**Title:**Simulating Sampling Communities and Calculating Diversity Indices with Scrabble® Game Tiles

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**Abstract:**Species diversity can indicate the relative health of a community of organisms. A diversity index is a quantitative representation of that community, and the calculated value of an index allows comparisons of communities in different habitats or within a habitat at different times. The concepts of sampling and species diversity are illustrated by simulated sampling exercises using Scrabble® tiles. Exercises are designed to be completed in single lab periods and conducted indoors. Each different letter (and blanks) represents a species and individual tiles represent individual organisms. Thus, one set of tiles represents 100 individuals of 27 species. In the basic exercise, students "sample" a habitat to generate the numbers of species and individuals, from which they calculate and compare diversity indices. Variations in the exercise include repeatability of samples, comparing indices generated from different sample sizes or different numbers of samples, and the effects of rare and common species on diversity indices. Advanced exercises include combining multiple sets of tiles to make more-complex habitats or represent a habitat dominated by an invasive species and then after restoration. Excel datasheets with pre-populated formulas are provided to simplify analysis and calculations. Students are guided by sets of questions that engage critical thinking through small-group and class discussions. The activities are intended to make science more accessible to students by demonstrating the scientific concepts of sampling and diversity, and illustrating how mathematical representations of data can be compared and used. Ideally, the lab exercise could be combined with sampling conducted in the field, to reinforce the processes and concepts.

**Learning objectives:**

1. Use Scrabble® tiles as proxies for species and produce a sample of a simulated habitat,

2. Apply the definitions and formulae to produce calculated diversity indices

3. Analyze and compare diversity indices from different scenarios

4. Evaluate and explain the contribution of rare and common species to diversity indices

**Timeframe:**Planning Time (instructor):

<1 hour for basic simulation; <1 additional hour for any of the advanced simulations

Class Time (students):

Both the basic and advanced one-set simulations can be completed in a 50-minute class period, with calculations made, discussion questions answered and conclusions

developed outside class time. For longer lab periods, additional replications can be completed, or calculations can be made and time can be used to discuss results.

The three-set simulations (advanced students) will require a longer (>90 min) lab period.

**Materials (one-set simulations, Appendix 2):**

* 1 Scrabble® board game (100 tiles) per group of 2-4 students (Alternative simulations require additional sets of game pieces)
* Data sheets
* Small stick-on dots (~1/4” diam), at least 40 per student group (Alternative simulations require additional at least 200 each of three colors per student group)

**Introduction**  
Ecological systems are inherently complex (Loehle 2004). Within systems, habitats contain a variety of species of different higher taxa, the number of which is seldom known with absolute certainty. Sampling represents a means to estimate the numbers of species in a habitat, as well as how many of each species there are. Sampling itself is complex (Morsdorf et al. 2015), and deriving unbiased estimates requires well-defined objectives and appropriate methods (Yoccoz et al. 2001, Legendre et al. 2002, Alberts et al. 2010). Even within a particular habitat type -- e.g., mesic forest -- numerous sampling approaches can be used, depending on the objectives of the sampling. For example, sampling can be used to assess the quality of a habitat, to compare changes in a single habitat over time, or to compare two or more habitats either at one point in time or across a time period. An entire body of literature exists on theoretical versus practical sampling methods, the importance of defining spatial structure and sampling units, and the effects of random versus non-random sampling (Kenkel et al. 1989, Yoccoz et al. 2001, Legendre et al. 2002, Diekmann et al. 2007, Alberts et al. 2010). Those discussions are beyond the scope of this exercise, which is to introduce the concept of sampling and using collected data to envision and compare habitats based on numerical calculations.

Species diversity can indicate the relative health of a community of organisms in a habitat. A diversity index (e.g., Shannon and Weaver 1948, Simpson 1949) is a quantitative representation of that community, and the calculated value of an index allows comparing communities in different habitats or within a habitat at different times. Such indices can be constructed for many taxa, though most uses have been for plants (Wilhelm 1977, Swink and Wilhelm 1994, Taft et al. 1997, Lopez and Fennessy 2002) and insects (Majer and Beeson 1996, Panzer and Schwartz 1998, Anderson et al. 2002). In another approach to assessing a community, Wilhelm (1977) and Swink and Wilhelm (1994) proposed a Floristic Quality Index to evaluate a habitat’s integrity, based on plant composition and assigning value to different species, particularly species of concern. Habitats with different indices of diversity may have different conservation value; thus, knowing the taxa in a given habitat – especially if some are endangered or if a habitat hosts invasive species – can help inform conservation decisions.

