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Assessing Biodiversity with Forest Plots

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This exercise for a non-majors course uses biodiversity estimates to evaluate habitats. The pre-lab homework introduces biodiversity assessment and leads students through the mathematical model. In the field, students use basic dendrology techniques to identify woody vegetation in two small plots. Back in lab, they use the indices to estimate relative diversity. The procedure for setting plots requires minimal equipment. We conduct it as a one-week exercise, but it can be adapted easily into a two-week inquiry lab suited to majors or upper level courses. It also can anchor a series of labs on plant identification, conservation, and bioremediation.

Keywords: biodiversity, species richness, diversity index, dendrology, non-majors

Introduction

Biodiversity is the degree of variation of life. The UN Environment Programme formally defines it as "the variability among living organisms from all sources, including terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are a part; this includes diversity within species, between species and of ecosystems (UNEP Convention on Biological Diversity, 1992; https://www.cbd.int/.) Yet many students have a deep misconception about biodiversity. In their minds, the term is synonymous with protecting Amazonian rain forests, rare Asian cloud forests, and other far- off "charismatic ecosystems."

These exercises were designed to help students learn that: 1) biological diversity is a fundamental attribute of all ecosystems, including local ecosystems they see daily; 2) diversity can be assessed and measured systematically; and 3) diversity estimates are used to compare ecosystems, monitor normal change, and track ecosystem health.

In the pre-lab homework, students compare two biodiversity estimates: **species richness** (number of species observed), and **Simpson's diversity index**. Simply counting the number of species makes intuitive sense to students, but as the pre-lab exercise shows them, species richness does not account for differences in population sizes. They learn that the Simpson's index considers both how many species are present AND their evenness, that is, how evenly distributed the number of organisms are between the species.

During lab the students walk to two field plots on campus, where they use basic dendrology techniques to identify the woody vegetation. Back in lab, they calculate the Simpson's diversity index for each site, and use the indices to compare relative diversity. We prefer the Simpson's index because other common indices (such as the Shannon-Wiener Index and Berger-Parker Index) are not as easy to calculate by hand, and can be harder for students to understand.

The student exercises reflect our local forests, but they can be modified very easily to match users' local flora, their available field sites, and relevant questions for their region.

Student Outline

Assessing Biodiversity

Biodiversity is short for "biological diversity." It is the variety of species in a particular area. Biodiversity is often used as a measure of the health and stability of ecosystems.

Today's lab will focus on species diversity, how it is measured and how one can interpret those results. We will be visiting field sites on campus, observing the similarities and differences of the sites, and calculating the biodiversity of the woody vegetation on each site we visit.

How Do We Measure Diversity?

One way to measure diversity is **species richness**, that is, the number of different species present in an area. The more species present in a sample the 'richer' the area.

Species richness on its own takes no account of the number of individuals of each species present. It gives equal weight to those species with very few individuals and those with many individuals. Thus, one daisy has as much influence on the richness of the area as 1000 buttercups.

Examine the following data from two different sites with equal richness (see Appendix A for diagrams that can be used as an alternative to Table 1).

Table 1. Species composition of two sample sites.

	Number of individuals	
Flower species	**Field A**	**Field B**
Daisy	300	10
Dandelion	330	50
Buttercup	370	940
Total	1000	1000

1. What does Field A look like?

2. Field B?

3. Is one more diverse than the other?

A more useful measure of diversity also will take into account the abundance of each species. **Evenness** is the relative proportion of each species. So, species diversity relates to the number of the different species and the number of individuals of each species within any one community.

Other Measures of Diversity

A number of objective measures have been created in order to measure species diversity which take into account both richness and evenness. Today, we will use one of these, **Simpson's diversity index**.

Simpson's index (**D**) is a measure of diversity, which accounts for both species richness and the evenness of abundance among the species present. The formula for calculating D is:

$$D = \frac{\sum n_i\,(n_i - 1)}{N(N-1)}$$

where n_i = the total number of organisms of each individual species
N = the total number of organisms of all species

The value of **D** ranges from 0 to 1.0. With this index, 0 represents infinite diversity and, 1.0, no diversity. That is, the bigger the value the lower the diversity.

This does not seem intuitive or logical, so some texts use derivations of the index, such as the inverse (1/D) or the difference from 1 (1-D). The equation used here is the original equation as derived by Edward H. Simpson in 1949.

