Species Richness versus Area Curves

SC Academic Standards: 5.L.4A,B; 7.EC.5A; H.B.6A,C,D.

NGSS DCI: 5-LS2.A; MS-LS2.A,C,D; MS-ESS3.C; HS-LS2.A,C; HS-LS4.D; HS-ESS3.C,D.

Science and Engineering Practices: S.1A.1; S.1A.3; S.1A.4; S.1A.5; S.1A.6; S.1A.7

Crosscutting Concepts: Cause and Effect: Mechanism and Explanation; Scale, Proportion, and Quantity; Energy and Matter: Flows, Cycles and Conservation; Systems Models, and Stability and Change.

Focus Question(s): How does the size of the habitat (area) affect species richness? How do we estimate species richness and species biodiversity? What does a high species biodiversity mean?

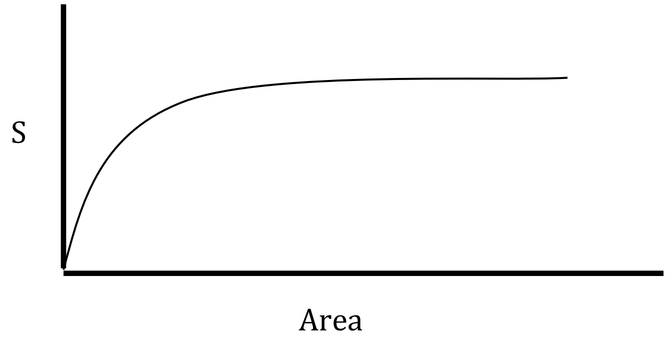
Background: You are all somewhat acquainted with terrestrial environments; humans are after all terrestrial organisms. The earth's numerous terrestrial environments can be divided into seven to nine **biomes** (large geographic areas dominated by a particular assemblage of plants) depending on what textbook you use. These biomes may include: tundra, taiga, coniferous forest, temperate deciduous forest, grassland, chaparral, deserts, and tropical forests. Vegetation type is the major factor used to describe biomes. The coniferous forest biome, for example, is dominated by conifers (e.g. pines), whereas deserts are dominated by plants that are able to survive hot and dry conditions (e.g. cacti). Unfortunately, we will not have time to investigate all of the earth's terrestrial biomes. For this lab we will focus our investigation on a smaller scale: forest communities. Remember the distinctions between ecosystems, communities, populations, and that at each level new emergent property arises. Two important emergent properties of communities (not found in populations) are **species richness (S),** the number of species in a given area, and **species diversity**, the number and frequency of each species present in a given area. **In this lab we will discuss how area (habitat size) can affect species richness and diversity.**

Different areas of the world have different species richness / diversity patterns. Things that can affect species richness and diversity include: latitude (with greater species diversity at the equator versus the poles), climate stability (the equator has had a stable climate for longer than temperate / polar areas and so has greater species diversity), primary productivity (the tropics have a greater productivity versus temperate areas and poles and so a greater species diversity) and number of specialists inhabiting the region (a greater number of specialists means a greater species richness through niche partitioning). Diversity tends to follow these patterns but we also see a pattern related to habitat size. Any particular habitat or ecosystem will have a maximum number of species that it can support – in effect, a carrying capacity for the region.

Why does knowing the effect of habitat size on species richness matter? First, know that there is a whole area of research devoted to looking at relationships between habitat size and species richness. This field of science is called **island biogeography** and it attempts to establish and explain the factors that affect the species richness of a particular community. The field was started in the 1960s by the ecologists Robert MacArthur and E.O. Wilson, who attempted to **predict** the number of species that would exist on newly created islands. The theory of island biogeography holds that the number of species found on an island (the **equilibrium number – similar to carrying capacity**) is determined by two factors, the effect of distance from the mainland and the effect of island size. These would affect the rate of extinction on the islands and the level of immigration. For example, an island closer to the mainland (from which it may receive immigrants) would have a higher equilibrium species richness than an island farther away.

The size effect reflects a long known relationship between island size and species richness / diversity. On smaller islands the chance of extinction is greater than on larger ones. Thus larger islands can hold more species than smaller ones. The play between these two factors can be used to estimate how many species an island can hold at equilibrium.