Conducting samples in a habitat may require more time than that allotted to most laboratory classes. Thus a method to simulate sampling and to calculate diversity indices or other biotic indices could be of interest for a lab exercise for biology, entomology, plant ecology or conservation biology, or to prepare students for actual field sampling.

In the exercises presented here, we propose simulated sampling of a habitat. We use a simple, readily available game (Scrabble®) to conduct the simulation. In the simulations, a set of 100 tiles from a Scrabble® game represents a community of 100 organisms and the sampling universe. Tiles depicting letters or blanks represent species in a habitat. Thus, there are 27 species (26 letters plus blanks). The point value depicted on each tile (e.g., A=1, Q=10) can be used to indicate rarity or be a proxy for conservation value. Samples are used to calculate a diversity index, either the Shannon-Wiener Diversity index (Shannon and Weaver 1948) or a Coefficient of Conservation Value, CCV (patterned after the Floristic Quality Index; Wilhelm 1977, Swink and Wilhelm 1994).

*Shannon-Wiener Diversity Index*

One common index to assess the diversity of communities is the Shannon-Wiener Index. This index combines two quantifiable measures: species richness (number of species) and species evenness (a measure of consistency of the numbers of individuals). In a sample, each species (termed *i*) in a habitat occurs at a certain richness, which is the proportion (P*i*) of all the species in the sample; the sum of all P*i* equals 1. The evenness of each species is calculated as the natural logarithm of the proportion, or *ln*P*i*. The contribution of each species to the index is given by the product of richness and evenness, or P*i* \* *ln*P*i* . Contributions of all species are summed, thus the index of total diversity (negative sign because logarithms of numbers less than 1 are negative, thus the final value is positive):

Diversity = -∑ (P*i* \* *ln*P*i* ).

To illustrate, consider three examples. The second and third have the same richness (10 species), but example 2 has unequal evenness, whereas example 3 has equal evenness.

1) This sample of 50 individuals yields only one species, which intuitively would be considered not to be diverse.

2) The sample of 50 individuals from this community yields 10 species, with 41 of one species and one each of nine species (unequal evenness).

3) The sample of 50 individuals from this community yields 10 species, with 5 each of 10 different species (equal evenness).

Calculations for the three examples are straightforward.

1) Pi = 1.0, *ln* Pi = 0.0 1.0\*0.0 = **0.0**

2) P1 = 0.82, P2…P10 = 0.02

ln 0.02= -3.910

P1\**ln* P1 = 0.82\*-0.1985 = -0.1627

P2\**ln*P2 = 0.02\*-3.9120 = -0.0782 (there are 9 of these)

-∑ (P*i* \* *ln*P*i* ) = -(-0.1627 + 9\*(-0.0782)) = **0.867**

3) P1…P10 = 0.10 ln 0.10 = -2.303

P1\**ln* P1 = 0.10\*-2.303 = -.2303 (there are ten of these)

-∑ (P*i* \* *ln*P*i* ) = -(10\*-.2303) = **2.303**

These examples illustrate the importance of evenness to the calculated diversity index. Example 3 has the greatest diversity (2.303), and Example 1 has zero diversity.

*Coefficient of Conservation Value*

Another way to quantify the composition of a community is to develop a Coefficient of Conservation Value (CCV), patterned after the Floristic Quality Index (Swink and Wilhelm 1994), which was specific for plant species. The CCV includes the number of species collected, the numbers of individuals of each species, and a conservation value assigned to each species, representing a species’ rarity or the importance to the system. Important components are the conservation value of each species (V, values range from 1-10), the contribution of each species to the sample (C), and the number of individuals in the sample (N). Although assigning value to any species is a human-imposed value judgment, such values can be useful in conservation planning or habitat restoration.