To calculate Simpson's index for a particular area, the area must be sampled to determine the number of species, and number of individuals of each species. For example, the diversity of aquatic insects may be determined by sampling from a stream. The number of different species *and* the number of individuals of each species should be recorded. It is not necessary (but it is helpful) to identify all the species provided that they can be distinguished from each other.

Frequently, biodiversity measures are used as an assessment of the *health* and *stability* of an ecological system (ecosystem).

Low species diversity SUGGESTS:

- relatively few successful species in the habitat
- the environment is quite stressful with relatively few ecological niches; only a few organisms are really well adapted to that environment
- food webs which are relatively simple
- change in the environment would probably have quite serious effects (unstable ecosystem)

High species diversity SUGGESTS:

- a greater number of successful species and a more stable ecosystem
- more ecological niches are available and the environment is less likely to be hostile
- complex food webs
- environmental change is less likely to be damaging to the ecosystem as a whole (stable ecosystem)

In the above lists, we said "SUGGESTS" because we must be careful interpreting biodiversity measures. Some habitats are more stressful or harsh, and fewer organisms may be adapted for life there, but, those that are may well be unique or, indeed, rare. Such habitats are important even if there is little biodiversity.

If a habitat suddenly begins to lose its animal and plant types, ecologists become worried and search for causes (e.g. a pollution incident). Alternatively, an increase in the biodiversity of an area could mean that corrective measures have been effective, or that conditions are changing in that habitat.

Using Simpson's Index to Measure Biodiversity – A Worked Example

This example will help you better understand how to use Simpson's index.

Scenario:

The State Department of Transportation is considering a proposal to connect two frequently used roads which will make it necessary to span a high quality stream in a heavily forested area (Site 1). In order to mitigate the potential negative effects that construction will bring, they need to improve a low quality stream elsewhere in the state. They sampled the construction site (Site 1) before any work was completed. In addition, they sampled other poorer quality sites from their list of potential restoration sites (Sites 2 & 3)

Site 1 has the highest diversity. It has high species richness and each species has a similar relative abundance. Site 2 has the same species richness as site A, but is dominated by one species (A) so that the diversity of this community is lower than in site 1. Site 3 has a lower diversity than site 1, due to its lower species richness.

Table 2. Species composition of three different sites.

Species	Site 1	Site 2	Site 3
A	10	72	35
B	9	6	34
C	11	3	31
D	10	3	0
E	8	1	0
F	12	3	0
G	10	4	0
H	11	3	0
I	10	2	0
J	9	3	0
Total	100	100	100

Which site might be the better option for restoration, Site 2 or Site 3? Why? (There may be many reasons why either of the sites would be a good option. What do *you* think?)

Now, let's use the index to quantify the differences among the sites. Recall that the formula for calculating Simpson's index is:

$$D = \frac{\sum n_i\,(n_i - 1)}{N(N-1)}$$

Where N = the total number of all organisms
n_i = the numbers of individuals of each individual species

The lower the value of D, the greater is the species diversity. Take for example site 1 in the table 1 above. The values of (n_i-1) and n_i(n_i-1) in the computation of D are shown in table 3.

Table 3. Data for calculation of Simpson's index for site 1.

Site 1			
Species	**n_i**	**$n_i - 1$**	**$n_i(n_i - 1)$**
A	10	9	90
B	9	8	72
C	11	10	110
D	10	9	90
E	8	7	56
F	12	11	132
G	10	9	90
H	11	10	110
I	10	9	90
J	9	8	72
Total	N = 100		$\Sigma n_i(n_i - 1) = 912$

So for site 1:

$$D = \frac{912}{100\times 99} = \mathbf{0.09}\ (\textbf{high diversity})$$

Using the same method, calculate the Simpson's index, D, for sites 2 & 3 in the tables below (or a spreadsheet).

Table 4. Data for calculation of Simpson's index for site 2.

Site 2			
Species	**n_i**	**$n_i - 1$**	**$n_i(n_i - 1)$**
A	72	71	5112
B	6		
C	3		
D	3		
E	1		
F	3		
G	4		
H	3		
I	2		
J	3		
Total	N = 100		$\Sigma n_i(n_i - 1) =$

$$D = \frac{\sum n_i\,(n_i - 1)}{N(N-1)}$$

D=

Table 5. Data for calculation of Simpson's index for site 3.

Site 3			
Species	**n_i**	**$n_i - 1$**	**$n_i(n_i - 1)$**
A	35	34	
B	34		
C	31		
Total	100		$\Sigma n_i(n_i - 1) =$

D=

Place the diversity indices (D) in the table below. Compare the values of the three sites.

