Biodiversity of Hydrothermal Vents at Brothers Volcano

Background

One measure of **biodiversity** of an ecosystem is the species diversity, which is a combination of both species richness and species evenness. The **Shannon-Weiner Diversity Index** is a common way of calculating diversity, taking into account not only number of different species (**species richness**), but also how well each of these species is represented in the habitat (**species evenness**).
JOIDES Resolution Expedition 376 sailed to Brothers volcano, on the Kermadec Arc north of New Zealand, from May – July 2018. Brothers volcano has an abundance of hydrothermal activity; dominated by fluids with high concentrations of metals & minerals, as well as low pH. These extreme conditions are still able to support diverse microbial communities, which we will examine in this activity.

Summary

Students will calculate and compare microbial species diversity at two sites at Brothers volcano.

National Science Education Standards

Standard C: Interdependence of Organisms
Standard D: Earth Sciences
Standard E: Science &

Ocean Literacy Essential Principles

Principle 5: The ocean supports a great diversity of life & ecosystems.
Principle 7: The ocean is largely unexplored.

Target Audience

Grades 10-12

Time Required

Approximately 70 minutes.

Acknowledgements

Citation for data used in activity:
Ken Takai, Takuro Nunoura, Koki Horikoshi, Takazo Shibuya, Kentaro Nakamura, Yohey Suzuki, Matthew Stott, Gary J. Massoth, B.W. Christenson, Cornel E.J. deRonde, David A. Butterfield, Jun-ichiro Ishibashi, John E. Lupton & L.J. Evans (2009) Variability in Microbial Communities in Black Smoker Chimneys at the NW Caldera Vent Field, Brothers Volcano, Kermadec Arc, Geomicrobiology Journal, 26:8, 552-569.

Credits: Tammy Orilio

Background:

A central theme in environmental science is **biodiversity**, which often serves as a measure of the overall health of an ecosystem, because an ecosystem with high biodiversity will have complex food webs, a variety of niches, and increased genetic diversity. There are many methods that ecologists use to calculate biodiversity. The **Shannon-Weiner Diversity Index** is a way to determine biodiversity using numbers of different species and the number of individuals in each species. The Shannon-Weiner value (designated as "H") can range from no diversity at 0.0 to a high diversity of over 4.0. These values have no real meaning by themselves; however, they can be used to compare separate communities or the same community at different times.

Species diversity is a combination of both species richness and species evenness.

- Species richness (R) is the total number of species present in the community.
- Species evenness (E) is the relative distribution of individuals among the species present in a community.

Calculating the Diversity Indices:

1. Species Richness (R) = the number of species found in the given area; not reflective of relative dominance of any particular species.

2. Shannon-Weiner Index (H) = -sum (P_i * ln(P_i))

   Where:

   P_i = relative abundance of particular species (n_i/N)
   n_i = number of individuals of species "i"
   N = total number of individuals of all species

Once calculated, an ecosystem with high species diversity will have a large H-value, while an ecosystem with low diversity will have a low H-value.

3. Species Evenness (E) = H / (lnR)
   - Species evenness is a measure of how similar the abundance of different species are. A community dominated by one or two species is less diverse than a community in which several different species have a similar abundance.

Check for Understanding:

A sample of 256 individuals is comprised of 5 different species, and the frequency of each species is recorded below. Complete the table and determine the R, H, and E values.

Table 1- Sample community.

Fish Species	Frequency	P_i	$\ln(P_i)$	$P_i * \ln(P_i)$
Species #1	84	0.3281	-1.1144	-0.3656
Species #2	4	0.0156	-4.1589	
Species #3	91	0.3555		
Species #4	34			
Species #5	43			
Sum		1	n/a	

↑ H value *remember, H is a *negative* summation, so it will end up a positive number*

$(H) = -\text{sum}\ (P_i * \ln(P_i))$

Calculate:

R =	H =	E =

Background: Biodiversity at Hydrothermal Vents

Hydrothermal vents are one of the most fascinating and challenging places to study ecology. They are located deep (>2000 meters) in the ocean, and can be found at both convergent and divergent plate boundaries. Hydrothermal systems begin as cold seawater seeps into cracks & fissures naturally present on the seafloor, and then travels downward through the curst due to the force of gravity. As the water nears the lower parts of the crust, it is heated by the hot magma in the mantle layer beneath the curst, reaching temperatures >200°C. The heated fluid then begins to rise up through the cracks & fissures, because the warm temperature makes it less dense, a process known as convection. Minerals (dissolved from the crust) and the hydrothermal fluid are released at vent sites, and when the fluid reacts with the cold surrounding seawater, the minerals precipitate out of solution.