The contribution (C) of each species to the sample is the product of the number of individuals of species *i* multiplied by its value:

C*i* = N*i* \*V*i*

Which can be summed as

∑ C*i*

The Coefficient of Conservation Value (CCV) is the product of the summed contributions (∑ C*i*) and the square root of the number of individuals in the sample (N). Note that the values will be much greater than the Shannon-Wiener values for the same sample, so the two are not comparable.

CCV = (∑ C*i*) \* (N)0.5

**Procedures and Instructions for Instructor:**

You will need one set of tiles from a Scrabble® game for the basic simulation. Data are collected by groups of 2-4 students. Interactive data sheets, with embedded formulas, to calculate the Shannon-Wiener Diversity Index (Datasheet A) and the Coefficient of Conservation Value (CCV) (Datasheet B) are appended, and these sheets make the calculations for the user, based on the data entered.

Basic simulation:

Place all 100 Scrabble® tiles in an opaque bag (to preclude selecting known tiles).

The first group of students collects 20 tiles, and records the number of each “species” on a data sheet (choose either the Shannon-Wiener Index or the CCV).

After the data are recorded from the sample, return the tiles to the bag.

Because the tiles are returned only after the sample is completed, this is considered sampling without replacement. "Replacement" in this case is only re-setting for the next sample to be taken.

Repeat with each student group, with each group recording data independently.

Make appropriate calculations, depending on the index chosen.

Have students answer questions, either individually or in their small groups.

Example with filled-in datasheet

20 tiles were selected, arranged to group like letters ("species") together. The "species" and number of each were entered into the two left-hand columns. The formulas calculated Pi, *ln* Pi and the product Pi\**ln*Pi. In the lowest two boxes, the number of species was summed and the Index value calculated as the sum of the contributions of each individual species. For this example, the sample of 20 individuals yielded 11 different species and an overall Index Value (Shannon-Wiener) of 2.207

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Species | Number | Pi | ln Pi | Pi \* ln Pi |
| A | 4 | 0.2 | -1.60944 | -0.32189 |
| E | 4 | 0.2 | -1.60944 | -0.32189 |
| H | 1 | 0.05 | -2.99573 | -0.14979 |
| I | 1 | 0.05 | -2.99573 | -0.14979 |
| L | 2 | 0.1 | -2.30259 | -0.23026 |
| N | 1 | 0.05 | -2.99573 | -0.14979 |
| S | 1 | 0.05 | -2.99573 | -0.14979 |
| T | 3 | 0.15 | -1.89712 | -0.28457 |
| V | 1 | 0.05 | -2.99573 | -0.14979 |
| W | 1 | 0.05 | -2.99573 | -0.14979 |
| Z | 1 | 0.05 | -2.99573 | -0.14979 |
|  |  | 0 | 0.00000 | 0.00000 |
|  |  | 0 | 0.00000 | 0.00000 |
|  |  | 0 | 0.00000 | 0.00000 |
|  |  | 0 | 0.00000 | 0.00000 |
|  |  | 0 | 0.00000 | 0.00000 |
| # of Species: |  |  |  | 11 |
| Index Value: |  |  |  | 2.20711 |

Variations using one set of tiles (Detailed in Appendix 2, with questions for students):

1) Use the same sampling data to compare the CCV with Shannon-Wiener Index.

2) Compare the diversity of 20-tile samples with that of the sampling universe (100 tiles).

3) Assess the repeatability of sampling.

For discussion of conservation decisions (i.e., using the CCV), these exercises would need economic values as inputs – value of land, cost of conserving rare species or other activities. By adding an economic value, the above exercises could simulate real-world decisions, by forcing students to think about the costs and benefits (and complexities) of conserving species.

Variations using three sets of tiles (Detailed in Appendix 3), for more-advanced students:

4) Compare indices and species compositions of different "habitats" by manipulating the numbers of individual species in one or more habitats.

5) Use larger sample sizes.

6) Use a larger sampling universe with very rare species

7) Calculate the index for habitats with more species

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**Background (for students):**Knowing all the members of a biotic community would be difficult, if not impossible, due to limitations of time or other resources. Sampling is a means of estimating the composition of a given entity. In the case of a biotic community, sampling can estimate the composition of the community without requiring considerable time and resources. Species diversity is a measure of the variety of species in a biotic community found at a specific place, or a habitat. Habitats can be assessed for the diversity of species they contain, by calculating one of a variety of diversity indices. Habitats with different diversity indices may have different value for conservation purposes – e.g., a habitat that contains endangered or threatened species will have a greater value, whereas one containing many invasive species may have a lesser value. Therefore, calculating the diversity can help conservation professionals make management decisions. Rather than conduct the assessment in the field, you will conduct a simulation. Sampling can occur with replacement (either literally replacing each individual sampled in the habitat where it can be collected again) or sampling without replacement, in which case each sample diminishes the remainder of individuals that can be sampled. In this exercise, you will use "sampling without replacement."

