Measuring the Health of the Earth Using the Theory of Island Biogeography

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Edited by: Brad Chen

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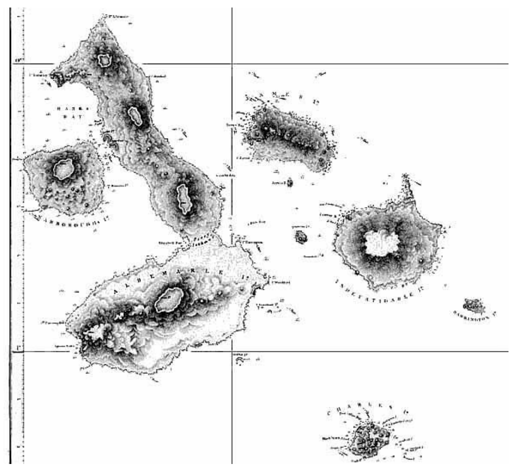


Figure 1: Admiralty 1845 Map of the Galapagos Islands
(Jungle Photos 2000-2014)

Module Summary:

Biodiversity has been shown to be a good measure of the health of the planet system (McGrady-Steed et al. 1997). The more species and genetic diversity, the more stable the ecosystem (Butchart et al. 2010). As we focus on the sustainability of the planet, we need this diversity to withstand stresses from changing weather patterns, disease and human population growth (Heller and Zavaleta 2009).

Island biogeography is the study of the factors affecting species diversity of natural communities. As our natural landscape is becoming more and more fragmented, it resembles a series of islands. While the Theory of Island Biogeography was developed in the 1960's (MacArthur and Wilson 1963), this attempt to predict the number of species on an "island" is still very valid today. Continuing research supports that the loss of species can have definite consequences for an ecosystem (Worm et al. 2006) .

This module uses a variety of available datasets to explore methods of calculating biodiversity and measuring landscape as well as the relationship between those. These points are then used to teach logarithms by estimating slopes and intercepts from a log-log plot of the number of species in a given location against a variety of metrics including island size and distance from mainland. Optionally, this could then be adapted to fragmented habitats near a national park or the like. Finally, the plots are used to estimate the level of fragmentation that would push the system to a given level of species loss.

Informal Description:
This module explores the relationship between species diversity and landscape features.

Target Audience:
Undergraduate courses in,…

Mathematics:

- Mathematics for Liberal Arts
- College Algebra
- Mathematic Modeling courses

Sciences:

- Introductory Biology
- Earth Science
- Ecology
- Evolution
- Oceanography
- Geophysical Laboratories

Prerequisites:
Students should be able to use the following in required calculations and discussions. The links provided are topical instructional and review videos.

Mathematics:

- Basic plotting skills:
  How to Graph/Plot Points or Ordered Pairs (x, y) on a Graph Math Help
  1 of 3 - The slope of a line - how to graph - how to calculate
  2 of 3 - How to graph y = mx (it's easy) *with practice*
- Slope-intercept line formula:
  3 of 3 - How to graph y = mx + b (it's easy) *with practice*
- Summation notation:
  Not More Maths for Dummies 1.1: Sigma notation

Sciences:

- Scientific method:
  Chemistry Music Video 1: The Scientific Method
  "Made Easy"
  Scientific Method, Grail Style "Monty Python's
  Search for the Holy Grail"
  Scientific Method "They Might Be Giants"

Fields Emphasized & Topics:

Mathematics:

- Summations
- Algebraic formulas
- Plots
- Regression lines
- Distance & Area
- Estimation

Biology:

- Species
- Biodiversity
- Sustainability
- Landscape fragmentation
- Theory of Island Biogeography
- Conservation biology

Application Areas:
As we focus on the sustainability of the planet, we need to be able to define and understand the role of biodiversity in withstanding a variety of stresses both natural and anthropogenic. As our natural landscape becomes more and more fragmented, it resembles a series of islands. The theory of island biogeography addresses the factors affecting species diversity of resultant communities. It is important both to understand the principles governing species richness, island biogeography and sustainability, as well as to be able to present the research data in an understandable form.

Goals and Objectives:
1. The student will be able to calculate area and distance.
2. The student will be able to plot data using log-log graphs.
3. The student will be able to calculate and then compare species diversity indices.
4. The student will be able to describe the concepts of species, biodiversity, landscape fragmentation, and sustainability.
5. The student will be able to compare and contrast biodiversity and sustainability.
6. The student will be able to synthesize the relationships among biodiversity, sustainability and fragmentation.
7. The student will be able to discuss the Theory of Island Biogeography.

Technology/Software Needs:
MSExcel, log-log graphing paper, *Optional:* GoogleDocuments

Instructors: There are many options for completing these exercises. If you and your students have access to MSExcel or GoogleDocuments, the exercise is simply done electronically and a definite application of sustainability! However, you may also purchase log-log graphing paper or even download it from a variety of online sources.

Logarithmic Graph Paper
Graph Paper

Module:

I. Student Reading Assignment & Review Material

What is biodiversity & sustainability – How are they related?

Biodiversity, as the name suggests, is a contraction of "biological diversity". Biodiversity encompasses both the richness and variety of life, e.g., genes, species and ecosystems.

Why is Biodiversity important? We use animals and plants for food, medicines and in our economy. According to the Food and Agriculture Organization of the United Nations, in 2009 it was estimated that the total capture of wild fishes caught commercially was just over 114.4 million tons of fish (Service 2011), a multi-billion dollar industry.

Higher biodiversity generally translates to a healthier Earth. Why?

- more plants = more food for other animals
- more genes = better chances for survival through adaptation
- more species = more links in food webs
- a variety of ecosystems = more habitat for different species

Sustainability is the capacity or power to maintain something for a long period of time. For an ecosystem, sustainability means maintaining ecological processes. *What ecological processes are included?* There are many, of which some are the cycles and interactions of biology, geology/geography, and chemistry, known as biogeochemical cycles, food webs, population dynamics, and succession. If an ecosystem is able to maintain its structure and function over time in the face of external stress, it is said to be sustainable (Chapin et al. 1996).