So increasing habitat size (or area) can increase species richness. In general the larger an area is the more species it will contain (up to an equililbrium point – the carrying capacity for # species in a given habitat). This relationship can be graphed (see below). As you can see at some given area there will be no more increase in species. Can you think why this may be? In the field this week you will examine the relationship between area and tree species richness and diversity by sampling trees within five quadrats of increasing size. Practically, once you reach the same value for 3 consecutively larger areas you have reached equilibrium, and carrying capacity.

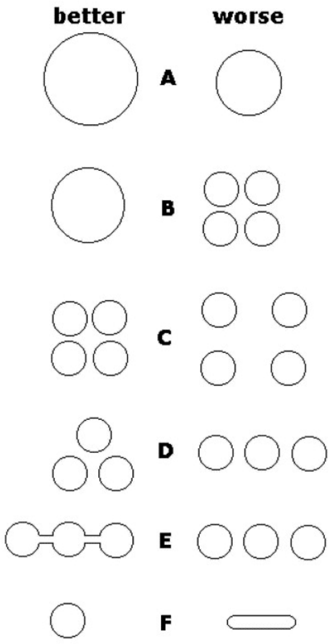


The relative abundance of species is also important. For example, two communities may both contain the same number of species but one community may be dominated by one species while the other community may contain large numbers of all species. The relative abundance of rare and common species is called ***evenness***. Communities dominated by one or a few species have a low evenness while those that have a more even distribution of species have a high evenness. ***Species diversity*** includes both species richness and evenness (or abundance). Communities with a large number of species that are evenly distributed are the most diverse and communities with few species that are dominated by one species are the least diverse. In this lab we will discuss how **area** (habitat size) can affect species richness.

<u>Materials</u>: Per group: two 30 m tape measures (forestry supply or from Carolina biological, 30 m tapes are about $50), orange marking flags (they come in packs of 50 and 100 at hardware stores), tape, marker.

<u>Previous Knowledge</u>: (Botany). It helps to have had some practice in Tree Identification using a Dichotomous Key – familiarity with the trees in the local area is a plus, though not required. You can arbitrarily label trees “species A” and “species B” and so on, picking one leaf from each tree, taping it to your notebook, and using a marker to designate it is “A”, or “B” or whatever. Then, when you run into the same species again, you can count it.

<u>Previous Knowledge:</u> (Conservation Biology): The **application** of this theory to the field of conservation biology is tremendous when you consider that the theory doesn’t apply to just islands, but in this context the island can be any area of habitat surrounded by areas unsuitable for the species including mountains surrounded by deserts, lakes surrounded by dry land, forest fragments surrounded by human-altered landscapes (such as a state park in the midst of a city).



The realization that reserves and national parks are islands inside human-altered landscapes (habitat fragmentation), and that these reserves could lose species as they 'relaxed towards equilibrium' (that is they would lose species as they achieved their new equilibrium number, known as ecosystem decay) caused a great deal of concern. This is particularly true when conserving larger species, which tend to have larger ranges. If we want to save a large species, like polar bears, we need a large protected habitat.

There is a strong correlation between the size of a protected National Park -in the U.S.- and the number of species of mammals. This led to the debate known as single large or several small (**SLOSS**). Conservation planning was taking the view that the one large reserve could hold more species than several smaller reserves, and that larger reserves should be the norm in reserve design. However, other ecologists still felt that habitat diversity (and spatial heterogeneity) was as or more important than size in determining the number of species protected. Island biogeography theory also led to the development of habitat corridors as a conservation tool to increase connectivity between habitat islands. Several smaller reserves that become connected by protected corridors can in effect act like a large reserve. Habitat corridors can increase the movement of species between parks and reserves and therefore increase the number of species that can be supported.

<u>Procedure</u>:

1. Go to a wooded area. Divide into 3 groups of 7-8 students each. Each group needs to be in an area at least 15 m away from the other groups.

2. Walk into the woods and, using flags provided, stake out a quadrat that is 2 meters by 2 meters square. You may need to station a student on each corner so the person counting species can see where to count.

3. Count the number of different species of trees (not grasses) in your quadrat. The actual names of the species aren't important, but whether or not they are the same species is. You want a count of how many *<u>total</u>* species there are in your 2 x 2 m quadrat, **<u>and</u>** how many individuals of *<u>each</u>* species. You may need to collect leaves from the different trees or shrubs to help you make sure you aren't counting the same thing twice.

