of natural systems, and students use these tools to make real-world predictions that they can test.

Learning Objectives:

This lab module has three main objectives:

1. Demystifying mathematical modeling and encouraging quantitative skills
2. Introducing students to spatial reasoning and techniques
3. Integrating these tools into the field of Ecology to make and test predictions about the behavior of the natural world

Target Level:

Intermediate-level undergraduate students

Tools and Materials:

- Computer Lab equipped with Excel and ArcGIS software
- Donovan, T.M. and C.W. Welden. *Spreadsheet Exercises in Ecology and Evolution*. Sinauer Associates, Inc. Sunderland, MA. 2002.
- Aerial photos of study site
- Tracking tubes or similar materials; see Connors, et al. (2005).
- Remotely triggered wildlife cameras
- General field equipment: compasses, measuring tapes, clipboards, timers, field guides, etc.
- Data sheets (<http://bioengineering.union.edu/gismodule/datasheets.pdf>)

General Outline of Exercises:

Exercise 1: Introduction to the Equilibrium Theory of Island Biogeography

This exercise is taken entirely from: Donovan, T.M. and C.W. Welden. *Spreadsheet Exercises in Ecology and Evolution*. (Sinauer Associates, Inc. Sunderland, MA. 2002.) Chapter 11. Island Biogeography. In addition to several exercises on models

commonly used in Ecology and Evolution, this book has an extremely useful introduction to spreadsheets, covering the most basic concepts through mathematical functions and macros. The chapters on statistical distributions and the central limit theorem are excellent introductions to mathematical statistics as well.

In this exercise, students follow the directions in the book, answering the questions as they go. I keep the class on track by stopping at certain spots to discuss the results and the answers to the questions.

Finally, students create a predictive model following the directions in **Handout 1** (<http://bioengineering.union.edu/gismodule/handout1.pdf>). This allows them to enter parameters from their own landscape (species richness, island area, and distance to mainland) and generates predictions of equilibrium species richness for each island. The spreadsheet **Model Demo** (<http://bioengineering.union.edu/gismodule/modeldemo.xls>) shows the Donovan and Welden exercise results, along with the data collected by the Ecology class in spring 2004 and fall 2005 from Union College and the model extension that allows calculation of predicted species richness.

Exercise 2: Introduction to Geographic Information Systems

This lab is a brief introduction to the software ArcGIS and it allows students to visualize the experimental landscape in which they will be working. The raw data comprise a satellite photo of the study site that is presented as a geodatabase. The site we use at Union College consists of a large preserve (approximately 120 ha) and a series of smaller forest fragments of varying sizes and distances from the preserve. Any fragmented landscape with a large patch surrounded by smaller fragments would be appropriate for this exercise

Using simple functions in the software, students trace various forest fragments to create a data layer in which they can estimate the size of each fragment. They also estimate the distance between the fragments and the mainland. At the end of the lab, they have most of the necessary data to parameterize the Island Biogeography Model that they created a week earlier.

Handout 2 gives complete instructions using ArcGIS 8.3.
(<http://bioengineering.union.edu/gismodule/handout2.pdf>)

GIS demo is a PowerPoint presentation that illustrates some of the capabilities of GIS. (<http://bioengineering.union.edu/gismodule/gisdemo.ppt>)

Exercises 3, 4, 5: Measuring Vertebrate Biodiversity in the Field

In the next three lab sessions, students divide into teams and visit the sites that they have previously been introduced to via satellite photos. Students are trained to use the equipment either during class or in an additional lab session. Each team consists of a “large mammal specialist”, a “small mammal specialist”, and a “herp (reptile and amphibian) specialist”. In an associated assignment, students familiarize themselves with the common species in their taxa and present brief descriptions to the class (see **Poster Instructions**; <http://bioengineering.union.edu/gismodule/poster.pdf>). During each lab,

groups are assigned a forest fragment and are dropped off to conduct their species inventory independently. Students maintain cell-phone contact with the instructor and each group is given a digital camera to photograph any animal species or sign that they are unable to identify with certainty. In addition to general observations, species richness is estimated using the following techniques:

Mammals:

- Tracking tubes
(**Handout 3A**; <http://bioengineering.union.edu/gismodule/handout3a.pdf>). These are tubes lined with contact paper with ink pads at either end and baited with seeds, using the technique described in Glennon, et al. (2002). Small mammals walk over the ink pads and leave tracks on the contact paper. Most common species can be identified by their tracks. A new paper by Connors, et al. (2005) describes a tracking plate system that might be easier to use than the Glennon, et al. system.
- Infrared cameras
(**Handout 3B**; <http://bioengineering.union.edu/gismodule/handout3b.pdf>). Baited with chicken and a standard scent lure, cameras are left in place for two weeks.