Sustainability is an indicator of ecosystem health. The more sustainable an ecosystem, the healthier it is due to its ability to deal with, or absorb the effects of external stresses. External stresses range from human activities, such as deforestation and pollution, to natural disasters like tornadoes and floods.

How are biodiversity and sustainability related?

Greater biodiversity in an ecosystem leads to greater stability and sustainability (Quinn and Harrison 1988). For example, let us consider two lakes in Finland. They are 50 km apart and each has the same 20 species of fishes. One year, Finland faces a catastrophic incident of sulfur pollution to its lakes, and Lake A loses two fish species while Lake B loses five fish species. Generally, the impact of losing 10% of species would be less than the impact of losing 25% of species. Therefore, it follows, that the probability of Lake A being able to *sustain* its ecosystem processes and functionality into the future would be lower than the probability of Lake B being able to *sustain* its ecosystem processes into the future. This, in a simple way, illustrates why it is important to maintain and encourage the greatest possible biodiversity in all ecosystems. *Note*: This concept of greater biodiversity leading to a more sustainable ecosystem applies when comparing similar ecosystems that vary in biodiversity, and does not imply that a temperate ecosystem with its lower species count is less sustainable than a tropical ecosystem with its greater species count. That is another aspect for greater discussion.

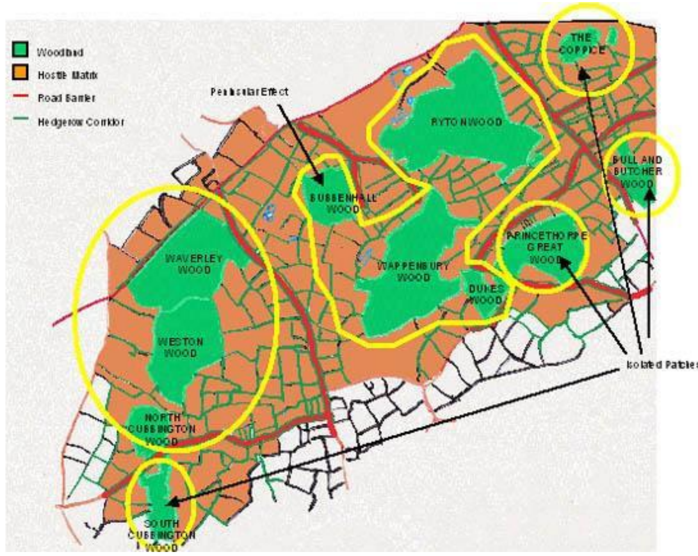


Figure 2: Simple Appraisal of the Current Fragmentation of the Princethorpe Woodland Project Area highlighting habitats and barriers. (Smith, 2004)

What is the role of landscape fragmentation on biodiversity and sustainability?

We use the term **landscape** as an area with land use that is defined by a series of either natural or anthropogenic, human caused or defined, boundaries. Geographically, those boundaries could be the edges of bodies of water such as lakes, rivers, oceans, wetlands, and mountain ranges. Boundaries are also evident as the shift in the community of plants from a forest to grasslands, or grasslands to a desert. Anthropogenic influences are most commonly due to agriculture, commercial and industrial development. Often the choice of a site for development coincides with ideal habitat for critical species necessary for ecosystem sustainability. The fragmentation, or breaking up of the landscape, can degrade the ecosystem and reduce the ability of it to sustain itself (Chapin et al. 1996). This continued fragmentation could then result in the collapse and final disintegration of a given ecosystem, causing a decline in biodiversity (b e et al. 2006).

The **biological species concept**, as described by Ernst Mayr, but republished in 1992 , defines a species as being populations, which coexist in a given landscape and cannot interbreed (Mayr 1992). If the landscape is fragmented in such a way that a population is divided into two groups, it is also possible that over time these populations could become separate species. The separation of the population initially results in fewer individuals available to reproduce, resulting in the reduction in the long-term health and persistence of a population. The persistence of a population is also dependent upon the levels of reproduction being greater than the death rate. New individuals may arrive from nearby, or adjacent habitats and those habitats are often referred to as “island” or satellite populations, with regard to the mainland. These satellite populations, if able to interbreed with the main population, may play a part in the continuation, or persistence of the mainland population’s success (Quinn and Harrison 1988).

A fundamental way to evaluate and represent the relationship between species richness and the area of a given habitat is to graph the data, which is known as a **species area curve** (Cain 1938). With respect to our theory of island biogeography, or habitat fragmentation, this graphical representation of species richness versus habitat area not only allows for the comparison of habitats of varying size but more clearly illustrates existing relationships. Most importantly, for habitat managers and ecologists, are how species richness varies with the size of the habitat. If habitat size is replaced with the distance from the mainland to an island, or a smaller fragment to a larger central habitat, using a species curve will show these relationships.

We analyze species richness and habitat size and/or distance data by graphical representations such as species area curves and by using biological indices. Biological indices are merely a way to compare the parts, or basic data representing a habitat. A graph of the basic data for a species-area relationship will appear as a curve with data points concentrated or condensed at one end. Using **logarithm plots**, also known as log-log plots,with this same data will scale the data. (Note: "log" will be used when referring to the term logarithm and should not be confused with trees on islands, … a mathematical versus a biological concept. To **scale** data is to place the data in proportion to each other in such a manner that existing relationships between our species richness and either area or distance are easier to see. Ecological **indices,** similar to those extensively used in economics to assess the distribution of wealth in a region, allow us to reduce down and compare habitats and the populations of species in terms of the probability that we will encounter a given species in a given location. We will discuss and calculate the reciprocal Simpson's and Shannon-Wiener Diversity Indices, as well as Evenness.

Biodiversity has been shown to be a good measure of the health of the planet system (McGrady-Steed et al. 1997). The more species and genetic diversity, the more stable the ecosystem (Butchart et al. 2010). As we focus on the sustainability of the planet, we need this diversity to withstand stresses from changing weather patterns, disease and human population growth (Heller and Zavaleta 2009).

