WHAT'S ALL THE BUZZ ABOUT? VECTOR-BORNE DISEASES AND CLIMATE CHANGE

Notes and Helpful Hints:

This *addendum* to the lesson plan "What's All the Buzz About: Vector-Borne Diseases and Climate Change" is geared toward high school students. Follow the instructions listed herein to provide additional challenge for your students.

Implementing the Lesson

Note: This lesson plan is designed for 27 students; modify per your specific needs

Step 1

Discuss the background slides explaining vectors, hosts, and transmission of disease. West Nile virus is used as the example.

1. A zoonose is any disease that normally resides in an animal host but can cross over to humans. Well-known examples include SARS, Ebola, and H1N1 (or bird) flu.

2. Vector-borne diseases involve any disease-causing microorganism that is transmitted to people by an animal intermediate rather than by normal person-person transmission.

3. Mosquitoes, ticks, fleas, mice, and deer are all examples of vectors that can harbor vector-borne diseases.

4. Examples of vector-borne diseases include West Nile virus, malaria, dengue, Lyme disease, hantavirus, yellow fever, Rocky Mountain spotted fever, and bubonic plague.

5. Vector-borne diseases involve a transmission cycle that involve vectors and hosts. In the case of West Nile virus, the vector is a mosquito and the host is a bird. When the mosquito bites an infected host (also known as reservoirs; in this case, birds that carry the virus) the mosquito gets infected with the virus. The host is usually not infected by the virus. West Nile virus is transmitted when the infected mosquito bites a secondary host (humans, pigs, horses). The virus enters the blood stream of the secondary host and spreads throughout the body causing infection and disease.

6. How does transmission of West Nile virus differ from other vector-borne diseases such as malaria? In the case of malaria, the mosquito is the host carrying the parasite. When the infected mosquito bites a human, the parasite is injected into the human bloodstream and causes infection.

Step 2

Explain the mathematical model to approximate the spread of vector-borne diseases.

1. The first equation is used to calculate how many people will be infected after one round of bites.

$$\text{Total \# Infected People} = \frac{\text{\# Uninfected People}}{\text{Total \# People}} \times \text{\# Infected Mosquitoes} + \text{\#Previously Infected People}$$

   Conceptually, you are calculating the probability that an infected mosquito is going to bite an uninfected person. After calculating this probability, you add the number of people that were previously infected to quantify the total number of infected people after a round of bites.

2. The second equation is used to calculate the number of mosquitoes infected after one round of bites.

$$\text{Total \# Infected Mosquitoes} = \frac{\text{\# Infected People}}{\text{Total \# People}} \times \text{\# Uninfected Mosquitoes} + \text{\#Previously Infected Mosquitoes}$$

3. Mosquitoes become infected by biting infected hosts. Conceptually, you are calculating the probability that an uninfected mosquito is going to bite an infected person. After calculating this probability, you add the number of previously infected mosquitoes to quantify the total number of infected people after a round of bites.
4. This process is iterative. That is, for each subsequent bite, you calculate the number of infected people who were added and then the number of mosquitoes infected by a round of bites.

5. After reviewing the equations, fill out the following table with the students. Additionally, the PowerPoint includes individual graphs to conceptualize this data.
   Optional: This table may also be assigned as homework.

Round of Bites	Total # People	Total # Infected People	Total # Mosquitoes	Infected Mosquitoes Added	Total # Infected Mosquitoes
0	20	0	7		2
1	20	**2**	7	**0.5**	**3**
2	20	**4.3**	7	**1**	**3.5**

6. Discussion questions:
   a. Consider the 0.5 mosquito. Would you round up or round down? Why? Usually scientists would round up to overestimate the number of mosquitoes as a worst-case scenario. In other words, even though there is a mathematical basis for findings, subjective interpretation can be involved in how you report findings.

   b. How many rounds would it take for half the individuals to become infected?

   c. How many rounds would it take for all individuals to become infected?

Step 3

Explain how we are going to model transmission of disease by mosquitoes.

1. Each cup represents a host (like people). Distribute 20 cups filled with uninfected solution to 20 students.
   a. Give syringe barrels to 7 volunteers. 2 are filled with infected solution, and 3 are filled with uninfected solution.

   b. Mosquitoes will simulate "biting" hosts by squirting out all the liquid into the cup.

   c. Mosquitoes will simulate feeding by mixing the contents in the cup and filling the syringe with solution from the host.

   d. The mosquitoes will bite a total of 3 people each. Note that a "host" can be bitten more than one time. The goal is to mimic random bites as occurs in the real world.

   e. After all the mosquitoes have bitten 3 people each, have them come to the front of the class.

   f. Why did the mosquitoes squirt out and suck up and the contents of the syringe barrel?

      This process mimics how a mosquito takes a bloodmeal. First it injects the contents of its salivary glands and then it sucks up blood from the host.