For this exercise, a set of tiles from a Scrabble® game is used to represent organisms of different species in a habitat. There are 100 tiles (individual organisms) of 27 species (26 letters plus blanks). Each species has a denoted point value, indicating its rarity or conservation value. Two possible indices to calculate are a Shannon-Wiener Diversity Index or a Coefficient of Conservation Value (CCV). See Appendix 1A for an illustration of how the set of tiles can represent a community of birds from the eastern deciduous forests of the US.

*Shannon-Wiener Diversity Index*

One commonly used diversity index is the Shannon-Wiener Index (Shannon and Weaver 1948). This index combines two quantifiable measures of a community: species richness (number of species) and species evenness (a measure of consistency of the numbers of individuals). In a sample, each organism (termed *i*) occurs at a certain richness, which is the proportion (P*i*), and the sum of all P*i* equals 1. The evenness of each species is calculated as the natural logarithm of the proportion, or *ln*P*i*. The contribution of each species to the index is given by the product of richness and evenness, or P*i* \* *ln*P*i*. The contributions of each species are then summed, thus the index of total diversity:

Diversity = -∑ (P*i* \* *ln*P*i* ).

*Coefficient of Conservation Value*

A Coefficient of Conservation Value (CCV) is patterned after the Floristic Quality Index (Swink and Wilhelm 1994), which was specific for plant species. A CCV includes the number of species collected, the numbers of individuals of each species, and a conservation value assigned to each species, representing a species’ rarity or the importance to the system sampled. Important components of the CCV are the conservation value of each species (V, values range from 1-10), the contribution of each species to the sample (C), and the number of individuals in the sample (N).

The contribution (C) of each species to the sample is the product of the number of individuals of species *i* multiplied by its value:

C*i* = N*i* \*V*i*

Which can be summed as

∑ C*i*

The Coefficient of Conservation Value (CCV) is the product of the summed contributions (∑ C*i*) and the square root of the number of individuals in the sample (N).

CCV = (∑ C*i*) \* (N)0.5

**Procedures and Instructions (for students):**

You will need one set of tiles from a Scrabble® game for the basic simulation. You will be assigned to a small group to collect the data and answer questions. You will be provided with interactive data sheets for the Shannon-Wiener Diversity Index (Datasheet A) and the CCV (Datasheet B), with embedded formulas that automatically make the calculations, based on the data entered.

Basic simulation:

Place all 100 Scrabble® tiles in an opaque bag (to preclude selecting known tiles).

The first group of students collects 20 tiles, and records the number of each “species” (either Shannon-Wiener Index (Datasheet A) or CCV (Datasheet B)).

After the data are recorded from the completed sample, return the tiles to the bag.

Repeat with each student group, with each group recording data independently.

Make appropriate calculations, depending on the index chosen.

As instructed, answer questions either individually or in your small groups.

**Student data sheets will be given by the instructor**

Each simulation listed in appendices has questions to answer.

APPENDIX 1

Scrabble® letter distributions and values

One Set of Tiles, Un-Modified

Letter Number (N) Value Total

A 9 1 9

B 2 3 6

C 2 3 6

D 4 2 8

E 12 1 12

F 2 4 8

G 3 2 6

H 2 4 8

I 9 1 9

J 1 8 8

K 1 5 5

L 4 1 4

M 2 3 6

N 6 1 6

O 8 1 8

P 2 3 6

Q 1 10 10

R 6 1 6

S 4 1 4

T 6 1 6

U 4 1 4

V 2 4 8

W 2 4 8

X 1 8 8

Y 2 4 8

Z 1 10 10

BLANK 2 0 0

TOTAL 100 187

Appendix 1A. Example of how the Scrabble® tiles can represent a community of birds from the eastern deciduous forests of the US.