Table 6. Values for Simpson's index for sites 1, 2 and 3.

Site	**D**	**Level of diversity**
1	0.09	Very high
2		
3		

What do you think of your assessment of which stream would be better to restore, site 2 or 3? Have you changed your thinking? How do the calculated indices effect your assessment of sites 2 or 3?

Field Exercise: Forest Biodiversity Assessment

Now, you will be assessing two different forested sites on campus. Your assessment will be based on your casual observations as well as your calculated diversity values of the woody vegetation at the sites. A description of the forest types is included at the end of this lab.

While visiting the two field sites, observe and record any information which may help describe the sites. Think about the effects that abiotic (non-living) factors, such as temperature, sunlight, soil conditions, may have on the organisms that use this habitat.

WARNING: Beware the poison ivy in the field sites!!
All parts of the plant (vine, leaves & berries) are poisonous. Do not touch.

Identifying and Sorting Woody Vegetation

Using the keys provided, identify all the **woody** vegetation (trees, shrubs, & vines) at the two different sites. Alternatively you may download a woody plants ID app to your phone.

Record your data on Tables 8 and 9. For species that you cannot identify, categorize them with a descriptive note which you can use for others of the same type.

In addition to an individual's species, record whether the tree is in the understory or canopy of the forest and its size category.

Table 7. Woody vegetation size categories defined.

Size category	**Description**
Seedlings	Between 15 cm tall and 50 cm tall
Saplings	Greater than 50 cm but less than 10 cm in circumference at breast height (BH=1.37 m from the base of the tree)
Small tree	Between 10 and 30 cm in circumference at BH
Medium-large tree	Greater than 30 cm in circumference at BH

Data Collection Sheet for Site A: Upland Oak-hickory Forest (Late Successional)

Site description:

Table 8. Data sheet for site A.

Species	Understory / canopy?	Size category	Other notes

Data Collection Sheet for Site B: Upland Pine Forest (Early Successional)

Site description:

Table 9. Data sheet for site B.

Species	Understory / canopy?	Size category	Other notes

Back in Lab: Determining Forest Biodiversity

Upon return to the lab, record your results in a spreadsheet, adding formulas for the calculation of the diversity index. Calculate the Simpson's diversity index, D, for each site as you did in Tables 3 and 4. As an alternative to Excel, you may hand write the calculations as we did for Tables 3 and 4.

D for Site A =

D for Site B =

Questions for Further Reflection

1. Compare the diversity of Sites A and B. What were some visual differences that you noted? What might account for these differences?

2. Did tree size have any impact on the diversity of the sites you visited?

3. Why do biologists use measures of biodiversity? Describe some different ways that you think the data could be useful as a measure of the health of biological systems.

4. What is meant by “stability” in an ecosystem? What is the relationship between stability and a forest’s successional stage? How can biodiversity measurements be useful in determining the stability of a site?

Materials

For Class of 25 Students
Assumes students work groups of 2 or 3

- 8, 2 to 4-meter cloth or plastic measuring tapes
- 8-9 clipboards
- 4-5 pictorial guides to local woody flora

Shared by Class

- 25-meter or longer field tape

OR

- 35-meter length of rope (adjust length for larger plots)
- 4, ~4-foot wooden stakes per plot (corner marking; length not critical)
- Hammer or mallet
- 1-2 rolls flagging tape
- 1 shovel

Notes for the Instructor

The basic procedure is extremely simple to set up, requiring only wooden stakes, flagging tape, a long rope or 25-meter tape to measure plots, and cloth or plastic tape measures for students. We conduct this as a one-week exercise for non-majors, but it can be the first week of a two-week inquiry lab suited to majors or upper level courses. It also can anchor a series of labs on other topics, such as plant identification, conservation, or bioremediation.

Choosing Sites

Locating appropriate sites for this exercise is the main challenge. Fortunately even heavily urban areas have parks, riparian zones, greenways, or other pockets of naturally growing vegetation. An ideal site will have two obviously different habitats within short walking distance of each other. For example, our students compare diversity between plots in a dry pine forest and an oak-hickory forest that are situated approximately 400 m apart.

When choosing where to situate the plots, keep in mind what questions you want students to answer. We want students to discover that diversity increases during succession. Therefore, we chose plots in earlier vs. later stages of succession.

