TIPS, TRICKS & TECHNIQUES

Improving Student Understanding of Spatial Ecology Statistics

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Abstract

This activity is designed as a primer to teaching population dispersion analysis. The aim is to help improve students' spatial thinking and their understanding of how spatial statistic equations work. Students use simulated data to develop their own statistic and apply that equation to experimental behavioral data for Gambusia affinis *(western mosquitofish). This activity can be adapted and conducted at the 9–16 grade levels.*

Key Words: *Spatial ecology; statistics; mathematics; behavior; index; dispersion; quantitative.*

○ Introduction

Spatial analysis is a powerful and broadly applicable analytical tool that is especially useful to biologists. Understanding how populations or individuals are distributed over space provides valuable insight into species–environment interactions, dispersal capacities, and behavior. Studying spatial pattern also invokes the use of mathematics and computational thinking, which is increasingly at the forefront of biological investigations.

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Traditionally, when spatial dispersion analysis is taught, students are provided a mathematical procedure such as calculating the variance-to-mean ratio or comparing observed frequency distributions to Poisson distributions (Cox, 2002). These data are typically provided or recorded in the field as tabular frequency data; thus, they are not spatially explicit. Ironically, with the exception of brief introductory materials showing figures of the three standard types of dispersion (e.g., random, clumped, and uniform), students are rarely exposed to pictorial visualizations showing spatially explicit data. When spatial data are viewed in tabular format, the analysis of spatial pattern immediately becomes abstract and centers on issues of frequency distribution (Cox, 2002). As a result, students lose the visual association between the spatial pattern observed and the statistics produced. This transition, we posit, often occurs too early – before most students have a robust understanding of spatial pattern – and inadvertently reduces the exercise to perfunctory "plug-and-chug." In the words of a former pupil, this approach regularly leaves students "knowing essentially nothing except for a formula that they have no idea how or why it works."

Here, we present a primer exercise aimed at improving students' spatial thinking by increasing their understanding of how spatial statistic equations provide information about spatial pattern. The data remain spatially explicit in the approach we present because we believe this visual connection is paramount in teaching and understanding introductory spatial ecological statistics. The central component of this approach is to have students develop their own spatial statistic equation to quantify dispersion, with the option of comparing the results of their equation to a standard statistic. In the end, by creating the equation themselves, many students gain a firmer understanding of "where the results came from, rather than simply getting a number that [they] can't relate to."

○ Project Description

The described project was implemented in the context of a module on behavioral ecology. The overarching goal of the exercise was to test for a difference in schooling behavior of western mosquitofish (*Gambusia affinis*) in the absence versus presence of a potential predator. The lab can be completed during a 3-hour lab period. The only preparation required is capturing the fish needed for the study. Feeder fish from a local pet store would be suitable. In this study, we used the locally occurring western mosquitofish, but any small fish species would suffice. The fish were collected in a small ephemeral stream using a 1.5 × 4 m seine with a 0.5-cm mesh. Fish selected for the study were then kept in aquariums until needed. Optimally, seven or more fish are used per lab group.

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Figure 1. Microcosm used for conducting the lab experiments. The plastic box is placed on top of the gridded lid when conducting the experiment.

○ Conducting the Activity

Step 1: Data Collection

Students are grouped into pairs. It is important that at least one person in each group has either a smartphone or digital camera, as the device will be used for data collection. Each pair is provided an observation microcosm and seven mosquitofish. The observation microcosm is a simple transparent plastic box (27 L) with grids marked out on the lid (Figure 1). The size of the grids is flexible; in our case, they were 10 cm^2. A grid-based approach is used to reduce problems with differences in how the students capture the image. The grids provide a consistent scale for reference.

The fish are first added to the microcosm and allowed to acclimate for 10 minutes. The students then begin taking images of the fish (capturing the entire tank) every minute for 20 consecutive minutes. These data are the control and represent the behavior of the fish in the absence of a potential predator. Then a potential predator is added to the microcosm. We suggest using a large-sized herbivorous or insectivorous fish species (i.e., stonerollers, shiners, or hogsuckers). So, in reality the students are testing the response of mosquitofish to a large fish in close proximity. The process of data collection is then repeated for the treatment. Each pair of students should now have 40 time-series photos, 20 for each trial. A total of about 60 minutes should be allowed for this step.

Step 2: Qualitative Assessment of Data

In pairs, the students' images are then viewed in Microsoft PowerPoint in a computer lab. One image is inserted per slide. The relative scales of the photos are likely to be very different between groups and within groups because of the different angles and heights at which photos were taken. Using the grid-based approach, this issue is eliminated. During this first stage of analysis, students are asked to qualitatively describe the response to the potential predator. Students have provided such assessments as *The fish usually formed one large group, The fish formed smaller groups packed more tightly*, or *The fish were more spread out*. Students should then determine the thought process used behind these qualitative observations. The aim of the second question is to get students thinking more quantitatively about the problem, and it should invoke references to *the number of fish per grid* or *the number of grids occupied* (etc.). Either the students can write out responses to the quantitative and qualitative questions or these can be discussed briefly as a class. The key is to reveal to students that their minds are naturally thinking within the realm of mathematical and spatial logic. The total time for step 2 is about 20 minutes.

