Tested Studies for Laboratory Teaching
Proceedings of the Association for Biology Laboratory Education
Volume 38, Article 36, 2018

A Flexible Framework for Community Diversity Lab Exercises

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The goals of this exercise are to get students outside, actively engaged with ecological principles, and to appreciate the diversity of the community around them. However, we want to be able to use the same basic lab in different seasons, or even indoors if necessary. We created a framework for comparing community diversities that can be applied to various settings as the need arises. This activity uses Species Richness, as well as the Shannon-Wiener and Gini-Simpson Indices, to teach students not only how to calculate various measures of diversity, but also how to convert them to a more useful value: the effective number of species. This background material provides a flexible framework that can easily be modified to compare systems which are available and relevant for your class. In this workshop, participants used this activity to sort fossils, collect data and compare the biodiversity of Maryland Paleocene and Miocene fish faunas.

Keywords: Community diversity, diversity indices, species richness, Shannon-Wiener index, Gini-Simpson index

Introduction

Ecologists frequently use diversity indices to describe and compare communities. As a result, this is a topic that is commonly taught in introductory ecology courses. Although ecologists regularly use a large number of indices, we designed this exercise to provide basic background using a few of the most common indices: species richness, the Shannon-Wiener Index and the Gini-Simpson Index. In addition, we introduce the concept of "effective number of species", a measure that provides a more useful method for comparing the diversities of different communities. Much of the background we present here is adapted from the more extensive exposition by Lou Jost (2006; www.loujost.com).

A significant challenge when designing ecology labs is that the options for communities to study changes by location, season, and weather. The background provided here can be adapted to any available communities. It also provides a basis for students to design their own experiments.

Student Outline

Introduction

Species of organisms occur together and interact in ecological communities. We all have a sense that some communities are "more diverse" than others. We can be fairly confident that if we studied the bird community on the 540 hectare University of Maryland College Park campus, it would be far less diverse than the bird community inhabiting 540 hectares of Peruvian rainforest.

But what exactly do ecologists mean when they talk about diversity? This turns out to be a rather complex question, but below we lay out the basic mathematics of measuring and comparing community diversity in a meaningful way using diversity indices. In lab this week, you will sample the diversities of two different communities and compare them using these mathematical tools.

Pre-lab Exercise 1: Diversity Indices

Species Richness

If one community has 100 equally abundant species and a second community has a different set of 100 equally abundant species, you would probably (and very reasonably) consider these two communities to be equally diverse. If, instead, the second community had 200 equally abundant species, you would presumably consider it to be twice as diverse as the first community. When all species are equally abundant, all that matters for measuring diversity is the number of species and the simplest diversity index, the **species richness**—which is just the number of species present—tells us all we need to know about a community's diversity.

Evenness and Diversity

The richness of a community refers to a simple count of the species present. The **evenness** refers to the *relative abundance* of the species present. If all species present are equally abundant, the community is perfectly even. Diversity is easier to think about for a perfectly even community, but in real communities, equal abundance of all species is unlikely. Generally, there are a small number of abundant species and a much larger number of uncommon or rare species. If we have one community with 100 equally abundant species and a second community with 5 very abundant species and 95 very rare species, which community is more diverse? Many diversity indices have been developed to address this and related questions by incorporating both richness and evenness. One important way in which these various indices differ is in how relatively sensitive they are to changes (or differences) in richness versus evenness. Species richness, for example, is at one extreme, completely ignoring relative abundance in describing the diversity of a community. As we will see, some other indices are far less sensitive to species number but more sensitive to differences in evenness.

What Is an Index?

To back up for a moment, what is an index? An index is a measure that is correlated with some quantity, *but it is not the quantity itself*. For example, an engineer might have a set of spheres of different volumes and choose to measure the *diameter* of each sphere as an index of its volume, but if she wishes to compare the volumes of her spheres with those of other engineers who are instead using the *surface area* of the sphere as an index of volume (or who are measuring the volume directly), all these index values must be converted to actual volumes before they can be meaningfully compared. Ecologists have sometimes made the mistake of treating the various diversity indices as if they were all equivalent measures of true diversity, leading to significant confusion and non-intuitive results. As we saw earlier, the simplest diversity measure, species richness, by definition doubles or triples as the number of species doubles or triples. This is not the case for most diversity indices, whose values will start out different from each other when applied to a particular community and will change in a wide variety of ways as the community composition changes, depending on the mathematical construction of the particular index. However, just as the engineers can convert their various sphere volume indices from larger and smaller spheres to true volumes, which can then be compared, so diversity indices can be converted to "true diversities", which behave in intuitively reasonable ways and can be compared.