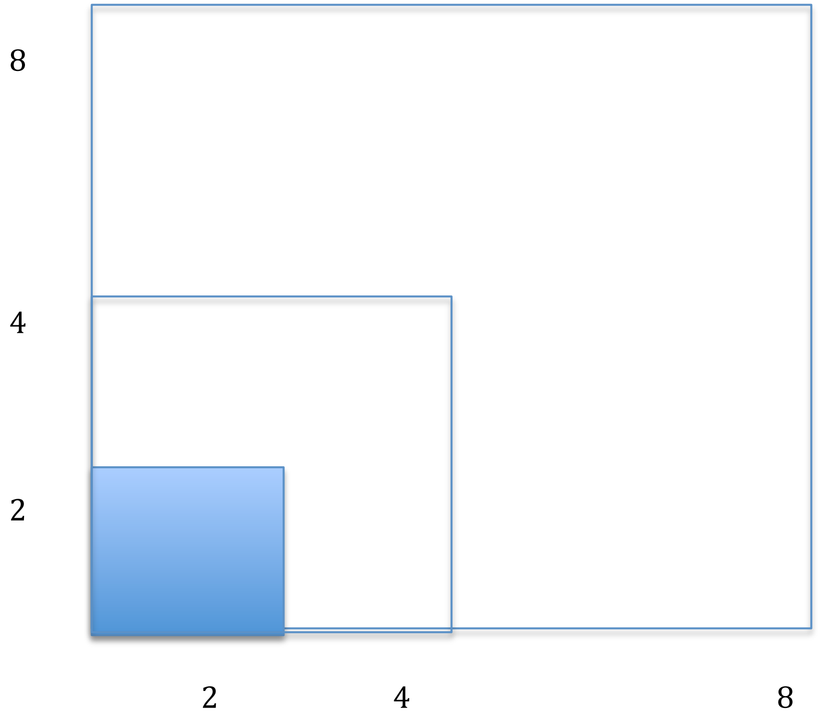
> **<u>How do we define "Tree"?</u>** We need to make sure that everyone is using the same definition of "tree" so that anyone counting trees in your quadrat will come up with the same number. In ecology, a "tree" is defined as being at least breast-height tall, with a diameter of about an inch. We'll take that to mean that a tree is alive, reaches up to at least chin height on an average sized woman, and is as big around as your thumb <u>at chin height</u>. If it isn't, don't count it.

4. After finishing with your first quadrat, use more flags to extend your square by 2 meters on a side – This makes your new quadrat ***Inclusive*** of the first quadrat. Now you have a 4 m x 4 m square quadrat. Count any *<u>additional</u>* species of plants (and how many of each) that you did not already count. You need a total number of species, and number of individuals for **each** species.

5. Repeat and extend the quadrat again to 8 x 8 meters, 12 m x 12 m and 16 m by 16 m. Each new quadrant *includes* the smaller ones, with the 2m x 2m quadrant forming the lower left corner of the 4m x 4m and so on.

6. Calculate the area for each of your quadrats. In your data sheet, write down how many species were found in each quadrat. As the quadrats get larger, they include all the species in the new part of the square **plus** the species in the previous square.

Figure 1: How to measure the quadrats so each larger quadrat is inclusive of the smaller ones.



7. Calculate the Species Richness for each quadrat, and then graphically display species richness versus area.

8. Calculate the Species Diversity, using the Simpson's Diversity Index, for the largest quadrat (16m x 16 m)

Teacher's note: if you don't have woods, this is possible in a grassy area (not a manicured, herbicided lawn) – you can set out smaller squares and count number of species of grasses / weeds. Ask your grounds person to leave you a stretch of lawn near the back of the school property that he doesn't mow. In the south, be careful to watch for fire ants before going out. And remember, you don't need to identify the grass / weed / tree species, just be able to label them as 'species A', 'species B' and so forth.

Quadrat	Area of Quadrat	# of species (**inclusive**)	# of individuals of <u>each</u> species (ID them as "holly", "pine", "unknown A" etc)
2 x 2 m			
4 x 4 m			
8 x 8 m			
12 x 12 m			
16 x 16 m			

Table 1: Number of species versus area of quadrat.