Reptiles and Amphibians:

- Amphibians are counted with timed counts in which all logs, rocks, and other debris of the forest floor are turned over in search of herptofauna (**Handout 3C**; <http://bioengineering.union.edu/gismodule/handout3c.pdf>). Typically, counts last for 1½ person-hours or three students searching for ½ hour, with adjustments for very small fragments. If a forest fragment contains standing water, students observe quietly to locate and identify aquatic species. When the class is taught in the spring, chorusing frogs are counted during an evening field trip.

Integration:

Students spend one class period compiling the data. They view the photos and identify each species photographed, identify the tracks, and enter all direct observation data into a database. They enter the final parameter, the number of species in the total species pool, into the model. Thus, they have values for predicted species richness and actual species richness.

The final part of this exercise is a formal lab report written in the form of a scientific paper. Students are told to assess the success of the Island Biogeography Model in predicting species richness both quantitatively and qualitatively, and then to propose one or two alternative hypotheses that might more accurately explain the results. See **Handout 4** “Lab Reports” (<http://bioengineering.union.edu/gismodule/handout4.pdf>) for more details.

Students generally evaluate the success of the model by performing a regression or correlation analysis of the predicted vs. actual species richness. I teach these analyses earlier in the term and students are quite familiar with them, although in this case it can be confusing to them since the two factors do not seem independent. Occasionally, a

student will come up with a novel way to quantitatively analyze the data, something that I encourage even if their thinking is a little fuzzy, as it shows a willingness to engage the data and think independently.

Theory and Background:

The Equilibrium Theory of Island Biogeography (McArthur and Wilson, 1963) seeks to explain species richness on islands based on the size of the island and the distance from the mainland. It conceives species richness as a dynamic equilibrium between immigration and extinction, in which extinction rate is governed entirely by the size of the island and immigration rate is dictated by the distance of the island from the mainland. Although developed for oceanic islands, this theory has been broadly applied to any system that involves isolated habitat patches, including mountain peaks, fresh water lakes, and forest fragments.

This theory is overly simple and has been broadly criticized over the past 35 years, a fact that students discover in their literature searches. During in-class discussions and in a final paper, students are encouraged to explore the problems and strengths of the theory, particularly as they apply to our “island” system.

There are many simplifying assumptions in the model, including the assumptions that all species have equal dispersal abilities, that the intervening matrix is uniform and equally permeable to dispersing individuals, and that there is no movement between islands.

In their final paper, students are encouraged to construct their own alternative model, either conceptual or mathematical, that might better explain the observed patterns of species richness. One class developed an alternate “habitat heterogeneity” hypothesis and designed an index with which they can measure heterogeneity in their fragments. Although their index was overly simple and did not correlate well with species richness, it was encouraging that the students were thinking critically about the model and the system.

Safety Precautions:

No special safety precautions are necessary for this exercise beyond what is normally expected on a field trip.

When we conduct this exercise in upstate New York, we warn students about Black-legged ticks (*Ixodes scapularis*) and Lyme disease. Students are required to wear white coveralls with their pants tucked into long socks. In addition, they are repeatedly reminded to check their bodies for ticks before they go to bed.

I also talk to students about respect for people living around the forest fragments in which they are working and tell them to identify themselves and immediately inform people of what they are doing and to be as non-confrontational as possible. Each group of students has a clipboard with directions, maps, data sheets, a copy of the letter of permission allowing them to work on the fragment and permits (when appropriate). In

some cases, I have informed neighbors in advance if I thought that the white-suited army of students might be alarming.