Making Meaningful Comparisons of Community Diversities

In the case of a perfectly even community (i.e., where richness is all that matters), it seems very reasonable to say that a community with 12 species has a diversity of 12. However, for communities that are *not* perfectly even (i.e., when the species are not all equally abundant), species richness becomes a very incomplete measure, failing to capture an important aspect of community structure. Consider, for example, the two communities we imagined earlier, Community A, with 100 equally abundant species, and Community B, with 5 very abundant species and 95 very rare species. One way (although not the only way) of thinking about diversity is that in a more diverse community, if you sample two individuals from the community, they

are less likely to belong to the same species than if you did the same thing in a less diverse community. *By this measure, which community would be more diverse, Community A or Community B?* The richness of these two communities is identical (100 species), but different diversity indices, constructed differently and with different sensitivity to evenness, will give very different values for these same communities. How can ecologists, like the sphere-measuring engineers, derive "true diversities" from these various diversity indices that will yield meaningfully comparable numbers? Before we address this question, let's try calculating values for several commonly used diversity indices to get a better sense of what we're talking about. Table 1 shows three common diversity indices: **species richness**, the **Shannon-Wiener** index, and the **Gini-Simpson** index.

Table 1. Formulas for common diversity indices and their conversion to effective number of species. p_i = the frequency of each species; s = number of species. You do not need to calculate these values yourself; you can use the Diversity Indices Spreadsheet.

Diversity Index	Formula	Effective Number of Species from Index Value, X	Effective Number of Species from Species Abundances, p_i
Species Richness	$\sum_{i=1}^{S} p_i^0$	X	$\sum_{i=1}^{S} p_i^0$
Shannon-Wiener	$-\sum_{i=1}^{S} p_i \ln p_i$	e^X	$exp\left(-\sum_{i=1}^{S} p_i \ln p_i\right)$
Gini-Simpson	$1-\sum_{i=1}^{S} p_i^2$	$1/(1-X)$	$\frac{1}{\sum_{i=1}^{S} p_i^2}$

Example 1

Consider a community with 5 equally abundant species:

Species name	Count	Frequency
A	5	0.20
B	5	0.20
C	5	0.20
D	5	0.20
E	5	0.20

1. Enter these data into the Diversity Indices Spreadsheet. You only need to enter the names and counts – the frequencies are calculated for you.

   What is the

   a) Species richness, S? _____

   b) Shannon-Wiener diversity? _____

   c) Gini-Simpson diversity? _____

Note that these three diversity indices yield three different numbers. Again, this should not be surprising because they are *indices* of diversity, not diversity itself. But we can, in fact, convert these index values to a common, comparable quantity often referred to as the **effective number of species** or **true diversity**.

Effective Number of Species

One of the most commonly used diversity indices is the Shannon-Wiener index, which, like other indices other than richness itself, factors in the evenness of the community. Consider two communities that have Shannon-Wiener diversity index values of 4.5. What is the effective number of species associated with a Shannon-Wiener diversity of 4.5? Suppose that one of these two communities has S equally common species. Using the intuitive definition proposed earlier, we would say that the effective number of species of this community is simply S, the number of species present. If these two communities have the same diversity according to the Shannon-Wiener index, and we know what the species richness, S, is for a perfectly even community with a Shannon-Wiener index of 4.5 (this turns out to be 90; see Table 1), we can say that *any* community with a Shannon-Wiener index value of 4.5 has that same effective number of species. So, for any index, we can use the formula for the index and some simple algebra to find the number of equally common species that yields any particular measured index value (see formulas in Table 1). This number, the **effective number of species**, is often referred to as the "true diversity" of the community in question. Converting index values to intuitively meaningful true diversities (i.e., effective numbers of species) allows us to compare results from different indices.

Is This Just Academic?

Why does any of this matter? Is this simply an esoteric topic for theoretical ecologists? In fact, understanding how to appropriately assess community diversity is critically important for many real world applications.

Example 2

Suppose you are comparing the diversity of marine crustaceans before and after an oil spill.

2. If you want to assess the impact of the spill on the crustacean community (i.e., crabs, shrimp, lobsters, etc.), why might just comparing species richness before and after not be a great approach?

The oil company hires a team of ecologists to measure the change in diversity, based on data collected before and after the spill. In this case, recognizing the limitations of simply measuring species richness, they instead choose to use the Gini-Simpson index, another common index which measures the probability that two individuals sampled randomly from a community belong to different species. They find that the pre-spill Gini-Simpson index is 0.99 and the post-spill index is 0.97, a drop of just 2%. Though this is a statistically significant difference, they conclude that given how small the change was, it is not biologically significant. The oil company is very happy with this finding. But is the conclusion valid?