Now calculate species diversity:

Simpson's Diversity Index

where N is sum of all individuals counted of all types (total number)

where n_i is number of species *i*

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

Total number of each species(ni) in ALL areas (16 x 16m quadrat) combined:

A = $n_{A,}$ so $n_A - 1 =$ and $n_A \times (n_A - 1)=$

B = $n_{B,}$ so $n_B - 1 =$ and $n_B \times (n_B - 1)=$

C = $n_{C,}$ so $n_C - 1 =$ and $n_C \times (n_C - 1)=$

D = $n_{D,}$ so $n_D - 1 =$ and $n_D \times (n_D - 1)=$

E = $n_{E,}$ so $n_E - 1 =$ and $n_E \times (n_E - 1)=$

F = $n_{F,}$ so $n_F - 1 =$ and $n_F \times (n_F - 1)=$

G = $n_{G,}$ so $n_G - 1 =$ and $n_G \times (n_G - 1)=$

H = $n_{H,}$ so $n_H - 1 =$ and $n_H \times (n_H - 1)=$

I = $n_{I,}$ so $n_I - 1 =$ and $n_I \times (n_I - 1)=$

J = $n_{J,}$ so $n_J - 1 =$ and $n_J \times (n_J - 1)=$

K = $n_{K,}$ so $n_K - 1 =$ and $n_K \times (n_K - 1)=$

L = $n_{L,}$ so $n_L - 1 =$ and $n_L \times (n_L - 1)=$

M = $n_{M,}$ so $n_M - 1 =$ and $n_M \times (n_M - 1)=$

N = $n_{N,}$ so $n_N - 1 =$ and $n_N \times (n_N - 1)=$

O = $n_{O,}$ so $n_O - 1 =$ and $n_O \times (n_O - 1)=$

P = $n_{P,}$ so $n_P - 1 =$ and $n_P \times (n_P - 1)=$

add all individuals to get N **The sum (∑) of all these ni =**

Sum (N) = **This is = ∑ ni (ni - 1) This goes at the bottom.**

and N-1 =

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

Data Analysis: Calculate the number of species for each area /quadrate (and graph quadrat size (m) on X, and # species on Y, then calculate the species diversity using the Simpson's Diversity Index (below) for your largest quadrat (16m x 16m).

$$D_s = \frac{N(N-1)}{\Sigma n_i(n_i-1)}$$

where N = the total number of individuals of all species
and n_i = the number of individuals of species i

A Simpson's index value of one means that there is only one species in your habitat. The larger the number, the more diverse the community. Now you can compare your habitat to other habitats.

Example: We will illustrate using Simpson's index on a hypothetical community with three species

Species	**No. of Individuals**
Beech	32
Maple	18
Oak	12

Table 1. A hypothetical community with 3 species

For this community, N = 32 + 18 + 12 = 62. The calculations are shown below.

$$D_s = \frac{62 \text{ X } 61}{(32 \text{ X } 31) + (18 \text{ X } 17) + (12 \text{ X } 11)} = \frac{3782}{1430} = 2.64$$

Extensions: Do some Tree Identification while outside. Discuss Leaves: shape (oval, palmate, lobed); arrangement on branch (alternate, opposite); margin (toothed or serrated versus entire (not serrated); presence of trichomes (hairs); color; thickness; and veination (parallel = monocot (the only monocot tree is a palm), netlike = eudicot).

Do some research on sizes of the state and national parks near you. Can you find information on how many tree species, or mammal species are in each park? Then order them by size. (You can't really compare parks in different areas of the world, like tropics versus tundra).

Reflection Questions:

- **What is the species richness (S) for each quadrat? This is just the total number of species found in the quadrat. Create a species area curve for the above data. Does it resemble the one in the lab manual?**

- **Why exactly do species area curves level off?** (Like a carrying capacity of number of individuals of one species that an environment can support indefinitely, there is an equilibrium number of species that can coexist in a particular area).

- **If your curve did level off, explain why. If it did not, realize that if you went on to do larger quadrats (20 x 20 m, 24 x 24 m, etc.) you would eventually get to the point where you kept getting the same number for species richness (it would level off). This is the carrying capacity for tree species in your habitat type. How many times do you have to get the same richness value before you can stop counting species in bigger and bigger quadrats?** (If it did level off, it is because you have reached that equilibrium number. If it didn't, it will, if you keep increasing your area / size of quadrat. Typically, ecologists agree that once you have increased the area but gotten the same number of species three times in a row then you can stop measuring, you've reached the equilibrium number).

- **What are the dependent and independent variables?** For the species richness versus area curve, area is on the X axis, and is the independent variable (quadrat size, in m). What you are measuring is the independent variable, and is the number of species in the quadrat, so that goes on the Y).