Setting Up Plots

Standard plots for this exercise are 10 m X 10 m square. Students will need about an hour to sample plots this size. Larger plots take longer, but work fine otherwise. Smaller plots are not recommended, unless students are sampling multiple small plots in the same habitat and pooling data.

For a single lab section, students can help set up the plots to be evaluated. For multiple class sections, set them up in advance.

We use a 25-m field tape to measure plots. To set plots without a long measuring tape, cut a 35- meter length of rope or heavy cord. Tie the two ends together. Measure 10 meters from the knot, and wrap tape around the rope to mark it. Measure another 10 meters, and mark the rope again. Measure the distance from the second mark back to the knot; it should be ~14.1 m. If needed, re-tie the knot to remove any extra length.

To set the corners of a plot:

1. Pound a 4-foot stake into the soil at the first corner. If the soil is compacted or root-bound, cut a slot with a shovel before pounding in the stake.
2. Place the knot in the tied rope over the stake or have a student hold the measuring tape, and walk out to the 10-m mark on the tape/rope. Set the second stake.
3. Walk at a right angle from the second stake for another 10 meters, and place the third stake.
    - If using a measuring tape, the diagonal distance between the first and third stake should be 14.1 m; if less or more, the corner is not square. Adjust the third stake until the distance from first to third stake is 14.1 m, and the distance from second to third stake is 10 m.
    - If using a pre-marked rope, adjust the position of the third stake so that the rope is taught between the first and third stake, and second and third stake.
4. Go back to the first stake, and repeat the process to set the fourth stake.
5. When the four corners of the plot have been set and the plot is square, mark the tops of each stake with flagging tape.

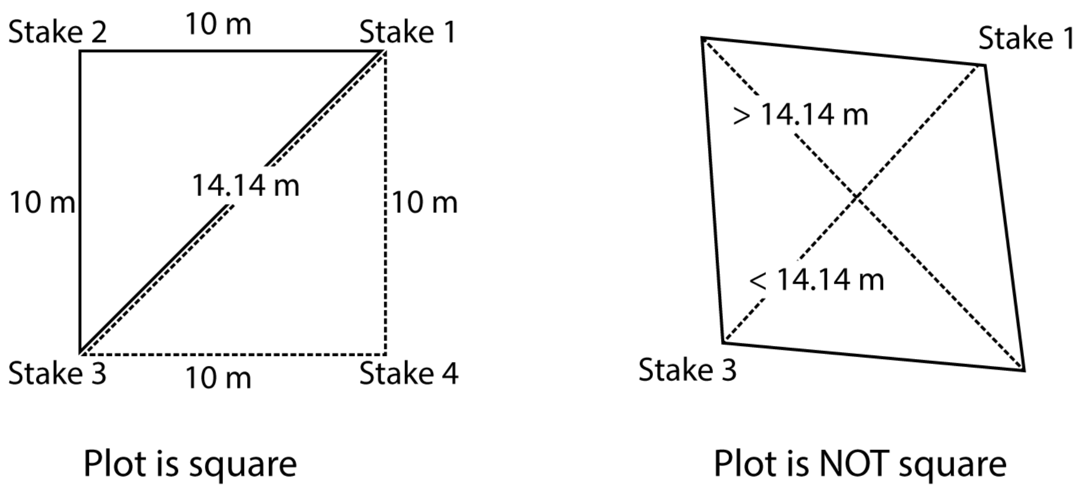

Figure 1. Layout of plots

Keys to Local Flora

For our course we created custom guidebooks using Creative Commons-licensed photos (a search tool is available at http://search.creativecommons.org) and descriptive data from the US Forestry Service and regional resources. Creating a key for locally common species would be a reasonable semester-long project for an undergraduate study student. They can collect images on location, and research the short descriptions online.

If students have learned local woody flora previously, this lab exercise is a good practical assessment of their knowledge.

Online Resources & Apps:

- The regional Cooperative Extension Service, State Dept. of Conservation, or local Nature Conservancy or Sierra Club often have online guides.
- Check with nearby colleges and universities. Many instructors post their guides online and are happy to share.
- State land grant universities with arboriculture, horticulture, or forestry training programs often have regional keys to woody plants.
- *What Tree is That?* is an online key and app available from the Arbor Day Foundation (http://www.arborday.org/trees/whattree/). It applies to much of North America.