Recall that the Gini-Simpson index, like other diversity indices, is not measuring diversity itself. In fact, it changes in a highly nonlinear way relative to changes in diversity. To see the effect of the spill on the effective number of species, we must first convert our index values to effective species numbers.

3. Use the Diversity Indices Spreadsheet to convert the pre- and post-spill Gini-Simpson Index values to effective species numbers and record your results in Table 2.

Table 2.

	Gini-Simpson Index Value	**Effective Species Number**
Pre-spill	0.99	
Post-spill	0.97	

4. By what percentage did the effective species number drop after the spill?

The reason for the disparity in decline of index value vs. effective species number is the nonlinear behavior of the index with respect to our intuitive concept of diversity, which is captured by effective number of species. In this case, a correct interpretation of the diversity measurements could have huge ramifications for public policy (e.g., law suits against the oil company, government fines, clean-up plan, etc.).

5. In Example 1, you calculated the richness, Shannon-Wiener index, and Gini-Simpson index for a perfectly even community with 5 species. Look back at the spreadsheet and enter those values in the Table 3. In addition, record the associated effective number of species for each index value.

Table 3.

	DIVERSITY INDEX VALUE	EFFECTIVE NUMBER OF SPECIES
Species richness		
Shannon-Wiener		
Gini-Simpson		

6. Repeat Example 1, but now assume 10 equally abundant species instead of five. Enter the values in Table 4.

Table 4.

	DIVERSITY INDEX VALUE	EFFECTIVE NUMBER OF SPECIES
Species richness		
Shannon-Wiener		
Gini-Simpson		

7. Fill in Table 5 based on Tables 3 & 4.

Table 5.

	DIVERSITY INDEX VALUE	EFFECTIVE NUMBER OF SPECIES
Richness (S=5)		
Richness (S=10)		
Shannon-Wiener (S=5)		
Shannon-Wiener (S=10)		
Gini-Simpson (S=5)		
Gini-Simpson (S=10)		

8. For each of the three indices, does doubling the number of species double the index value?

9. For each of the three indices, does doubling the number of species double the effective number of species?

Example 3

Now let's see what happens if we consider a community that is NOT perfectly even.

Species	Count
A	60
B	40

Calculate the index values and effective numbers of species for this community and record your data in Table 6.

Table 6.

	INDEX DIVERSITY	EFFECTIVE NUMBER OF SPECIES
Richness		
Shannon-Wiener		
Gini-Simpson		

In Example 1, we saw that when the community was perfectly even, although the various raw diversity index values varied a lot, the calculated effective species numbers were identical regardless of which index was used. In Example 3, however, when not all species are equally abundant, not all the calculated effective species numbers are identical (although in this case they are similar). This is because the different indices have different degrees of sensitivity to unevenness, or dominance. When species abundances are unequal, the Shannon-Wiener effective number of species will be less than the species richness, and the Gini-Simpson effective number of species will be less than the Shannon-Wiener effective number of species. The more uneven the species abundances, the more different the calculated effective numbers of species will be among the different diversity indices. Richness ignores species abundance. Shannon-Wiener weights each species exactly according to its relative abundance, making it the "fairest" of these diversity indices. Examining the Gini-Simpson formula shows how it strongly discounts rare species (i.e., those occurring at low frequency), since the square of a small number is a *very* small number. If rare species are of particular interest, simple richness may be the best diversity index to use. On the other hand, if one is mainly interested in dominant species, an index like Gini-Simpson may be most relevant. In general, it makes sense to calculate all three since the magnitude of differences among effective species numbers calculated using these three different indices provides an indication of the degree of unevenness in a particular community.

Exercise 1 – Biodiversity of Prehistoric Seas

Until very recently, geologically speaking, the Chesapeake Bay and much of the surrounding land was part of a larger body of water called the Salisbury Embayment. This area has fluctuated in size, and based on marine sediments, it dates to at least 88 million years ago (see Figure 1). In this exercise, you will examine the diversity of fish species (sharks, rays and bony fish) from two distinct time periods. The first of these is the Paleocene (about 60 mya) and the second is the middle Miocene (about 20 mya). The material from the Paleocene was collected along the Maryland shores of the Potomac River below Washington, D.C., and the Miocene material is from a beach on the Chesapeake Bay in Calvert County (see Figure 1 for approximate locations).