2. At this point, you can test the mosquito syringes to determine after-the-fact how many were infected. Use clean cups to test the solution from each of the syringes. Have students pour a small amount of vinegar (approximately 2 tbsp) in each cup and swirl. An infected host will be identified by bubbling on the surface.

(Note: Too much vinegar will cause the solution to bubble over and make a mess. The reaction is the same as that in homemade volcanoes where the acetic acid in vinegar reacts with baking soda to release carbon dioxide, the gas in the bubbles.)

   a. How many mosquitoes do you think are infected?

      Bring 5 cups to the front of the class and have each mosquito squirt the contents of their syringe into a cup. Add a small amount of vinegar and determine how many mosquitoes are infected.

      Because of the dilution that occurred during the course of the experiment, usually a quarter of the mosquitoes are infected, although this may vary.

   b. Why were fewer mosquitoes infected than you would have anticipated?

      This is because of the dilution effect. Just as in a real world, the bloodmeal taken by the mosquito represents a small amount of the host's total volume. Another way this mimics real-world scenario is the fact that it takes time for microbes to reproduce before they are transmitted back to the mosquito, such that hosts are not infectious right after a mosquito bite. Likewise, a mosquito does not usually infect a host immediately after taking a blood meal. This is one example of a factor that was not incorporated into our simplified mathematical model.

   c. Why didn't we test the mosquitoes before they bit?

      Similar to conditions in the wild, we cannot tell which mosquito carries a disease-causing microbe unless we kill it. There are no visible markers of infection, and you cannot identify an infected vector without killing it. Usually the vector is crushed, and DNA or protein specific to the microbe can be tested.

      Students may also ask whether a vector carrying a microbe is "sicker" or less fit than a vector without disease. The answer to this is not straightforward. For many microbes, like *Plasmodium*, the causative agent of malaria, the parasite must make a hole in the gut epithelium in order to migrate to the salivary glands. This damage stimulates the insect's immune response and causes the mosquito to have a lower parasite load. However, the impact of the parasite load on fitness is typically not that high; otherwise, insects would not survive to transmit the disease.

3. Compare the results obtained from this exercise with the predicted results from the table. What are possible sources of the discrepancy?
    a. As mentioned above, dilution is not incorporated into this model.
    b. With a small sample size, person-to-person varibaility in conducting the experiment can contribute a lot of error. These variables include not fully expelling the contents of the syringe into the cup, the degree of mixing of contents of the syringe, and the cup. Experiments with more samples are more reproducible because the sampling error is reduced.

Step 4

Discussion with worksheet and presentation.

1. How does weather affect vector-borne diseases?
    a. Temperature
    b. Humidity
    c. Surface water
    d. Vectors are more common in tropical and subtropical regions
    e. Predator patterns
2. Brief overview of climate change
    a. Climate change is occurring as a result of an imbalance between the incoming and outgoing radiation in the atmosphere. When solar radiation enters the atmosphere, some of it is absorbed by the earth, and some of it is reflected back into the atmosphere. Increases in greenhouse gases like carbon dioxide in the atmosphere prevent the solar radiation from escaping back into the atmosphere, and the retained heat is causing an increase in the earth's temperature. Additionally, deforestation is causing removal of plants that normally remove carbon dioxide from the atmosphere and act as carbon sinks. The InterGovernmental Panel on Climate Change (IPCC) forecasts a temperature rise of 2.5 to 10 degrees Fahrenheit over the next century.
    b. Increasing temperatures will alter humidity and the water cycle because warmer air can retain more water than cooler air. This means more extreme temperatures and weather, including both colder and warmer temperatures, than normal. Some geographic areas will see increase in rainfall, and some areas will experience more drought, which is why scientists have redefined the phenomenon as "climate change" rather than "global warming."
    c. The general consensus among public health officials is that climate change and increased extreme weather events will move infectious diseases northward. Warmer winters and high-latitude warming are contributing to shifts and expansion of vector ranges. These events will likely lead to outbreaks of water-, mosquito- and rodent-borne diseases. Other factors may also contribute to the spread of these diseases, and more research is needed to better understand and determine the many factors that play a role in disease outbreak.
3. How could climate change affect vector-borne diseases distribution and outbreaks?
    a. Climate constrains the prevalence of many vector-borne diseases and many of these diseases are restricted to tropical and subtropical regions. For example, temperature is a limiting factor in the lifecycle of a mosquito. Winter freezing not only kills many invertebrates like mosquitoes and ticks but also limits food availability for many vectors.
    b. Warmer temperatures may result in a larger geographic distribution where the disease is common.
    c. Warmer temperatures and increased rainfall could increase the intensity and duration of outbreaks.
    d. Erratic weather patterns could alter the seasonal distributions of vectors and hosts.
4. How could climate change alter the distribution of mosquitoes in particular?
    a. The implications of climate change are complicated. For example, the increase in humidity and temperature will likely increase the incidence of West Nile virus. This is because at higher temperatures:
        i. Mosquitoes develop more rapidly
        ii. Mosquitoes bite more frequently
        iii. Mosquitoes have a higher viral load and some parasites develop faster
        iv. Because more people are infected, more mosquitoes become carriers that transmit disease
    b. However, increased drought may also increase vector-borne diseases by brining mosquitoes and carriers (like birds and mice) into proximity because of limited water. Additionally, fewer natural predators can also lead to increase mosquito populations. The spread of dengue to eastern Africa is thought to be a result of drought conditions that were not previously present in the area.
    c. Vector-borne diseases and the effects of climate change will disproportionately affect the developing world because of the effects on equatorial regions.