Step 3: Developing the Spatial Statistic

For this task, the professor provides students with images of grid-based dispersion data to view in PowerPoint. These data should be similar in appearance to the data they collected. Each major type of dispersion (random, clustered, and uniform) should be provided. The students are again asked to describe the dispersions, and then they are tasked with developing an equation capable of capturing elements of both group size and overall spread with a single number. They can use any tools available in PowerPoint to collect dispersion information, such as shape tools (e.g., drawing lines, polygons, circles), which also permit some level of distance and area measurement by viewing the shape dimensions. Given the simple nature of the data, there will be some convergence in the variables students use to describe group size and spread, but the mathematical operations used to derive results usually vary considerably (Figure 2). Students should be allowed about 30 minutes to develop their equation.

Step 4: Sharing Equation Design

Next, have a representative of each group write their equation on the whiteboard (or blackboard) and give examples of the numerical values derived for each of the example dispersions. Then, in turn, give each students 2–3 minutes to explain their equation and how it works to capture spatial dispersion information. When all groups have presented their equations, initiate a discussion to begin using the variety of ideas to come up with a single equation to use as a class. It is preferred that students not simply choose to adopt a single group's equation. The purpose is to encourage the synthesis of ideas and further refining of the equation. Although having students share and integrate their ideas is optional, it is very valuable and allows more time for thinking critically about the project. For a formula, the class decided to divide the *number of fish found in the box with the highest number of fish in it by the total number of contiguous grids necessary to cover the entire sample of fish within the tank*. We called the equation the "CODIS index" because it captured elements of group *cohesion* and overall *distance* spread out. The shape tool was used in PowerPoint to evaluate each image (Figure 3) by creating squares similar to the relative size of one grid box. These boxes were then copied and pasted several times and arranged such that a path of boxes encased all of the fish. Various rules can be developed to guide grid placement and how much of a fish must be covered to be considered within a grid.

Step 5: Applying the Statistical Equation

Finally, students are to return to their images from the behavioral experiments and calculate the selected spatial statistic for each of the