Miscellaneous Advice to Instructors:

The Island Biogeography Model usually does a fairly poor job of predicting species richness on the habitat islands. Via class discussions and individual conversations with students, I encourage them to look at the spatial configuration of the fragments and the surrounding and intervening matrix when they propose alternate hypotheses. Many use the species/area relationship, which generally explains a fair amount of the variation in species richness. I strive to have students figure out for themselves that they should examine the assumptions of the model when discussing its shortcomings and I hope that this helps them to understand how important it is to choose their assumptions to fit their particular system when they attempt to write their own model. Students often develop their own version of the “target effect”, where large islands have higher immigration rates due to their size, and the “rescue effect”, where extinction rates are reduced and immigration increased when animals migrate from island to island.

In the future, I intend to integrate global positioning system (GPS) units into the field component of the lab, allowing students to map the location of their cameras and tracking tubes, etc. to be downloaded into the GIS system as a data layer. Alternatively, I may designate appropriate camera sites that the students must then locate, an option that is attractive given the inappropriate camera sites that students sometimes choose. Although students respond very positively to the independence that comes with being sent into the field alone, they must be well trained to use the equipment and held responsible, via a lab grading system, for setting the equipment up properly and collecting accurate data. This usually induces students to take the exercise seriously and it is generally enthusiastically received.

References:

- Connors MJ, Schauber EM, Forbes A, Jones CG, Goodwin BJ, Ostfeld RS. 2005. Use of track plates to quantify predation risk at small spatial scales. *Journal of Mammalogy*; 86:991-996.
- Donovan TM and Welden CW. 2002. *Spreadsheet Exercises in Ecology and Evolution*. Sinauer Associates, Inc. Sunderland, MA.
- MacArthur RH and Wilson EO. 1963. An equilibrium theory of insular zoogeography. *Evolution*; 17:373-387.
- Glennon MJ, Porter WF, Demers CL. 2002. An alternative field technique for estimating the diversity of small mammal populations. *Journal of Mammalogy*; 83:734-742.

Laboratory Handouts for Students:

1. Handout 1. Model Addendum. The Donovan and Welden exercise is copyrighted and thus is not included.
(<http://bioengineering.union.edu/gismodule/handout1.pdf>)
2. Handout 2. Introduction to ArcView
(<http://bioengineering.union.edu/gismodule/handout2.pdf>)
3. Handout 3A. Conducting a Biodiversity Inventory: Large Mammal Specialists
(<http://bioengineering.union.edu/gismodule/handout3a.pdf>)
4. Handout 3B. Conducting a Biodiversity Inventory: Small Mammal Specialists
(<http://bioengineering.union.edu/gismodule/handout3b.pdf>)
5. Handout 3C. Conducting a Biodiversity Inventory: Herpetologists
(<http://bioengineering.union.edu/gismodule/handout3c.pdf>)
6. Handout 4. Lab Reports
(<http://bioengineering.union.edu/gismodule/handout4.pdf>)
7. Optional assignment. Poster Instructions
(<http://bioengineering.union.edu/gismodule/poster.pdf>)
8. Instructor materials
 - a. Exercise 11. Model Demo (Excel file)
(<http://bioengineering.union.edu/gismodule/modeldemo.xls>)
 - b. GIS demo. (PowerPoint presentation)
(<http://bioengineering.union.edu/gismodule/gisdemo.ppt>)
 - c. Data sheet templates
(<http://bioengineering.union.edu/gismodule/datasheets.pdf>)
 - d. Sample results from the entire exercise (Excel file)
(<http://bioengineering.union.edu/gismodule/sampleresults.xls>)
 - i. Results from Spring, 2004. These seem to be typical results, with the Island Biogeography model explaining only about 35% of the variation in species richness, but the species/area relationship doing a better job.
 - ii. Results from Fall, 2005. For some reason, this year the Island Biogeography model did an excellent job of predicting actual species richness on the forest fragments. I think it was a fluke.

Extensions and Options:

As written, this lab module requires a fair amount of specialized equipment and software. It works best when a highly fragmented forest system with a fairly diverse vertebrate community can be found in close proximity to campus. It can be tailored to fit many taxonomic groups and fragment types, however, such as plant diversity in prairie fragments, tree diversity in forest systems, invertebrate diversity in planters on campus,

etc. A varied matrix and different dispersal abilities are also beneficial so that students have the opportunity to consider the importance of multiple factors when interpreting their results.

A logical extension of this project would be to fit a mathematical model to the data via a multiple regression or another multivariate process and then to validate that model on a new data set taken from a similar system.

If you have problems accessing any of the documents in this lab module, please contact Lisa Christenson (christel@union.edu).