Island biogeography is the study of the factors affecting species diversity of natural communities. As our natural landscape is becoming more and more fragmented, it resembles a series of islands. While the Theory of Island Biogeography was developed in the 1960's (MacArthur and Wilson 1963), this attempt to predict the number of species on an "island" is still very valid today. Continuing research supports that the loss of species can have definite consequences for an ecosystem (Worm et al. 2006) .

Plotting:

Review:

- Basic plotting skills:
  How to Graph/Plot Points or Ordered Pairs (x, y) on a Graph Math Help
  1 of 3 - The slope of a line - how to graph - how to calculate
  2 of 3 - How to graph y = mx (it's easy) *with practice*
- Slope-intercept line formula:
  3 of 3 - How to graph y = mx + b (it's easy) *with practice*

Math facts:

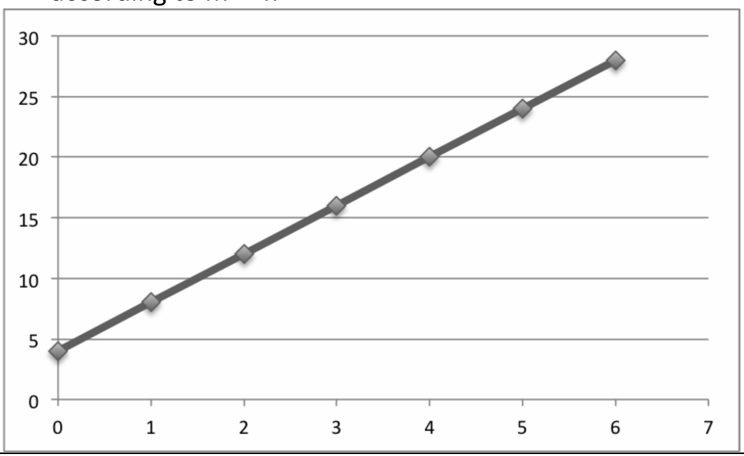
Slope-intercept form: $y = mx + b$
m = slope of line = change in y over change in x
b = y-intercept = value of y when x = 0

Example Problem:

1. Find the equation of the straight line that has slope m=4 and passes through the point (2, 12).
2. Plot this line.

For the instructor--Solution

1. $y = 4x + 4$. With $m = 4$, $y = 12$, and $x = 2$, $y = mx + b$ becomes $12 = 4(2) + b$, so $b = 4$.
2. (0, 4) is then plotted below. Other points on the line can be found by moving from (0, 4) according to m = 4.



Scientific Method:

For a quick review of the parts of the scientific method and it in action select the links below:

- Chemistry Music Video 1: The Scientific Method "Made Easy"
- Scientific Method, Grail Style "Monty Python's Search for the Holy Grail"
- Scientific Method "They Might Be Giants"

Pre-test for the Student

1. Please define the two terms that make up the word "biodiversity."
2. ________________is the ability to maintain something for a long period of time.
3. A landscape is an area with land use that is defined by a series of what two types of boundary classifications?
4. More genes equaling to better chances for survival through adaptation is an example of what characteristic that translates to a healthier earth?
5. Name the concept that defines a species as being populations that coexist in a given landscape and cannot interbreed.
6. Give an example of how you could use indices.
7. List the key steps of the scientific method.
8. Find the equation of a line with a slope of 1 that passes through the point (3,6).
9. Species richness and the area of a habitat are related in what type of graph?
10. Briefly describe how an island habitat and a fragmented landscape might be similar.

For the Instructor--Answers:

1. "Biological" means "pertaining to life" and "diversity" is a "state of being different or unlike."
2. Sustainability
3. Natural or anthropogenic (human caused or defined) boundaries
4. Higher biodiversity
5. The biological species concept
6. Answers will vary. In general, indices, or index numbers, are composite measures of relative change in a variable from multiple contributors. Biological indices compare the parts, or basic data representing a habitat. Economic indices assess the distribution of wealth in a region. Ecological indices allow us to compare habitats and the populations of species in terms of the probability that we will encounter a given species in a given location.
7. Question, Hypothesis, Experiment, Observation, Analysis, Conclusion
8. $6 = 1x + b$, so $b = 3$, and $y = x + 3$.
9. Species-area curve
10. A fragmented landscape may be similar to an island if its population is divided into distinct groups that become separate species.

II. Lecture Material for Instructor & In-class Problems

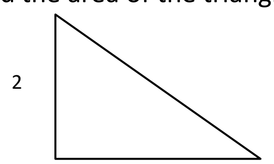
Calculating area and distance:

Math facts for Area:

Triangle: Area = one half base times height = ½ b x h
Square: Area = length of side squared = a^2
Rectangle: Area = length times width = l x w
Circle: Area = pi times radius squared = πr^2, where $\pi = 3.1416$

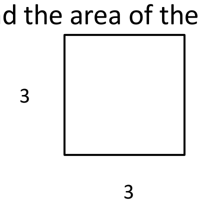
Example Problems for the board:

1. Find the area of the triangle.



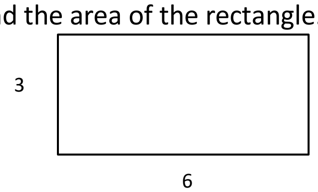
For the Instructor--Solution: A = 1/2 x 2 x 3 = 3

2. Find the area of the square.



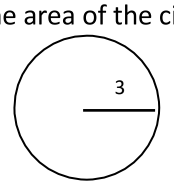
For the Instructor-- Solution: A = 32 = 9

3. Find the area of the rectangle.



For the Instructor-- Solution: A = 3 x 6 = 18

4. Find the area of the circle.



For the Instructor--Solution: A =

Math facts for Distance:

Between **(x_1, y_1) and (x_2, y_2):** $d = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}$

Example Problem for the board:

1. Find the distance between (1,1) and (3,3).

For the Instructor—Solution: $d = \sqrt{(3-1)^2 + (3-1)^2} = \sqrt{4+4} = \sqrt{8} = 2.83$

For the Instructor—Extensions:

- *Can be extended to do estimation of area or integration for area under the curve.*
- *Can be extended to discuss distance between squares or other geometric shapes.*

Logarithms:

Math facts for Logarithms:

The logarithm function (**log**) is defined by:

$y = \log_b(x)$ if and only if **$x = b^y$**

and $x > 0$, $b > 0$ and $b \neq 1$.