Published Guides:

Look for guides to common local flora in area bookstores, outdoor supply stores, or a local library. Additional general options:

- A printed version of *What Tree is That?* is available from the Arbor Day Foundation (http://shop.arborday.org/product.aspx?zpid=583). It uses color codes to introduce students to dichotomous keys more gently. Limited coverage of other woody species.
- Peterson Field Guides (http://www.houghtonmifflinbooks.com/peterson/) are available for trees and shrubs of eastern and western North America. Audubon, National Geographic, Sibley, and Princeton publish field guides too.
- Laminated plastic folding guides are available from Steven M. Lewers & Assoc. (http://www.foldingguides.com/foldingguide_all.html).
- Customized guides to specific sites are available from Waterford Press (http://www.waterfordpress.com/index.php).

Key to Questions in the Exercises

In: How Do We Measure Diversity?

1. What does Field A look like?

Field A has a relative even distribution of individuals from all three species.

2. Field B?

Field B is dominated by buttercups. The other two species are uncommon. Thus, the distribution of individuals is uneven.

3. Is one more diverse than the other?

On the basis of species richness (number of species) they are equivalent, but using the Simpson's index, Field A is more diverse.

In Pre-Lab: Using Simpson's Index to Measure Diversity

Diversity indices (D) for the three hypothetical sites.

Table 6. Values for Simpson's index for sites 1, 2 and 3.

Site	D	Level of diversity
1	0.09	Very high
2	0.75	Low
3	0.34	Intermediate

1. Which stream would be better to restore, site 2 or 3?

We ask this question twice. The first time gets students thinking about which site could be raised to the diversity index of Site 1 most easily. They will need to calculate the indices for Sites 2 and 3 before they can answer with any confidence.

Either site could be improved to match the diversity of Site 1, but which site makes more sense? Site 2 has more species already; improving diversity would require improving the conditions for the populations already present. Site 3 will require importing or restoring species no longer present on the site. If restoring species to former ranges is important, Site 3 might be the better choice. If restoring species will be too great a challenge, Site 2 will be easier to improve.

In Pre-Lab: Questions for Further Reflection

1. Compare the diversity of Sites A and B. What were some visual differences that you noted? What might account for these differences?

The goal for this question for students to summarize their direct observations, and attempt to connect the diversity index values to observable differences.

2. Did tree size have any impact on the diversity of the sites you visited?

Tree size does impact diversity, but whether students observe it depends on the age class of the trees in the site. Each tree counts as an individual of the species; hence, a site with small saplings of one species will have lower diversity, while a site with saplings from multiple species with have higher calculated diversity.

3. Why do biologists use measures of biodiversity? Describe some different ways that you think the data could be useful as a measure of the health of biological systems.

So we know whether an ecosystem is changing, and how. We can calculate and compare biological diversity indices for two locations that should be similar, and see if one is more or less diverse than the other. Using this information we can assess impacts of human activities, climatic changes, etc., on less diverse ecosystem. We can compare the diversity indices for one location at two different times, and determine if and how that location is changing over time. This might be normal change, or an unexpected change due to a shift in local conditions.

4. What is meant by "stability" in an ecosystem? What is the relationship between stability and a forest's successional stage? How can biodiversity measurements be useful in determining the stability of a site?

For a stable ecosystem, calculated diversity will not change much over time, AND the species that make up the ecosystem tend not to change. In general, mature climax forests are stable, while earlier successional stages are less stable. However, over time an ecosystem can continue to have the same Simpson diversity value, while undergoing species replacement. For example, when chestnut blight decimated eastern hardwood forests, chestnut was replaced by oak or hickory. Diversity estimates made several decades apart would not show much change.

Frequent, regular sampling is the best means of monitoring stability. Samples that are widely spaced in time are less valuable.

Other Commonly Asked Questions

Why is Biodiversity Important?

The importance of maintaining biodiversity has been ingrained in students by educators and popular media. Yet when pressed for details, most students have a very difficult time explaining why. Most responses will reflect a human-centered view ("to protect the beauty"; "that's where we get new drugs").

Biological diversity is vital to overall health of ecosystems. Each of the species in an ecosystem provides different ecological services. Wetlands are a widely used example. Many species commonly found in wetlands absorb chemicals from runoff, feed and shelter other species, or buffer adjacent ecosystems from extreme weather. Removing one species from a wetland ecosystem is unlikely to eliminate the ecological services it provides entirely, but it does mean there now are fewer species available to participate in that function.