Models and Explanations: In this lab we explored how species richness changes with area. **A student who demonstrates understanding** of this concept can explain what factors affect the biodiversity of an area (like climate stability, latitude, number of specialists in the area, etc) and explain the relationship between area and species richness. **Further, this student can explain what** a Diversity Index is used for, and can calculate species diversity of a given area, given the number of species in the area, and number of individuals of each species. Last, the competent student can discuss the application of island biogeography to species diversity and the creation of natural parks so that they can protect and maintain a high species diversity.

Bibliography:

Campbell Biology (9th edition). (2010). Benjamin Cummings Publishing.

Pike, L., Krebs, J., Stoeckmann, A., Steinmetz, J., Ludlam, J., Malakauskas, D.; Malakauskas, S.; and Vanderhoff, N. (2013). *Biology 103L Environmental Biology*

Laboratory, 3rd edition. Francis Marion University custom publishing, Florence SC, USA.

Scheiner, S., S. Cox, M. Willig, G. Mittelbach, C. Osenberg and M. Kaspari (2000). Species richness, species–area curves and Simpson's paradox. _*Evolutionary Ecology Research*, 2000, **2**: 791–802.

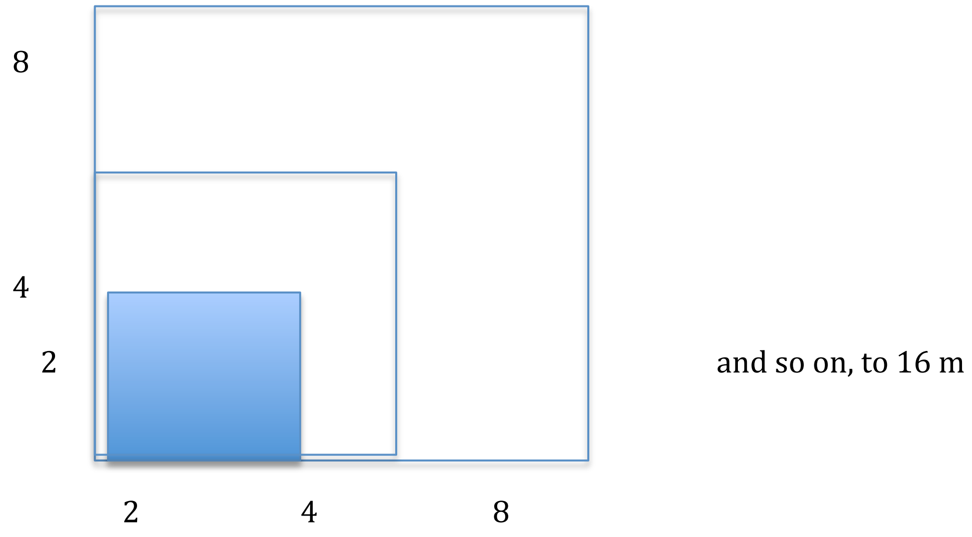
Student Worksheet:

Two important emergent properties of communities (not found in populations) are **species richness (S),** the number of species in a given area, and **species diversity**, the number and frequency of each species present in a given area. **In this lab we will discuss how area (habitat size) can affect species richness and diversity.**

Different areas of the world have different species richness / diversity patterns. Things that can affect species richness and diversity include: latitude (with greater species diversity at the equator versus the poles), climate stability (the equator has had a stable climate for longer than temperate / polar areas and so has greater species diversity), primary productivity (the tropics have a greater productivity versus temperate areas and poles and so a greater species diversity) and number of specialists inhabiting the region (a greater number of specialists means a greater species richness through niche partitioning). Diversity tends to follow these patterns but we also see a pattern related to habitat size. Any particular habitat or ecosystem will have a maximum number of species that it can support – in effect, a carrying capacity for the region.

Increasing habitat size (or area) can increase species richness. In general the larger an area is the more species it will contain (up to an equililbrium point – the carrying capacity for # species in a given habitat). This relationship can be graphed (see below). As you can see at some given area there will be no more increase in species. Can you think why this may be? **In the field this week you will examine the relationship between area and tree species richness and diversity by sampling trees within five quadrats of increasing size.** Practically, once you reach the same value for 3 consecutively larger areas you have reached equilibrium, and carrying capacity.

Figure 1: How to measure the quadrats so each larger quadrat is inclusive of the smaller ones.