The function,

$y = \log_b(x$

) is read aloud as, "y is the log base b of x". When no base (b) is noted, the assumed base is 10. Thus,

$y = \log(x)$ is the same as **$y = \log_{10}(x)$.**

When the base is the number ***e*** (~2.718...), the logarithmic function is called the "natural logarithm" and notated as **ln**. Thus,

$y = \log_e(x)$ is written **$y = \ln(x)$.**

Laws of logarithm:

1. **$\log_b(MN) = \log_b M + \log_b N$**
2. **$\log_b$**$(M/N) = \log_b M - \log_b N$
3. $\log_b M = \log_b N$ if and only if $M = N$
4. $\log_b M^k = k \log_a M$
5. $\log_b b = 1$
6. $\log_b 1 = 0$

An example for the board, of how log-log plots work:

Given the equation, $S = bA^k$, first take the log of both sides:

$$\log S = \log\left(bA^k\right)$$

Using the fist law listed above, we can rewrite the equation:

$$\log S = \log b + \log\left(A^k\right)$$

Using the fourth law listed above, we can again rewrite the equation:

$$\log S = \log b + k \log A$$

And by rearrangement:

$$\log S = k \log A + \log b$$

Compare this to our previous equation:

y = mx + b

Look familiar?!

Example Problem for the board:

Using the data points in the Table 1:

a. Plot using standard graph paper.

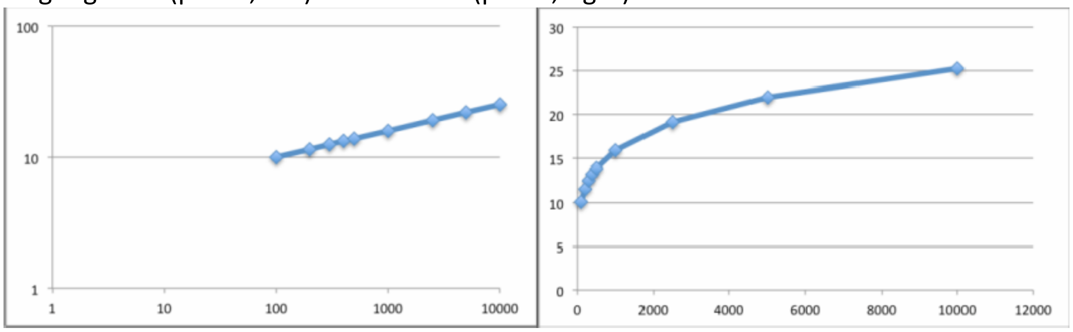
b. Plot using logarithm (log-log) graph paper.

c. Compare and contrast the two graphs. Note how the shape of the graphs differ.

Table 1:	
100	10.05
200	11.54
300	12.52
400	13.26
500	13.86
1000	15.92
2500	19.13
5000	21.97
10000	25.24

For the Instructor—Answer

Log-log Plots (part b, left) vs. Standard (part a, right)



c. Notice that the easy-to-identify linear relationship in the logarithm plot illustrates the existence of the harder-to-identify logarithmic relationship in the data.

Example Problem for in-class attempt by students:

Using Table 2 below, plot the area of island (x-axis) found throughout the Sunda Group of islands and those in the Philippines and New Guinea versus the number of species (y-axis).

a. Draw the graph on both standard and logarithm graph paper.

b. Compare the two plots. How do they differ in shape?

c. Using the log plot, describe the relationship between the island area and the number of species found on those islands.

Table 2: Species vs. Island Area

Island:	Area of Island (mi^2)	# of Species
Christmas	90	15
Bawean	95	45
Engano	300	50
Savu	350	70
Simalur	900	80
Alors	1050	85
Wetar	1110	87
Nias	1250	120
Lombok	1290	150
Billiton	1300	95
Mentawei	1140	83
Bail	1350	250
Sumba	1600	100
Bangka	1600	80
Flores	1690	225
Sumbawa	1700	150
Timor	11000	200
Java	16000	500
Celebes	175000	300
Philippines	110000	480
Sumatra	1300000	625
Borneo	1500000	610
New Guinea	1650000	650

**This data is adapted from MacArthur and Wilson (1963).

In-class Instruction Continued:

Diversity indices:

Biodiversity calculations can be discussed and considered in several ways, depending on the desired mathematics. The most common measures of biodiversity are **Species richness, Simpson's index** and **Shannon-Wiener index.**

Online calculators for diversity indices:

Excel spreadsheet

Online calculator

Species richness (S) is a simple count of the number of species in a designated area at a specific point or duration of time. For example, in the table below, the Species richness (S) is the total count of the number of each species present.

Table 3: *Region:*	*Species 1:* Poison ivy	*Species 2:* Red oak	*Species 3:* Live oak	*Species Richness (S)*
Wetlands	Absent	Absent	Present	1
Forest	Present	Present	Present	3
Grassland	Present	Absent	Absent	1

Indices are statistical calculations used to determine the distribution or complexity of a population and are often associated with the fields of economics, demographics, and ecology. In mathematics, indices describe the location of a variable. Using our biological concept framework, the equations for the **(reciprocal) Simpson's diversity index (D)** and **associated evenness (equitability) (E_D)** are:

$$D = \frac{1}{\sum_{i=1}^{S} (p_i)^2}$$

$$E_D = \frac{D}{S}$$

where $p_i =$ proportion of total individuals (N) of all species (S) made up of species i

A Step-b-step example of calculating indices:

Step 1: Given the counts for each species in Lakes 1, 2, and 3 and the computed proportions for Lake 1 below, compute the proportions for Lake 2 and 3.