High biological diversity also helps ecosystems adjust to random disturbances. If one species disappears from an ecosystem, its roles in food webs and ecological services can be taken over by another, similar species.

Genetic diversity is also important. As the number of individuals in a species declines locally, diversity in the local gene pool decreases. This makes the local population more vulnerable to disease in the short term, and potentially reduces fitness long-term.

The United Nations Environmental Programme's World Conservation Monitoring Centre (http://www.unep-wcmc.org/) is an excellent resource for students to learn more.

Is Low Diversity Always Bad?

No. Students can develop the misconception that low diversity is always bad, and high diversity is good. This is an overly simplistic view that we try to discourage. Diversity can be low for many reasons. For example, during succession (which is what our students study) diversity normally increases with time. Plots in earlier successional stages have lower woody plant diversity because they are dominated by the pioneer specialist species. Highly challenging habitats such as deserts may have only a few species adapted to survive there.

Acknowledgments

The authors greatly appreciate the input and diligence of the graduate teaching assistants that helped to test and refine this lab. In addition, we recognize the vast wealth of knowledge from many similar labs used to better teach countless students and hope this contribution continues the effort.

Lab adapted from www.rewardinglearning.org.uk

About the Authors

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Dr. A. Daniel (Dan) Johnson is a Teaching Professor of Biology, and co-founder of The Adapa Project, a nonprofit consortium of science education innovators and content creators. He received his B.S. in biology from the University of North Carolina, Charlotte, and Ph.D. from Wake Forest University School of Medicine. After postdoctoral fellowships at the Texas Heart Institute and University of Virginia, in 1998 he joined the faculty of Wake Forest University. He has developed inquiry-based lab activities and programs for students from middle school through college. His current work centers on improving college science teaching, strategies for engaging non-major students, and building digital tools to support teaching.

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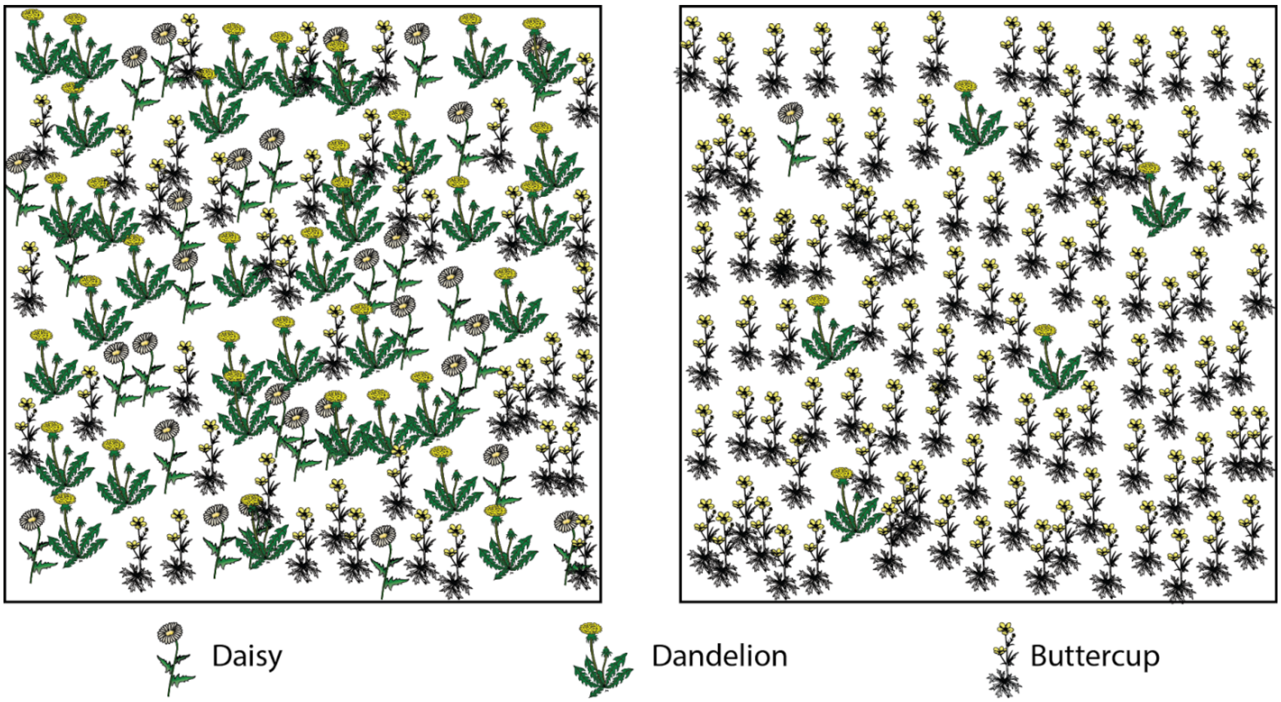
Appendix A

If students cannot imagine the differences in the two plots described in Table 1 of the pre-lab assignment, the two images below have the same ratios of species as in Table 1. Larger versions are on the next 2 pages. The original vector files are available on request from the authors, and included as digital supplements to the published chapter.

