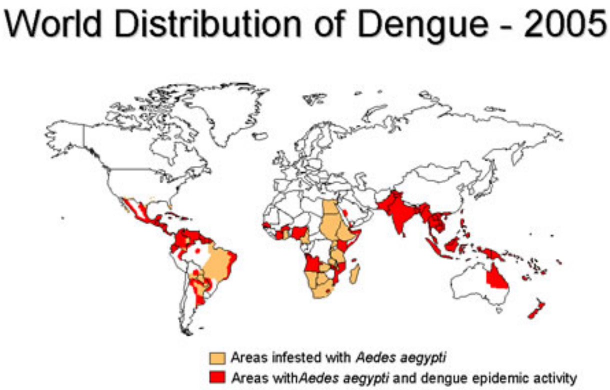
Tropical Ecology (EEMB 159)
Case Study #3: Climate Change and Infectious Disease

Introduction

Dengue fever is a mosquito-borne viral infection which has developed into a major international public health problem over the last 50 years. Outbreaks of dengue fever have been recorded since the 18th century, but were generally rare, occurring only once every 40 years or so. However, after World War II, both frequency and intensity of outbreaks sharply increased. Before 1970, only nine countries in the world had ever experienced dengue epidemics; by 2002, the disease had become endemic in more than 100 countries. While dengue probably originated in southeast Asia, its range has increased dramatically, and outbreaks now occur in Asia, Africa, and Central and South America (see map). The World Health Organization estimates that there are 50 million new cases of dengue infection every year, with 2.5 billion people at risk – more than a third of the world's population.



The disease occurs predominantly in urban areas. The virus is transmitted primarily by the mosquito *Aedes aegypti*, which lives so successfully around humans that it has been called a domestic species. The mosquito can breed in any man-made container that holds water, such as trash cans, used tires, empty plastic food containers, etc. Female *Aedes* mosquitoes acquire the virus when they feed on the blood of an infected person; after several days of incubation, the infected mosquito can then transmit the virus to any other human it bites for the rest of its life.

There are four different types (serotypes) of dengue virus; infection with one type provides life-long immunity to that type, but actually increases susceptibility to infection from other types. All four types are not present in all parts of the world; for instance, while southeast Asia has all four, only types 2 and 3 are found in Africa. In 1970 only type 2 was found in South America, but type 1 was introduced there in 1977, type 4 in 1981, and type 3 in 1994; each introduction of a new type was accompanied by major epidemics throughout the region (including Venezuela, Colombia, Brazil, Puerto Rico, and Cuba).

Dengue infection in humans lasts between two and seven days, and is characterized by high fever (41º C, or 105º F), severe headache, rash, and debilitating muscle and joint pain (hence the common name "breakbone fever"). Mortality is generally low, except in cases where dengue fever develops into dengue hemorrhagic fever (DHF) which is characterized by liver enlargement, convulsions, circulatory failure, and shock. Mortality from DHF is around 1% when proper supportive care is received, but can be as high as 20% for people without access to modern medical facilities. While the causes of DHF are not entirely understood, prior infection with a different strain of dengue virus is known to greatly increase the probability of a new dengue infection developing into DHF.

Dengue is a leading cause of hospitalization and death among children and adults in Thailand, where all four types of the virus circulate. Although there is one, moderately successful vaccine for the dengue virus (see http://www.who.int/immunization/research/development/dengue_q_and_a/en/), disease control efforts focus on controlling the mosquito vector of the disease. Reliable prediction of the location and times of high incidence would allow public health systems to allocate their limited resources more effectively.

In this case study we'll use two standard models to investigate both the causes and the severity of outbreaks of dengue fever, and see how they are affected by urbanization and climate change. We'll set the model in Thailand, where all four types of the virus circulate widely, and where the disease already has immense impacts on social, economic, and political life.

Part 1: Vector Capacity

Since dengue transmission is entirely dependent on *Aedes* mosquitoes, the best way to predict whether or not an outbreak will occur is to model the ability of the mosquitoes to transmit it. This is known as the vector capacity (VC). VC is dependent on the number of mosquitoes, the probability that they acquire and transmit the virus each time they bite a human, the duration of the incubation of the virus in the mosquito, the rate at which humans are bitten by mosquitoes, and the survival rate of the mosquitoes. It uses the following formula:

m = # female mosquitoes per person

t = probability that an infectious mosquito transmits virus while biting a susceptible human

c = probability mosquito acquires virus while biting viremic human

b = # bites per person per day

d = incubation period of the virus inside the mosquitoes in days

s = average survival rate of mosquitoes – expressed as a probability that an inoculated female mosquito will survive until the end of the disease incubation period, that she will survive long enough to pass on the disease while biting a susceptible human

If VC is greater than one, then an epidemic will begin and persist; if VC is less than one, the disease will tend to die out. VC is directly proportional to the number of humans infected from one infected person in a susceptible population, so the higher VC, the faster and more widely the disease will spread.