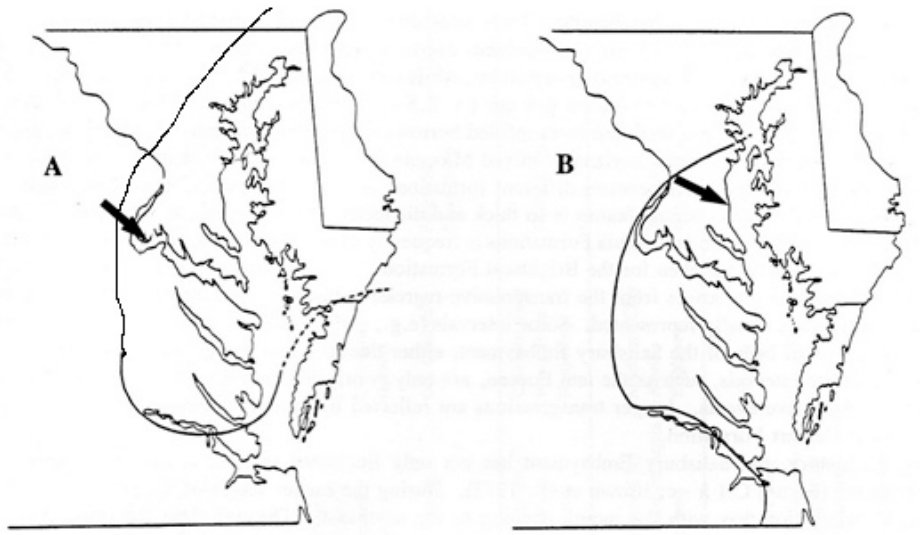

Figure 1. The borders of the Salisbury Embayment and locations where the fossil-containing material was collected. A = Paleocene site, B = Miocene site. Adapted from Kent (1994).

1. Get a sample bag of material for your group. Half of the groups in your section should get a sample from the Miocene site and the other half from the Paleocene site. Record your sample number on your data sheet. This material consists primarily of sand, gravel and broken bits of shell, but mixed in, you will find the fossilized remains of bony fish, sharks and rays.
2. Pour a small amount of the material into your sorting chamber (the petri dish with a grid on the bottom). It is best if you don't try to do too much at once. It is easier to scan through a few chambers with thin layers than to try to pick through a thick pile of material.
3. Place the chamber under a dissecting microscope and examine your material under the lowest power. This should be sufficient magnification to pick out specimens.
4. Using forceps, pick out anything that you think is a fossil. Fossils will be black or dark brown. Don't pick up anything that is light colored. Place any apparent fossils that you find in a small petri dish.
5. Repeat this procedure until your group has worked through your whole sample. Pour the sorted material into the waste container on your bench.
6. Once your group has worked through your whole sample, use the picture key to identify what you found. If you are unsure about an identification, give it your best shot. If you find something that isn't in the key, you can call it "Species A" or whatever you want to keep it separate from everything else.
7. Combine your group's data with data from the other groups that are working on the same time period.
8. Use the BSCI161_Diversity_Indices spreadsheet to calculate the index values and effective species numbers for each time period and record these values in Table 7.
9. Clean up
    a. Put the fossils that you found in a small reclosable bag and label it with your sample number. Give that bag to your TA. It is important to label the bags as we will be sending the best specimens that we find to a museum to add to their collection.
    b. Return your waste material to the sample bag and label the bag as complete.
    c. Clean up your bench.

Table 7.

	Index Value		Effective Number of Species	
	Paleocene	**Miocene**	**Paleocene**	**Miocene**
Species Richness				
Shannon-Wiener				
Gini-Simpson				

Cited References

Kent B. 1994. Fossil sharks of the Chesapeake Bay. Columbia (MD): Egan Rees & Boyer.

Materials

Samples

The samples containing the fossils were collected along two different beaches in Maryland. Both were screened at the beach to isolate material between ~1-6mm. These samples were brought back to the lab, dried for a few days, and then screened again with a #16 mesh screen (1.19mm) to remove fine material that does not contain fossils that we are looking for. During both of these screenings, larger fossils were retained and added back in to the final samples. The Miocene samples were collected from the Chesapeake Bay south of Bayfront Park in Chesapeake Beach, Maryland. The Paleocene samples were collected from the Potomac River in the Douglas Point State Natural Resources Management Area in Nanjemoy, Maryland.

The material is divided into divided into ~150mL samples and plastic into 5"x7" reclosable poly bags. The bags are given a unique sample number that indicates where and when the material was collected. This is important as we plan to donate any specimens of interest to a local museum.