Expedition 376 took the JOIDES Resolution to Brothers volcano, which has more hydrothermal activity than any other volcano in the Kermadec Arc. Brothers volcano, and other submarine volcanoes along the Arc, was created as the Pacific plate subducted under the Australian plate at a convergent plate boundary and magma was forced up through the lithosphere. Hydrothermal activity at this spot is characterized by fluids with high concentrations of metals & minerals, as well as an acidic pH; however, these extreme conditions are still able to support some of the most diverse microbial communities on Earth. Microbes form the base of the food web in hydrothermal vent communities, utilizing the chemicals present in the vent fluid to produce foods via the process of chemosynthesis.

In this activity, you will calculate the diversity of microbes at two black smoker hydrothermal vent sites at Brothers volcano. The two black smoker sites are similar in depth and temperature of the hydrothermal fluid released; however, one major distinction is the presence or absence of chloride in the fluid. Sample site 851-3A has Cl-enriched hydrothermal fluid, while sample site 852-2B has Cl-depleted hydrothermal fluid. Sections of the black smoker chimneys were retrieved from each site and sub-sampled into the "surface" and "inside" rock layers. Microbial abundance was then determined for both the surface and inside layers at each site.

Microbial abundance retrieved from
Ken Takai, Takuro Nunoura, Koki Horikoshi, Takazo Shibuya, Kentaro Nakamura, Yohey Suzuki, Matthew Stott, Gary J. Massoth, B. W. Christenson, Cornel E. J. deRonde, David A. Butterfield, Jun-ichiro Ishibashi, John E. Lupton & L. J. Evans (2009) Variability in Microbial Communities in Black Smoker Chimneys at the NW Caldera Vent Field, Brothers Volcano, Kermadec Arc,Geomicrobiology Journal, 26:8, 552-569, DOI: 10.1080/01490450903304949; → Figure 3, "Total cell count in the chimney environments".

Table 2- Cell count in number of cells/ml.

Microbe Genera	Site 851-3A Surface	Site 851-3A Inside	Site 852-2B Surface	Site 852-2B Inside
Thermococcus	100,000	1,000	1,000,000	100
Marinithermus	5,500	x	x	x
Halomonas	6,000,000	10	x	x
Vibrio	10	x	1,000	x
Persephonella	x	x	1,000,000	10
Sulfurimonas	x	x	100,000	x
Rhodothermus	x	x	10,000	x
Deferribacter	x	x	1,000	x
Aquifex	x	x	100	x
Desulfuromusa	x	x	100,000	x
Pseudoalteromonas	x	x	100	10

Procedure:

1. Create a data table, like Table 1, for the data from the above table, ensuring you have enough space to include all of your calculations (or you could make 4 separate tables, one for each site).
2. Complete Table 3 below, comparing the 4 sampling sites at Brothers volcano.

Table 3. Diversity Measurements.

Diversity Measurements	Site 851-3A Surface	Site 851-3A Inside	Site 852-2B Surface	Site 852-2B Inside
Most abundant genus:				
Species Richness (R)				
Species Evenness (E)				
S-W Index (H)				
Relative Diversity (rank most diverse = 1, so on…to 4)				

Conclusion Questions:

1. The importance of biodiversity has been correlated to ecosystem resilience and stability. According to your results, which site demonstrates the higher degree of ecological stability? Explain why high diversity = ecological stability.
2. Describe two advantages to using a diversity index like the Shannon-Weiner instead of a simple population count to determine the diversity of a site.
3. Discuss the type of (hypothetical) community that has a H-value = 0. Mathematically back up your statement.
4. You're working on designing a nature reserve, but the final size & location has not yet been decided, and YOU must choose between the two proposed sites. Site 1 has a very low H-value because it is largely dominated by a single species; however, one of the rare species found here is so rare it's only found in one other park in the world. Site 2 lacks this particular rare species, but has much higher diversity values because it contains more species than Site 1, and none of the species is particularly dominant. Which site would you choose for the reserve and why?
5. When hydrothermal vents were first discovered in 1977, scientists were amazed to find life in these extreme conditions. They've begun to think that life may be able to exist in other areas previously thought to be too hot or too cold for life to exist. What might this discovery of abundant microbial life at hydrothermal vents mean in terms of seeking life on other planets?