Open the Excel worksheet “VC”, in which all of these parameters are set to reflect current conditions. As you can see, VC is very close to 1, which means outbreaks are likely to happen (and they do, every year). Now let’s see what might happen in the future, with changes in climate and human population densities.

Complete the line graphs for parts 1a, 1b, and 1c on the sample graphs tab; no graph is necessary for part 1d, just report your results for VC in the text.

1a) The incubation period in mosquitoes is highly temperature dependent; when temperatures are warmer, the virus replicates faster, and the incubation period decreases. Average temperature in Thailand during the months with peak dengue incidence is 27ºC; at this temperature the incubation period is 20 days. At 30°C the incubation period decreases to 12 days, and at temperatures above 32ºC the incubation period decreases to 7 days. Change the incubation period (d) in the model and see how this affects VC. Global temperatures are predicted to rise by up to 3ºC by the year 2050, and up to 5ºC by the year 2100. **Before moving on, change ‘d’ back to 15.**

1b) Transmission rates from mosquitoes to humans is also highly temperature-dependent, and in laboratory studies has been shown to range from 25% to 95% over a temperature range of 20º to 35ºC. Set the transmission rate (t) in the model to 0.25, 0.5, 0.75, and 0.95, and record the VC in response to each. **Before moving on, change ‘t’ back to 0.6.**

1c) Mosquito populations increase with increasing urbanization, as there is more trash and containers which collect rainwater and make suitable breeding habitat for mosquitoes. You can simulate this by increasing the number of female mosquitoes per human (m) from 1 to 5. **Before moving on, change ‘m’ back to 1.**

1d) In reality, temperature affects both incubation period and transmission rate simultaneously, and urbanization is going on at the same time. To simulate conditions in the year 2050 (not very far off), set the incubation period to 12 days, the transmission rate to 0.75, and the # mosquitoes per person to 5.

<u>Part 2: Modeling an outbreak</u>

In this section we’ll see what happens to the human population once an epidemic outbreak occurs. We’ll start with a population of 1,000 people, who can be divided into four categories: susceptible (never had the disease), infectious (currently has the disease and can transmit it to mosquitoes), recovered (no longer has the disease, and now immune to it), and dead (pretty self-explanatory). The parameters that control how someone moves from one category to another are the <u>transmission rate</u> (from susceptible to infectious), <u>recovery rate</u> (from infectious to recovered), and <u>death rate</u> (from infectious to dead). The “Alive” category includes everyone who is not “Dead”. We will run the model for one full year. **For Part 2, complete the line graphs in the ‘Sample Graphs’ worksheet.**

<u>Simple outbreak (**“Outbreak” tab**)</u>: At the beginning of a new outbreak, the entire population is susceptible. Typical parameters are a daily transmission rate of 0.04, recovery rate of 0.1, and death rate of 0.0001 (because the first infection with dengue is very rarely fatal). Record how many people fall into each of the S, I, R, and D

categories on the Sample Graphs table. Record these data as decimals out of 1,000 people, so 50 = 0.050, and 500 = 0.500. In addition, record the actual number of deaths in Sample Graphs Column G.

Outbreak of multiple types: What happens when a new *type* of dengue virus is introduced to an area? If the human population has already been exposed to type 1, they are therefore immune to this serotype. However, they are still susceptible to types 2, 3, and 4, and have a higher risk of developing dengue hemorrhagic fever instead of just regular dengue fever. Thus, death rates for this new epidemic are much higher. With the best of medical care, about 1% of people with DHF die; often the death rate is closer to 5% because health care is not readily available to everyone. During major epidemics hospitals and doctors are often swamped with cases, and many, many people are left without basic medicine or supportive care. This is particularly true in developing countries where resources are limited to begin with. Death rates from DHF can approach 20% in some cases. Continue filling in the values for the S, I, R, and D state variables in the "Multiple Outbreak Conditions" section of the graph (increase the death rate to 0.01, 0.05, 0.08, 0.10, 0.12, 0.15, and 0.20). Use the data in the completed table to consider the meaning of your results in Part 2.

Part 3: Preventing epidemics

There are many different ways that have been attempted to prevent or mitigate dengue outbreaks. Your background readings discuss many of these options, as well as their relative success as they have been implemented. In this section, you will describe **two ideas or strategies** to reduce the severity of dengue. Think about how these strategies might change either vector capacity or the spread of an outbreak. Once you have decided how to simulate your options, compare them to the part 1-1d 2050 conditions or to the part 2 outbreak model by having a death rate of 0.08. Throughout this discussion**, refer to the background readings** to support your rationale for implementing a given strategy and the parameter values you chose to change. Create a graph or graphs that provide a comparison of your two chosen strategies.

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