Quadrat	Area of Quadrat	# of species (**inclusive**)	# of individuals of <u>each</u> species (ID them as “holly”, “pine”, “unknown A” etc)
2 x 2 m			
4 x 4 m			
8 x 8 m			
12 x 12 m			
16 x 16 m			

Table 1. Number of species and number of individuals for each quadrat.

Now calculate species diversity:

Simpson's Diversity Index

where N is sum of all individuals counted of all types (total number)

where n_i is number of species *i*

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

Total number of each species(ni) in ALL areas (16 x 16m quadrat) combined:

A	= n_A, so $n_A - 1$ =	and $n_A \times (n_A - 1)$=
B	= n_B, so $n_B - 1$ =	and $n_B \times (n_B - 1)$=
C	= n_C, so $n_C - 1$ =	and $n_C \times (n_C - 1)$=
D	= n_D, so $n_D - 1$ =	and $n_D \times (n_D - 1)$=
E	= n_E, so $n_E - 1$ =	and $n_E \times (n_E - 1)$=
F	= n_F, so $n_F - 1$ =	and $n_F \times (n_F - 1)$=
G	= n_G, so $n_G - 1$ =	and $n_G \times (n_G - 1)$=
H	= n_H, so $n_H - 1$ =	and $n_H \times (n_H - 1)$=
I	= n_I, so $n_I - 1$ =	and $n_I \times (n_I - 1)$=
J	= n_J, so $n_J - 1$ =	and $n_J \times (n_J - 1)$=
K	= n_K, so $n_K - 1$ =	and $n_K \times (n_K - 1)$=
L	= n_L, so $n_L - 1$ =	and $n_L \times (n_L - 1)$=
M	= n_M, so $n_M - 1$ =	and $n_M \times (n_M - 1)$=
N	= n_N, so $n_N - 1$ =	and $n_N \times (n_N - 1)$=
O	= n_O, so $n_O - 1$ =	and $n_O \times (n_O - 1)$=
P	= n_P, so $n_P - 1$ =	and $n_P \times (n_P - 1)$=

add all individuals to get N

The sum (∑) of all these ni =

Sum (N) =

This is = ∑ ni (ni - 1) This goes at the bottom.

and N-1 =

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

1. Species Richness: What is the species richness (S) for each quadrat? This is just the total number of species found in the quadrat.

Quadrat #1: size ____2__m x ___2__m. The area of this square is: _________.

Quadrat #2: size __4____m x __4___m. The area of this square is: _________.

Quadrat #3: size __8____m x __8___m. The area of this square is: _________.

Quadrat #4: size __12___m x __12__m. The area of this square is: _________.

Quadrat #5: size __16__m x __16___m. The area of this square is __________.

A. Create a species area curve for your data.

Figure 1: Species Richness Curve for a Terrestrial Forest

B. Does it resemble the one in the lab manual?

C. Why exactly do species area curves level off?

D. If your curve did level off, explain why. If it did not, realize that if you went on to do larger quadrats (20 x 20 m, 24 x 24 m, etc.) you would eventually get to the point where you kept getting the same number for species richness (it would level off). This is the carrying capacity for tree species in your habitat type. How many times do you have to get the same richness value before you can stop counting species in bigger and bigger quadrats?

E. What are the dependent and independent variables?

2. Species Diversity: Diversity indices can be used to **compare** one habitat to another of equal size. Which is more diverse? How is a high diversity a sign of a healthy ecosystem (or habitat)? In this part of the lab we will calculate **diversity** using the Simpson's Diversity Index. For this, you only need the total number of species, and how many of each. You do not need to do this for every quadrat, only the 16m x 16 m quadrat, which contains all the rest.

Use this equation – and use the scratch sheet for data provided to work out your calculations:

$$D_s = \frac{N(N-1)}{\Sigma n_i(n_i-1)}$$

where N = the total number of individuals of all species
n_i = the number of individuals of species i

A Simpson's index value of one means that there is only one species in your habitat. The larger the number, the more diverse the community. Now you can compare your habitat to other habitats.

Example: We will illustrate using Simpson's index on a hypothetical community with three species. For this community, N = 32 + 18 + 12 = 62. The calculations using equation 1 are shown below.

Species	No. of Individuals
Beech	32
Maple	18
Oak	12

$$D_s = \frac{62 \times 61}{(32 \times 31) + (18 \times 17) + (12 \times 11)} = \frac{3782}{1430} = 2.64$$

Calculate the Simpson's Diversity Index for **<u>your</u>** 16 m x 16 m quadrat. ____________