Field A　　　　Field B



	Number of Individuals	
Flower species	**Field A**	**Field B**
Daisy	300	10
Dandelion	330	50
Buttercup	370	940
Total	1000	1000

Figure 2. Schematic images showing relative diversity of Fields A and B. The two images have the same ratios of species as listed in Table 1 of the pre-lab assignment.

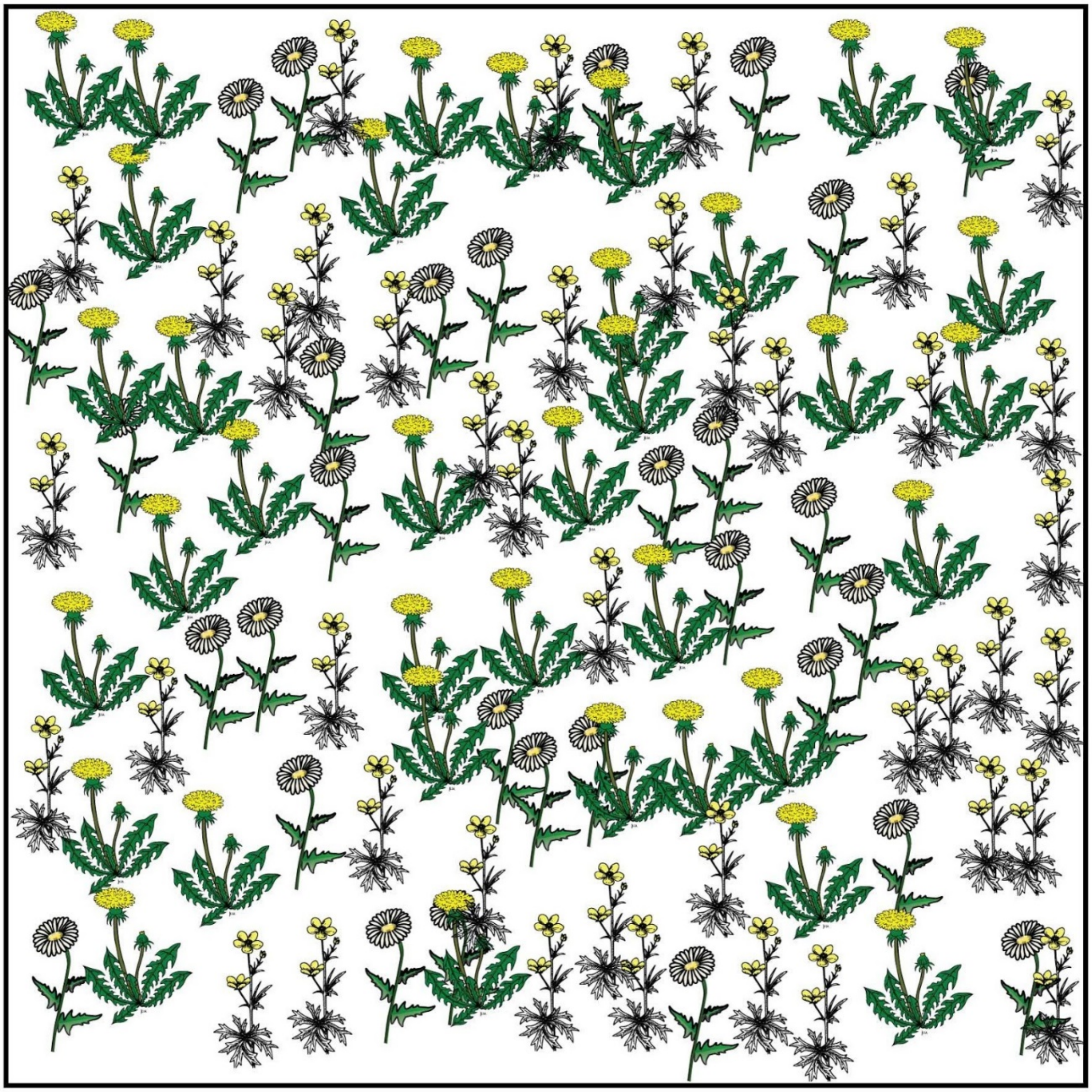


Figure 3. Larger schematic image of Field A.