Table 4:

Species	Lake 1 Count	Lake 2 Count	Lake 3 Count
Brown Trout	70	100	50
Channel Catfish	30	5	50
Smallmouth Bass	20	5	50
Largemouth Bass	30	5	50
Totals:	150	115	200

We merely added, or counted up the total number of fish in the lakes.

Step 2: Using the total number of fish in each lake and the total of each species in each lake, we can now calculate the proportion, or share of each species in each lake. In Lake 1, 47% are Brown Trout, 20% are Channel Catfish, 13% are Smallmouth Bass, and 20% are Largemouth Bass. Once Lakes 2 and 3 are calculated, you can then see the same sort of relationship for each, as well as being able to see how Brown Trout vary in each of the lakes, for instance.

Now complete Table 5 for Lakes 2 and 3.

Table 5:

Species	Lake 1	Lake 2	Lake 3
Brown Trout	70/150 = 0.47		
Channel Catfish	30/150 = 0.20		
Smallmouth Bass	20/150 = 0.13		
Largemouth Bass	30/150 = 0.20		

For the Instructor—Answers

Lake 2: 100/115 = 0.87, 5/115 = 0.043, 5/115 = 0.043, 5/115 = 0.043

Lake 3: All are 50/200 = 0.25

While you can compare the three lakes using the proportions we calculated above, it is very time-consuming to write out how all of the fish differ in each lake, as well as how they differ from each other. A better way is to use a single number, or index, that represents all of that in one!

Step 3: To calculate the **Simpson's diversity index (*D*)** and **associated evenness (*E_D*)**, using the equations below:

$$D = \frac{1}{\sum_{i=1}^{S} (p_i)^2}$$

$$E_D = \frac{D}{S}$$

where p_i = proportion of total individuals (N) of all species (S) made up of species i

Adding the squares of the data from Table 5, for Lake 1 yields
$0.47^2 + 0.20^2 + 0.13^2 + 0.20^2 = 0.32$, and taking the reciprocal $D = 1/0.32 = 3.17$

Noting that the Species Richness, $S = 4$, $E_D = 3.17/4 = 0.79$

We now need to calculate these for Lakes 2 and 3 to complete Table 6.

Table 6:

	Lake 1	Lake 2	Lake 3
D	3.17		
E_D	0.79		

For the Instructor—Answers
Lake 2: $D = 1/(0.87^2 + 0.043^2 + 0.043^2 + 0.043^2) = 1/0.7624 = 1.31$, $E_D = 1.31/4 = 0.33$
Lake 3: $D = 1/(0.25^2 + 0.25^2 + 0.25^2 + 0.25^2) = 1/0.25 = 4$, $E_D = 4/4 = 1$
Note that the highest values of D and E_D for Lake 3 reflect the greatest degree of diversity and evenness observed in the counts for that lake.

Step 4: To calculate the **Shannon-Wiener Diversity Index (H)** and **associated evenness (*E_H*)**, using the equations:

$$H = -\sum_{i=1}^{S} (p_i \ln p_i)$$

$$E_H = \frac{H}{\ln S}$$

where p_i = proportion of S made up of species i. Plugging in the data from Table 5 for Lake 1 yields:

$H = -[0.47*\ln(0.47) + 0.2*\ln(0.2) + 0.13*\ln(0.13) + 0.2*\ln(0.2)] = 1.27$

$E_H = 1.27/\ln(4) = 0.91$

We can finish off calculating the Shannon-Wiener Diversity Index (H) and associated evenness (E_H) for Lakes 2 and 3, to complete Table 6.

Table 7:	Lake 1	Lake 2	Lake 3
H	1.27		
E_H	0.91		

For the Instructor—Answers

Lake 2: $H = -[0.87*\ln(0.87) + 0.043*\ln(0.043) + 0.043*\ln(0.043) + 0.043*\ln(0.043)] = 0.53$,,

$E_H = 0.53/\ln(4) = 0.38$

Lake 3: $H = -[0.25*\ln(0.25) + 0.25*\ln(0.25) + 0.25*\ln(0.25) + 0.25*\ln(0.25)] = 1.39$, $E_H = 1.39/\ln(4) = 1$

Note that the highest values of H and E_H for Lake 3 reflect the greatest degree of diversity and evenness observed in the counts for that lake.

Interpretation of values

Species Richness is probably the easiest of values to calculate with regard to measuring biodiversity. Simply, it is the count of the number of unique species in a given area at a given point in time. Species richness does not indicate where or how the species interact, use the habitat, or how the population is distributed throughout the area or sample site. For instance, if you sample a site and discover that you have 7 species of small mammals, this would be your s*pecies richness* value. This tells you that within the small mammal community, you have 7 different species, or 7 total different populations. It does not tell you anything more, neither total number of animals, nor where they are located. Additionally, as a researcher, you often wish to know what percentage of the whole community each different population, or species, represents. Are meadow voles 50%, 35%, or 90% of the small animals on the site? Species richness does not answer that question, but does answer how many different species are present/detected.

Using **indices** allows us to reduce down and compare habitats and the populations of species in terms of probability, or chance that we will encounter a given species in a given location. The reciprocal **Simpson's Diversity Index** uses the abundance, or proportion of each species in addition to species richness. The proportion represents the probability that when selected, two individuals from the community will be of the same species. As the proportions for the different species become more similar, or equitable, the index value will increase.
For the **Shannon-Wiener Diversity Index** when the evenness, or likelihood that you will select two individuals from the community that are the same species is equitable, the index will approach one. When the proportions of the populations in the community are the greatest, so is the value of the index.

The Theory of Island Biogeography, using the equation, $S = bA^k$, where S = number of species, A = area of habitat, and b and k are parameters, allows us to determine the relationship between the number of species and the size of either an island or fragmented habitat. As mentioned before, the distance from an island or fragment to a mainland may be substituted for the area of the habitat. Using the log-log graph allows us to clearly visualize relationships, as well as to predict additional species richness with regard to habitat size and/or distance. The standard relationships exist such that the greater the distance, the lower the species richness values, and the greater the size, the greater the species richness values.

Will all these relationships hold true with real data? What factors or processes could cause these relationships to change? Hint: What roles do humans play? How adaptable are species?