Letter Number (N) Species Name

A 9 Carolina Chickadee

B 2 Summer Tanager

C 2 Orchard Oriole

D 4 Mourning Dove

E 12 Northern Cardinal

F 2 Brown Thrasher

G 3 American Robin

H 2 Wood Thrush

I 9 Blue Jay

J 1 Blue-grey Gnatcatcher

K 1 Eastern Screech Owl

L 4 Downy Woodpecker

M 2 Ruby-throated Hummingbird

N 6 American Goldfinch

O 8 Tufted Titmouse

P 2 Hairy Woodpecker

Q 1 Great Horned Owl

R 6 Carolina Wren

S 4 Yellow-rumped Warbler

T 6 Red-eyed Vireo

U 4 Red-bellied Woodpecker

V 2 Yellow-billed Cuckoo

W 2 Gray Catbird

X 1 Red-shouldered Hawk

Y 2 Warbling Vireo

Z 1 Cooper's Hawk

BLANK 2 European Starling

TOTAL 100

APPENDIX 2

Variations on the basic simulation using one tile set, with student questions

1) Compare Two Different Indices

Use the same sampling data to compare the Shannon-Wiener Index with the (CCV). Record the same sample data on two different data sheets – one for Shannon-Wiener (Datasheet A) and the other for CCV (Datasheet B), and make calculations. Examine sample means and overall means for each index.

2) Compare a Sample Distribution with a Known Distribution

Compare the distribution and diversity of 20-tile samples with that of the community (100 tiles).

3) Repeatability of sampling

Choose one of the two indices (or assign different indices to different groups). Have each group conduct five samples and calculate the index per sample, then an overall average.

**Student Questions for Sampling Variations, One Set of Tiles**

1) Compare Two Indices

Questions:

Is one index more likely to be influenced quantitatively by rare species than the other?

Is one index more likely to be influenced quantitatively by very common species than the other?

Is there greater variability among sample means by one method than the other?

2) Compare a Sample Distribution with a Known Distribution

Questions:

Is the sample of 20 individuals a good representation of the entire sampling universe (i.e., an exhaustive sample of all individuals in the community?

How would you improve it? Which would be better -- more samples or larger samples?

3) Repeatability of sampling

Questions:

How variable were the samples and index scores for each sample?

How variable were the samples and index scores across different student groups?

Each group sampled the same "habitat" and the composition of species was identical – why would the values differ among samples or among groups?

APPENDIX 3.

Variations on sampling simulations using three sets of tiles, with student questions.

4) Simulate a Habitat with an Invasive Species, and Restoration After Its Removal

Using three sets of tiles, manipulate the composition of tiles in one tile set to simulate a habitat that has been invaded by one species, and subsequently eliminated to restore the community. To do this, keep one set of 100 tiles unmodified (as in Appendix 1). For the second set, remove selected tiles and add the same number of tiles, but different letters (species) from the third set. Two scenarios are proposed -- invaded and restored.

In Scenario One (Invasion), an invasive species (letter A) becomes very common and five rare (Q) or semi rare (C, G, P, W) species are eliminated. In Scenario Two (Restoration), the invasive species (A) is eliminated and five rare (Q) or semi-rare (C, G, P, W) species are restored.

Scenario One (Invasion): Make one species very common and eliminate rare species

Habitat 1: Use Tile Set 1 that is intact and unmodified

Habitat 2: Begin with an intact Tile Set 2

Add (from Tile Set 3) nine "A" tiles to Tile Set 2 (making a total of 18)

Remove from Tile Set 2: 1 “Q” tile, 2 each of "C," "G," "P" and "W" tiles

Scenario Two (Restoration): Eliminate the invasive species and restore five rare species

Habitat 1: Use Tile Set 1 that is intact and unmodified

Habitat 2: Begin with an intact Tile Set 2

Remove all nine "A" tiles from Tile Set 2 (leaving zero)

Add (from Tile Set 3): 1 “Q” tile, 2 each of "C," "G," "P" and "W" tiles.

Conduct the sampling as in the basic simulation, collecting 20 tiles for a sample and using the Shannon-Wiener Index.

Comparisons include:

For each Scenario, compare data from Habitats 1 and 2 (Datasheet C).