Step 5

To model a population where more people are infected and mosquitoes have higher parasite load and bite more frequently.

1. If you are repeating the experiment to model the effects of climate change, pour out the contents of all of the cups and syringes. Rinsing the cups or syringes is not necessary.

2. Repeat the experiment with 2 infected people that have cups with infected baking soda-containing solution. The remaining 18 uninfected people have cups filled with uninfected solution.

3. To model higher parasite load, use larger syringe barrels for this experiment. Syringes that hold 20 mL or more are sufficient. Of the 7 mosquitoes, 4 syringe barrels will be filled with infected solution and 3 syringe barrels filled with uninfected solution represent uninfected mosquitoes.

4. The mosquitoes will bite 4 people each.

   Have students pour a small amount of vinegar (approximately 2 tbsp) in each cup and swirl. An infected host will be identified by bubble formation on the surface. *(Note: Too much vinegar will cause the solution to bubble over and make a mess.)*

5. How many rounds of bites would it take for all people to be infected?

   According to the model, there is a shift from 6 rounds of bites to only 4 rounds of bites.

Step 6

Concluding discussion.

1. Why were so many more people and mosquitoes infected? Specifically, how did the modified experiment incorporate possible effects of climate change?
   a. There will be more mosquitoes (we didn't account for this)

   b. The mosquitoes bite more frequently (increased number of bites)

   c. The parasite develops faster (accounted for by increased syringe volume)

   d. The parasite load within the mosquitoes is higher (Increased syringe volume)

   e. Because more people are infected, more mosquitoes become infected too. (4 people were infected at the start of the experiment).

2. What factors does this model not incorporate? What assumptions are made in this model?
   c. It assumes that mosquito bites always transmit disease to both the vector and the host. In reality, there may be a delay before a mosquito can transmit a particular microbe.

   d. The model also assumes that mosquitoes are equally capable of transmitting disease. In reality, there is variation between mosquito strains in the parasite/microbe load and the degree to which it can transmit a microbe.

   e. The model assumes that people continue to transmit the disease. People may die or they can be cured of the disease. Either way, those individuals in the population do not continue to transmit the disease.

   f. This experiment assumed that there are more people in mosquitoes. That is never the case.

   g. This model also assumes that all people attract mosquitoes to an equal extent. Mosquitoes are attracted to 3 things: taste (they have odorant receptors on their feet; DEET makes our skin taste bad), heat (some people are hotter than others) and carbon dioxide (people who breathe faster release more carbon dioxide). Any one of these components can vary from person-to-person.

Possible extentions

1. Make a longer version of the table used to calculate the number of people and mosquitoes that are infected after a round of bites. Have the students experiment with different starting conditions to get a sense of how the infection curve can change.
2. Allow students to select different vector-borne diseases and comment on the effects of climate change. This portion is adapted from the Climate Change and Disease lesson plan developed by the Union of Concerned Scientists for the WWF: http://www.worldwildlife.org/climate/curriculum/WWFBinaryitem5967.pdf
   a. What are the direct impacts on the vector?
   b. What are the impacts on vector habitat?
   c. What is the impact on the parasite?
   d. What is the potential impact on disease transmission?
   e. Climate change parameters to consider:
      i. More heat waves
      ii. Change in flooding
      iii. Change in drought frequency
      iv. Heavier snowfalls
      v. Sea level rise
      vi. Extreme weather

Table to determine proportion of hosts and vectors. This is a starting point for modeling vector-borne diseases. Increase the proportion of infected people and mosquitoes when modeling the effects of climate change

Total Students	People	Mosquitoes	Infected Mosquitoes
10	8	2	1
11	8	3	1
12	9	3	1
13	10	3	1
14	11	3	1
15	11	4	1
16	12	4	1
17	13	4	2
18	14	4	2
19	14	5	2
20	15	5	2
21	16	5	2
22	17	5	2
23	17	6	2
24	18	6	2
25	19	6	2
26	20	6	2
27	20	7	2
28	21	7	2
29	22	7	2
30	23	7	2
31	23	8	3
32	24	8	3
33	25	8	3
34	26	8	3
35	26	9	3
36	27	9	3
37	28	9	3
38	29	9	3
39	29	10	3
40	30	10	3
41	31	10	3
42	32	10	3
43	32	11	4
44	33	11	4
45	34	11	4
46	35	11	4
47	35	12	4
48	36	12	4
49	37	12	4
50	38	12	4