III. Exercises:

PART ONE:

1. Plot the Species Richness versus Area for the following lakes:

Table 8: Area and number of fish species found in 16 lakes in the northeastern lowlands in Germany

Name of lake	Area of lake (km^2)	Number of fish species
Kleiner Döllnsee	0.24	10
Teutzensee	0.03	6
Kleinvätersee	0.09	8
Großvätersee	0.12	10
Großer Krinertsee	0.75	12
Duestersee	0.42	10
Klarersee	0.47	10
Luebbesee	3.14	13
Werbellinsee	8.04	13
Wolletzsee	3.29	13
Grirnnitzsee	7.93	14
Redernswalder See	0.53	9
Parsteiner See	10.5	13
Kleiner Plunzsee	0.04	5
Großer Plunzsee	0.22	9
Tiefer See	0.10	7

2. Use your graph to estimate the slope and intercept of the species area curve.

3. Re-plot as a log-log plot, then compare and contrast which graph gives a better interpretation of the data. What is the relationship between the area of the lake and the species richness?

4. Hypothesize why the lakes might be similar to islands.

PART TWO:

1. Calculate the area and distance from the nature preserve for each of the city parks shown on the map. You may assume that each block is one mile and the distance is measured from the closest edge of the Park to that of the Nature Reserve. For example, Park 4 is 6mi^2 (2 blocks x 3 blocks) in area and 1 mi (1 block) in distance from the Nature Reserve. Do not forget to measure distance using the distance formula (Pythagorean theorem) for Parks 1 and 3 and round to the nearest tenth (one decimal place).

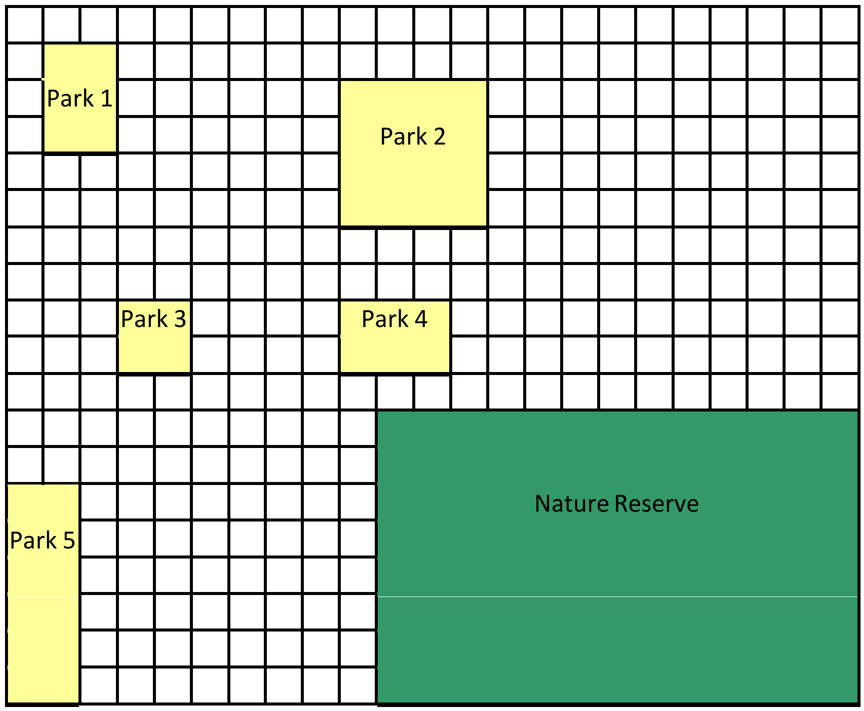


Table 9: City Park Nature Preserve:

Park	Area (mi^2)	Distance (mi)
1		9.9
2		
3		
4	6	1
5		

Table 10:	Count in Park 1	Count in Park 2	Count in Park 3	Count in Park 4	Count in Park 5
Hispid cotton rat	**13**	**13**	**26**	**23**	**27**
Eastern harvest mouse	**15**	**10**	**16**	**11**	**15**
Golden mouse	**0**	**28**	**0**	**13**	**0**
Meadow vole	**30**	**27**	**0**	**0**	**23**
Pine vole	**0**	**0**	**0**	**20**	**0**
White-footed mouse	**0**	**25**	**0**	**20**	**15**
Total number of animals	**58**				
Species Richness	**3**				

2. Complete the calculations for the Total Number of Animals and Species Richness in Table 10.

3. Using the data in Tables 9 and 10, plot the following as log-log plots:
   a. Total number of animals versus area
   b. Species richness versus distance
   c. Compare and contrast the two graphs by stating the shape of the graphs and possible relationships observed in the data.

4. Using the small mammal trapping results in Table 10, calculate the Simpson and Shannon-Wiener Diversity indices for each of the Parks.

5. Using the results of your calculations, plot the following as log-log plots:
   a. Species richness for each Simpson Diversity Index
   b. Shannon-Wiener Diversity Index versus area
   c. Simpson Diversity Index versus area
   d. Shannon-Wiener Diversity Index versus distance

6. For each of the above log-log plots, compare and contrast the relationships observed. State whether these were or were not as expected. If not, why not?

References & Resources:

Miscellaneous online resources

GapMinder World (http://www.gapminder.org/world/): Can be used to explore visual of linear versus log plots for a wide variety of datasets.