For Habitat 2, compare data in Scenario 1 (invaded) & Scenario 2 (restored)

(Datasheet D).

Note – Variations 5, 6 and 7 are time-consuming to undo! If you want to do these, you will need to acquire three sets of tiles per student group, and you may want to keep them solely for these exercises. The simplest way to be able to "undo" these variations is to label all tiles from one set with a ¼" colored sticker, and tiles from another set with a ¼" sticker of a second color. Place the stickers on the labeled face, being sure to be able to see the letter and its value.

5) Larger sampling universe and larger sample size

Combine tiles from three sets. Increase the sample size from 20 to 50. Use the Shannon-Wiener Index (Datasheet E)

6) Larger sampling universe with very rare species

Before combining pieces from three sets, manipulate very rare species (per Appendix 4). For example, remove one "J" and one "X" tile from one game, and one "Q" and one "Z" tiles from 2nd and 3rd games – thus leaving a total of only one "Q" and one "Z," and two "J" and two "X" in the final sampling universe (294 tiles). "Q" and "Z" are now extremely rare -- each represents 0.33% of the sampling universe -- and "J" and "X" are very rare -- each represents 0.67% of the sampling universe.

Use the Shannon-Wiener Index. You can either use a sample of 20 tiles (use Datasheet A) or increase the sample to 50 tiles (use Datasheet E).

7) Habitats with more species

In this simulation, you will have additional species.

Before combining all the pieces, label tiles with colored stickers as indicated above (Variation 6). Place the stickers on the labeled face, being sure to be able to see the letter and its value. Thus, you have increased the number of species from 27 to 81 (e.g., an unlabeled "A", a green-dot "A" and a pink-dot "A" are different species).

Use the Shannon-Wiener Index. You can either use a sample of 20 tiles (use Datasheet F) or increase the sample to 50 tiles (use Datasheet G). Label the species on the datasheet by letter and either "unlabeled," "green," or "pink" (or whatever colors of dots you have).

**Student Questions for Sampling Variations, Three Sets of Tiles**

4) Simulate a Habitat with an Invasive Species, and Restoration After Its Removal

Questions:

Scenario 1:

Do indices differ between Habitat 1 and Habitat 2?

Are species richness and evenness in Habitat 2 different than Habitat 1?

What are some consequences of an invasive species eliminating five rare species?

Scenario 2:

Do indices differ between Habitat 1 and Habitat 2?

Are species richness and evenness in Habitat 2 different than Habitat 1?

What are some consequences of restoring five rare species by eliminating the invasive species?

Comparing Scenario 1 and 2:

Do indices differ between the invaded Habitat 2 and the restored Habitat 2?

How do species richness and evenness differ in Habitat 2 when it is invaded or restored?

5. Larger sample size and larger sampling universe

Questions:

Is a 50-specimen sample a better estimate than a 20-specimen sample?

The species composition and proportions are the same between a 100-organism and 300-organism habitat, so why would the values differ?

Is the index for either sample size more likely to be influenced by occurrence of a rare species?

6. Larger sampling universe with very rare species

Questions:

How likely is it that your sample will record the very rare or extremely rare species?

Would a larger sample size help?

Or more samples?

7. Habitats with more species

Questions:

How does the tripling of species affect the index?

How do samples of 20 differ from samples of 50 with this more-rich species assemblage?

APPENDIX 4

Scrabble® letter distributions and values from modified three tile sets (Simulation Variation 6).

Note: total of 294 tiles.

Species Rarity by Altering Three Sets of Tiles

Letter Number (N) Value Total

A 27 1 27

B 6 3 18

C 6 3 18

D 12 2 24

E 36 1 36

F 6 4 24

G 9 2 18

H 6 4 24

I 27 1 27

J 2\* 8 16

K 3 5 15

L 12 1 12

M 6 3 18

N 18 1 18

O 24 1 24

P 6 3 18

Q 1\*\* 10 10

R 18 1 18

S 12 1 12

T 18 1 18

U 12 1 12

V 6 4 24

W 6 4 24

X 2\* 8 16

Y 6 4 24

Z 1\*\* 10 10

BLANK 6 0 0

294 505

\* remove 1 of the tiles, leaving a total of 2

\*\* remove 2 of the tiles, leaving a total of 1