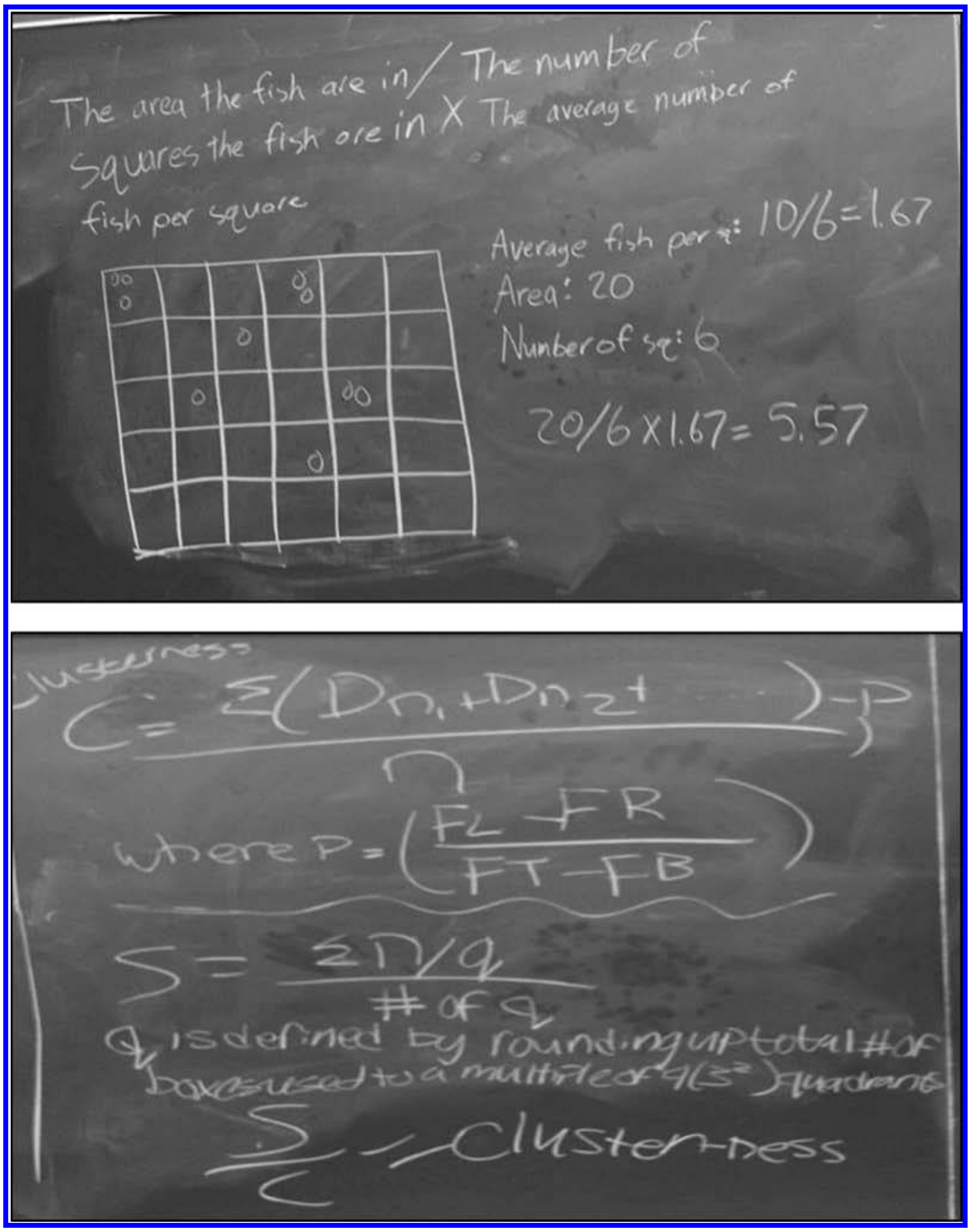

Figure 2. Student equations range from very simple and straightforward (top) to complex (bottom). The inputs for the top equation were the total area covered by the fish (as defined by the number of grids in a minimum bounding square) and the mean number of fish in the grids occupied. The inputs for the bottom equation were the mean number of fish in the grids occupied, and the distance each individual fish moved was from an estimated center-point of the group. The bottom equation required using PowerPoint tools to measure distances and involved tedious steps to standardize distances between images.

20 control and 20 predator-present images. Once those data have been analyzed, they calculate a mean value and standard error for the control and treatment, graph the results (Figure 4), and qualitatively describe the dispersion differences between the two treatments.

Step 6: Sharing Results

The results are then pooled for the class, and a group-level discussion occurs, focused on similarities or differences in results between groups, possible problems with experimental design and analysis, and the results compared to predictions based on ecological theory. Typically, this activity accompanies a lecture unit on behavioral ecology in which students explore the benefits and costs of group living, thus providing the basis of the class discussion. Many students also were naturally curious as to how their index would compare to the results of a more standard dispersion equation such as the variance-to-mean ratio. Therefore, depending on the scope of the class, this project could provide a good segue into a more computation-intensive follow-up project.