Biological Concepts

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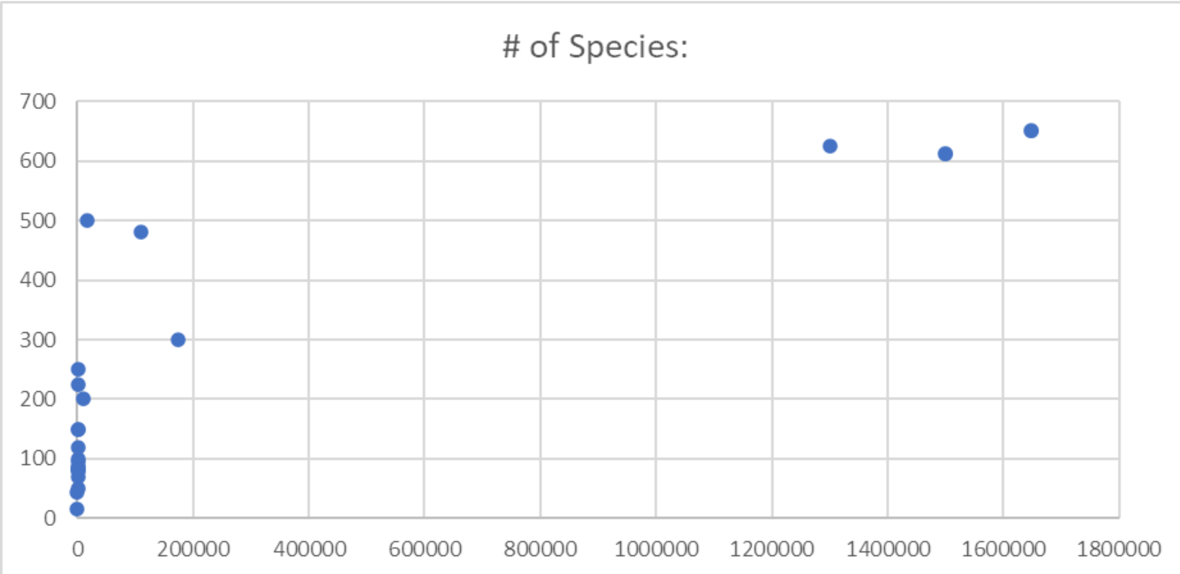
IV. Remaining Answers to Examples & Exercises:

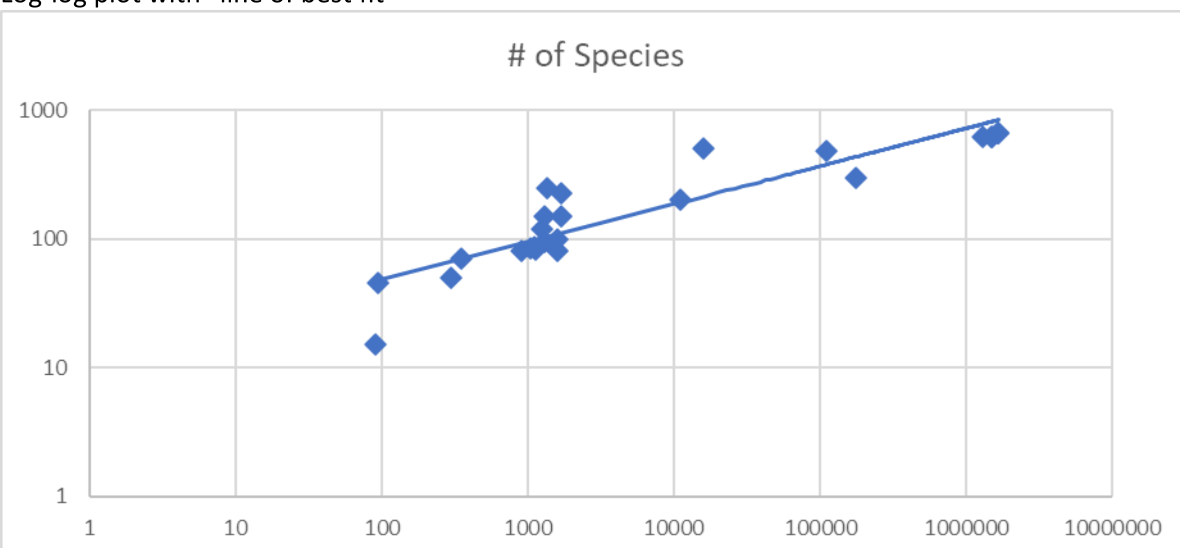
Example on page 13:

For the Instructor—Answer

a. Standard



Log-log plot with "line of best fit"



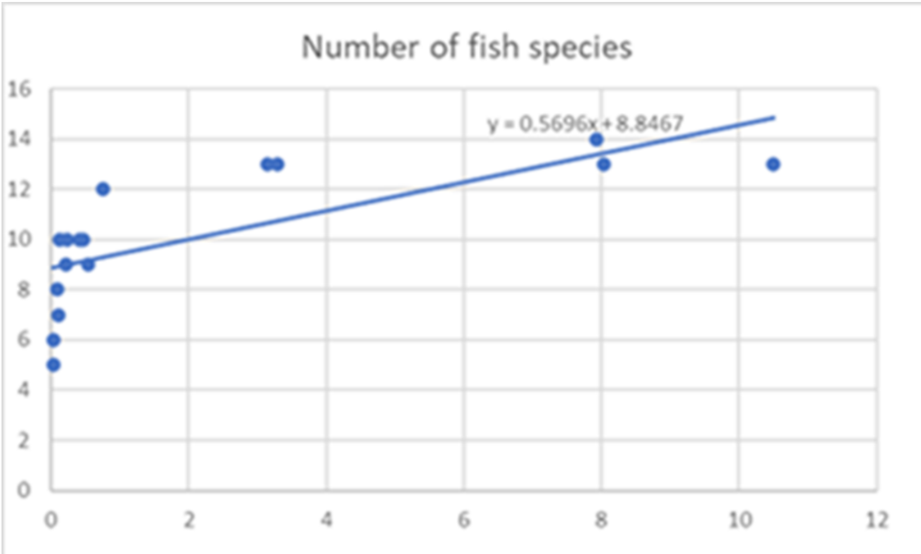
b. **Notice the clear linear relationship in the logarithm graph, whereas the standard graph does not yield much of an interpretation.**

c. **For the data, the number of species tended to increase with the increase in the area of the island. This is only a basic principle and does not always hold true, but that is more of a topic for an advanced biology course.**