Other Materials

- Dissecting microscopes – you could do this with a powerful magnifying glass, but it is a lot more difficult
- Forceps
- Sorting trays – standard 100 x 15mm polystyrene Petri dish with 3", 32-square grid Petri Stickers attached
- Standard 60 x 15mm polystyrene Petri dishes
- Sample bags
    - 5"x7" 2 mil white block reclosable bags
    - 2"x 3" 2 mil reclosable bags
- Permanent markers

Spreadsheet

We provide a spreadsheet that students can use to calculate the various indices as well as convert between index values and effective number of species. For more advanced students, it may be preferable to have them create their own spreadsheets.

Notes for the Instructor

This lab runs during week 12 of 13 of the *BSCI161: Principles of Ecology and Evolution* course at the University of Maryland. This course is designed to be taken concurrently with the lecture, *BSCI160: Principles of Ecology and Evolution*. These courses are populated primarily with life science majors and students who aspire to be life science majors in the future. There is very little direct support for the material covered in this lab in lecture, but it does line up with the portion of the lecture course that focuses on ecology.

Pre-lab

1. Background and exercises covering community diversity, the indices that will be used in lab, and practice problems allowing them to calculate the indices using the provided spreadsheet.
2. An exercise teaching them how to use dichotomous keys (not included here).
3. Assessment using an online quiz.

In-lab

1. Brief intro reviewing the concepts from pre-lab and discussing the habitats that they will be working with.
2. Data collection.
3. Compile class data.
4. Analyze and discuss results.
5. Turn in worksheet summarizing their findings for the day.

Our primary study site for this lab is a wooded area on campus that was hit by a tornado in 2001. The background for that version of the lab is included as Appendix A. The version that we completed in the workshop, i.e., comparing fauna of the Paleocene and Miocene seas, is our indoor backup plan in case of inclement weather.

This lab is easily adaptable for any systems that you want to compare. It is designed so that the background is consistent, and the only thing that needs to change is the in-lab exercise. It could easily be expanded to include more than two environments. Students can use this basic background and framework to design their own experiments, providing a wide range of possibilities to turn it into an inquiry-based lab.

Cited References

Jost L. 2006. Entropy and diversity. Oikos 113: 363-375.

Acknowledgments

We are grateful to Bretton Kent for his assistance identifying fossil shark teeth and to Jason Osborne for guiding us to our Paleocene collecting site.

About the Authors

Hans is the Lab Coordinator for the Principles of Ecology and Evolution Lab (BSCI161) at the University of Maryland. He holds a B.A. in Biology from St. Mary's

College of Maryland, an M.S. in Entomology from the University of Maryland, and an M.D.E. in Distance Education from University of Maryland, University College. In addition to coordinating the labs, he helps to teach courses on experimental design. Current research focuses on educational outcomes in laboratory and online settings and a survey of tiny Miocene shark and ray fossils found along the Chesapeake Bay. Leo is a Lecturer in the Department of Entomology at the University of Maryland, where he teaches Principles of Ecology & Evolution (BSCI 160) and Organismal Biology (BSCI 207). He received his Ph.D. in Ecology & Evolution from Stony Brook University

Appendix A

Biodiversity of Tornado Ravaged Forests

On September 24, 2001, an F3 tornado tore a 17.5 mile path from Chillum to Savage, MD, touching down in College Park and destroying temporary classroom and office buildings, uprooting trees, and flipping cars. Tragically, it took the lives of two University of Maryland students. For years afterward, the tornado's path through the patch of campus woods known as "The Hillock" was quite obvious, at first due to the reduced density of trees and later because many of the regenerating trees were characteristic of more open habitats than the woods that had been there previously.

Fifteen years later, can we still detect a difference in the tree communities growing along the tornado's path versus in the surrounding woods? This week, we will visit the site of the tornado and systematically record the woody plant species present (including the abundance of each) in circular sample plots within and outside the disturbed area. For your sampled plot, you will calculate effective numbers of species using three diversity indices: species richness, Shannon-Wiener, and Gini-Simpson to see whether we can still detect differences between the tree communities in the two areas. You will also look at specific species differences between the two sites.

To compare the biodiversity of trees in the disturbed and undisturbed sites, we have already laid out four 0.18 ha plots (ha = hectare = 10,000 m^2) at each site. Your group will be assigned to one of the plots at each site and at the end of lab, you will combine your data with the rest of your class.

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Citing This Article

Lemke HL, Shapiro L. 2018. A Flexible Framework for Community Diversity Lab Exercises. Article 36 In: McMahon K, editor. Tested studies for laboratory teaching. Volume 39. Proceedings of the 39th Conference of the Association for Biology Laboratory Education (ABLE). **http://www.ableweb.org/volumes/vol-38/?art=36**