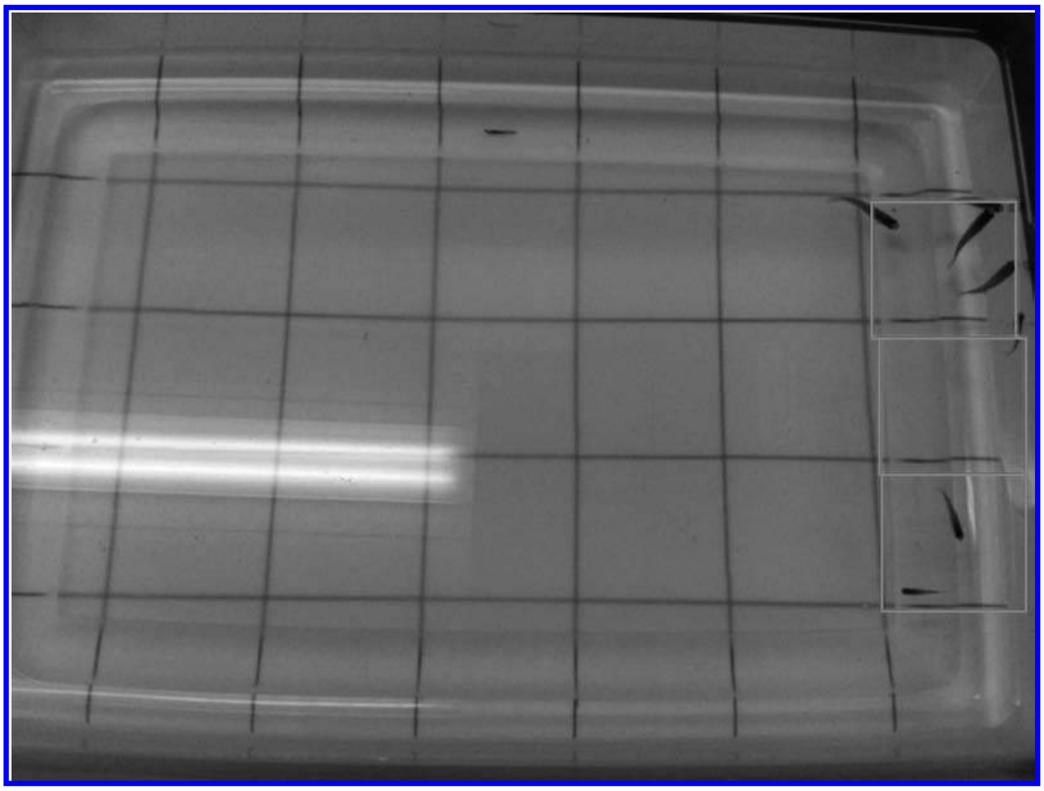

Figure 3. This is an example of the spatial dispersion in the absence of a potential predator. Based on our equation, the CODIS index (see text) would be 1.67. There is a maximum of 5 fish within a single grid, and 3 contiguous grids are required to cover all fish. Thus, 5/3 = 1.67.

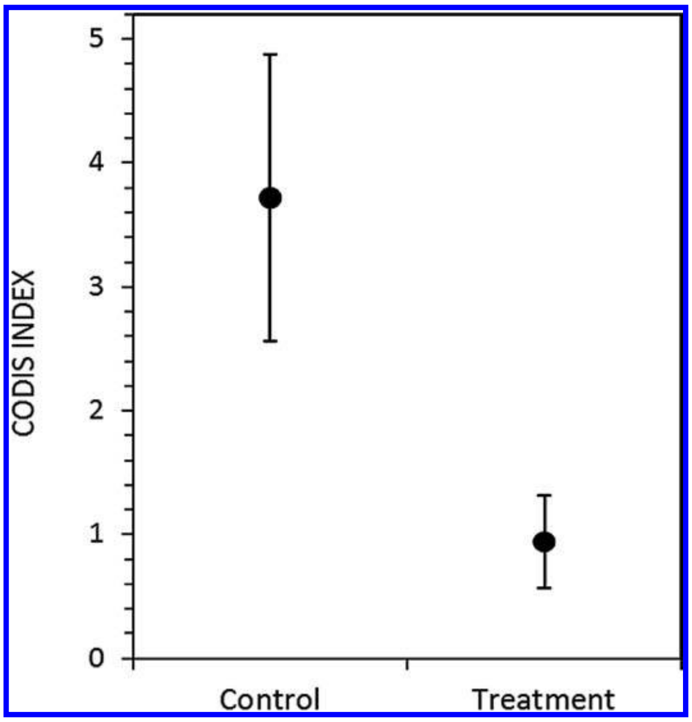

Figure 4. Example of contrasting CODIS values (see text; means ± SE) for control (no predator) and treatment (potential predator present) scenarios, where the CODIS value is equal to the number of fish in the box that has the most fish, divided by the number of contiguous boxes needed to encase all of the fish. These data show that the mosquitofish tended to disperse widely into smaller groups when a potential predator was present.

○ Conclusions

To date, this activity has proved very useful for introducing students to basic spatial analysis and putting them more at ease with statistical equations and mathematical logic commonly used in ecology. Students also enjoy completing a project without a predefined outcome. Giving students the responsibility of deriving the method by which their data are analyzed makes them more engaged in the activity and more interested in the scientific process. Furthermore, they are forced to think critically about their data and they better understand and appreciate the overall analytic approach. Based on their performance on exam questions related to spatial ecology, students in our class developed a solid basic understanding of the logical approach of spatial dispersion statistics and were better able to critically evaluate the experimental results and discuss ecological implications. Some student comments from an end-of-project questionnaire:

- "[The project] was something different than other assignments and gave me an opportunity to use critical thinking to solve for something that did not already have a defined formula."
- "It encouraged me to take a closer look at the data."
- "Instead of just knowing that the outcome was a clumped distribution, I know why it was and what equation I used to get that answer."
- "I was able to understand why the answer was exactly what it was."

Although we present this as a study of behavior, the analysis can be performed on any data that are spatially explicit. If the data are grid based, it seems to improve understanding because the space being studied is consistently partitioned and provides a constant frame of reference. Performing this lab does take time and may not seem to cover enough material. But instructors often advance through material at too rapid a pace, which leaves students developing only superficial or incomplete knowledge of the concepts being explored. Lastly, although it may seem counterintuitive to develop a statistic after collecting data, the kinesthetic and visual experience of designing an experiment and collecting data complements and enhances the task of developing a spatial statistic equation. Furthermore, this reversed approach helps prevent the project from appearing too abstract.

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Reference

Cox, G.W. (2002). *General Ecology Laboratory Manual, 8^{th} Ed.* New York, NY: McGraw-Hill.

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