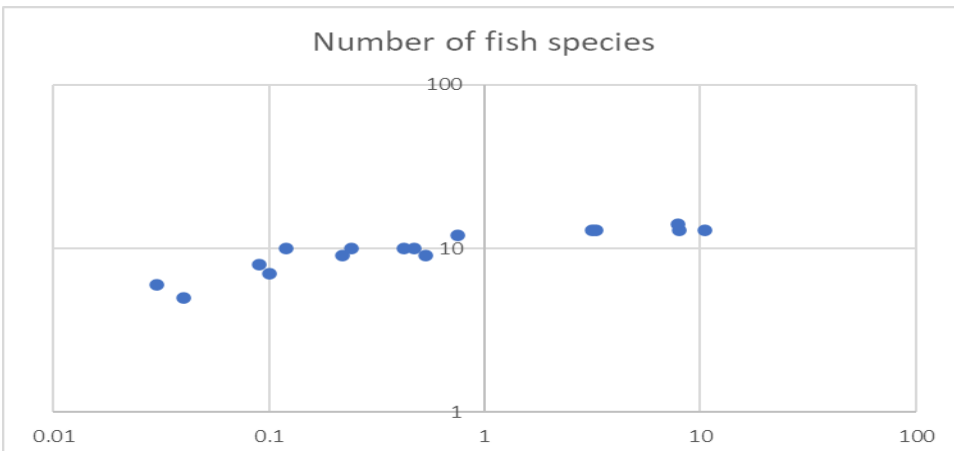
Exercise PART ONE

For the Instructor—Answers

1. & 2. Standard plot with equation of line



3. Log-log plot



The second graph indicates a logarithmic relationship between species and area. In terms of logarithms and exponentials, the species-area equations are:

$S = 10.99 + 3.07 \log_{10}A$ ($R^2=0.874$)

$S = 10.67*A^{0.141}$ ($R^2 = 0.808$)

where S is species richness and A is lake area in km^2

Reference: Eckmann, R. (1995) Fish species richness in lakes of the northeastern lowlands in Germany. *Ecology of Freshwater Fish* **4**: 62-19.

4. The lakes might be similar to islands if they are not connected by bodies of water, such as streams, that would allow fish to move between the lakes.

Exercise PART TWO

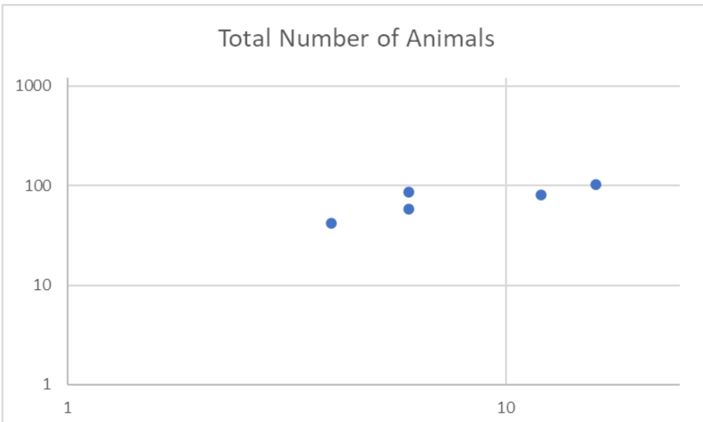
For the Instructor—Answers

1.

Table 9: City Park Nature Preserve:

Park	Area (mi^2)	Distance (mi)
1	6	9.9
2	16	5
3	4	5.1
4	6	1
5	12	8

2. Total Number of Animals--Park 2: 103, Park 3: 42, Park 4: 87, Park 5: 80. Species Richness--Park 2: 5, Park 3: 2, Park 4: 5, Park 5: 4
3. a. Total number of animals vs. area



b. Species richness vs. distance to Nature Reserve

c. There is an apparent logarithmic relationship between the total number of animals and area (graph a) but not a strong logarithmic relationship between species richness and distance to the nature reserve (graph b).

4. Simpson—Park 1: 2.60, Park 2: 4.41, Park 3: 1.89, Park 4: 4.68, Park 5: 3.75
Shannon-Wiener—Park 1: 1.03, Park 2: 1.54, Park 3: 0.65, Park 4: 1.57, Park 5: 1.35

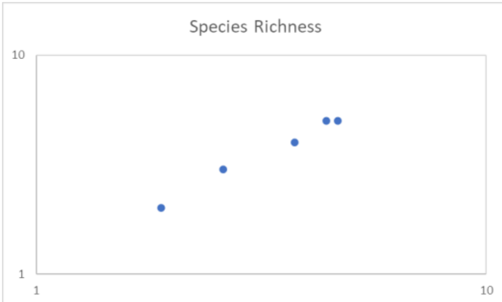
Continued on next page

Exercise PART TWO

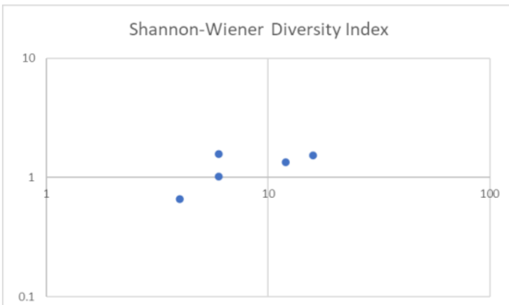
(continued)

5. and 6.

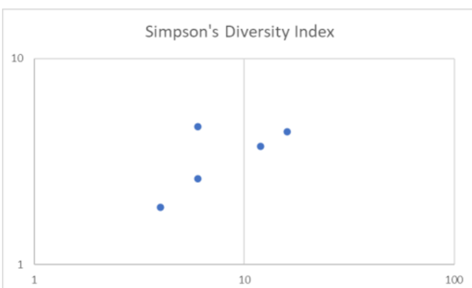
a. Species richness vs. Simpson Diversity Index Expected and observed a very strong relationship, as both measure species diversity.



b. Shannon-Wiener Diversity Index vs. area. Expected and observed a strong relationship, as area enables species diversity.



c. Simpson Diversity Index vs. area. Expected and observed a strong relationship, as area enables species diversity.



d. Shannon-Wiener Diversity Index vs. distance. Expected and observed a strong relationship, as proximity to the Nature Reserve could facilitate species diversity.