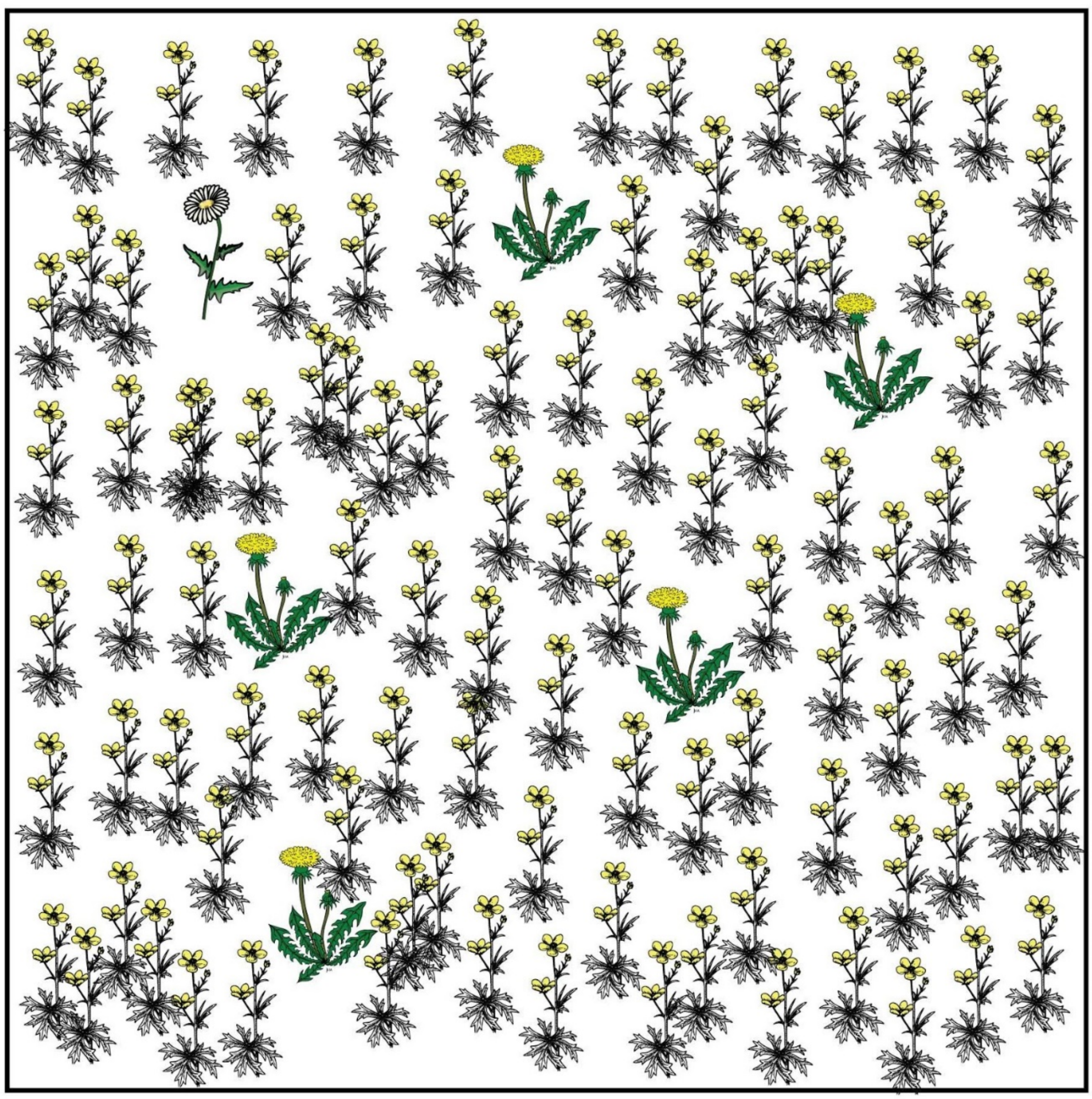


Figure 4. Larger Image of Field B