Introduction to Mathematical Modeling

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Project 4 Introduction
The Joshua Tree is one of many plant and animal species that are believed to be struggling as a direct result of climate change. Environmentalists are worried about the decline of the Joshua tree both because of the record breaking five year California drought and due to extreme wet years between droughts. Here is some information about these beautiful desert plants and the system you are modeling:

- Assume that you are modeling a closed area currently containing 20 mature Joshua Trees. We choose a small number here to keep your spreadsheets reasonable.
- The Joshua Tree takes 50 to 60 years to mature and which point it produces seeds and have a very low death rate in normal to good conditions.
- They bloom only sporadically and seeds can drop from the blooms to become a new tree. The probability of blooming depends on the weather. It is believed that they bloom only when stressed, meaning when temperatures are below freezing or when there is a drought. In the absence of freeze or drought only a small number of trees will flower and create seeds.
- They reproduce from seeds, which have a very low germination rate. Like most desert plants, their seed germination depends on rainfall and temperature at the proper time. Seeds germinate best in 60-70 degree temperatures under somewhat wet conditions. They can also send up shoots to form a grouping of trees from the same root system, but we will ignore this in our model
- Lack of water (below average rainfall) stresses existing trees and increases the death rate.

Information about Joshua Tree weather can be found here:

https://weatherspark.com/y/2133/
Average-Weather-in-Joshua-Tree-California-
United-States-Year-Round

Your goal is to build a simulation for the life of the Joshua Tree. You will have to keep track of the age of your trees. You will have to create equations that decide if the trees live, are old enough to create seeds, or die. You will also need to keep track of the number of seeds available and the chance for a new tree to be “born”. Finally you will need to keep track of “weather changes” by updating probability distributions in a logical way. There is a lot to keep track of here! This is by far our most complicated and open ended project of the year. Please start early with a simple model and some data analysis.

Here are some numbers and information to get you started.

- Under "Normal" conditions here are some numbers for the Joshua Tree:
  - Germination Rate α is small. Maybe only 1 out of every 1000 or so seeds germinate to create a new tree.
  - Death Rate d_{J_T} for Joshua Trees is small, if they can get established they live a long time. Maybe only 1 out of every 400 trees would die naturally in a given year.
  - Under normal conditions only a few trees will produce blooms. So the probability of blooming P_f is something like 2 out of 45 trees.
  - If a tree blooms in a normal year, it will create between $B = 1$ to $B = 3$ blooms and each bloom will have $F = 24$ to $F = 46$ flowers. Each flower, if pollinated, creates a fruit that contains many seeds, I can't find a good source on this number but we can assume $S = 10$.

- Under "Normal" Conditions, here are some ideas for modeling the Seeds:
  - The seeds are allowed to survive from year to year, but some do become so damaged that they will never again germinate. You can think of this as a seed death rate d_s. In normal years let's say this rate is $d_s = .5$ meaning that half of the seeds remain from year to year.
  - The germination rate is small as we stated above, but seeds that germinate are removed from the seed population.
  - The "growth rate" of seeds would depend on how many Blooms are available. The maximum growth rate of seeds would depend on the number of seeds per flower and the pollination rate of the seeds so $R_S = SP$ where we said that $S = 10$ and we can assume that under normal conditions $P = .8$. You might have to add an IF statement to make sure that the number of seeds can't exceed the number of seeds available in the blooms and if you want more complexity maybe there is a logistic relationship here.

- Now what happens in NON-NORMAL YEARS?
  - The temperature will effect the blooming rates. You can assume that if the area gets temperatures below 32 degrees Fahrenheit then it increased the probability of flowering

    $$P_f = \text{normal probability} + P_{\text{cold}}$$

    We will have to make up a number for this, but maybe $P_{\text{cold}} = .3$.
  - During drought, when the trees are stressed and believe they will die soon, they are more likely to flower. This happened when we had very dry years in 2015/2016. Here we would have

    $$P_f = \text{normal probability} + P_{\text{dry}}$$

    Again we have to make up a number $P_{\text{dry}} = .3$
  - During drought the death rate of the trees is increased. How much of an increase depends on how dry it is. You should come up with a function that tests how far from average precipitation the given year is and then converts that into an increase in the death rate of Joshua Trees d_{J_T}.
  - You could imagine that the weather would also effect the seed germination rate α. Dry years would mean way fewer seeds are able to germinate, wet years would mean that more seeds can germinate.
  - The maximum temperature and precipitation might also effect the death rate of the seeds s. If it is extremely hot and dry the seeds dry up or if it is very wet the seeds rot.

I would suggest the following steps:

1. PART 1
   (a) First get some weather data for Joshua tree and decide how you will simulate weather, especially rainfall and temperature, for each year in the simulation.
   (b) Next, decide which of your parameters should be stochastic and which just set to specific values.
   (c) Then build a stochastic model for the mature living trees from one year to the next. This spreadsheet should also keep track of the number of seeds that the trees produce (also based on stochastic weather). Don't yet add in the idea of new trees being born. There are a lot of ways to do this, but if you feel lost to start, look back at our stochastic squirrels model.
2. PART 2
   (a) After you have the basic model working, then add in the ability of the seeds to germinate and create new trees. You will need to create the trees! If you are following the squirrels model, you might have some empty spaces (rows/columns) where the new trees can start their life and you can keep track of their age so you know when they can begin creating seeds.
   (b) Double check that this model is running by setting parameters to zero and making sure the results make sense.
3. PART 3
   (a) Next you should simulate multiple years and gather data about what your model tells you for the baseline case. Remember you should do multiple runs and average the results.
   (b) After you are happy with your baseline model, then run a few simulations that would represent climate change. What would happen if the average temperature went up or the chance or prolonged drought increased?
   (c) Finally analyze your data and tell a good story about the future of the Joshua Tree.

   HINTS:
   * You can simulate climate change by either making the standard deviations larger to model fluctuations, or sliding the averages up to model temperature change.
   * Because we are "making up" many of our parameters you should test how sensitive your model is to some of those assumptions. Remember that every time you change a parameter you need to do multiple simulations before you can analyze the results.
   * At first build your model really small just for say 10 or so years and 10 trees. Once you are convinced it is working you can expand the number of trees and years to get a better long term statistical sample.

LA Times Article: Drought hastens decline of the Joshua tree, California's desert symbol, 2015

Under canopies of dead angular branches and drooping fronds, UC Riverside ecologist Cameron Barrows made his way across a forest of skeletal Joshua trees that have not reproduced in decades.

As Barrows explained, it's a tough time to be a Joshua tree. Climate change is taking an enormous toll, and the current drought has hastened the decline of a species that is regarded as the symbol of California deserts.

"For Joshua trees, hotter, drier conditions are a problem — but a bigger problem is that what little rainfall occurs evaporates faster," Barrows said. "So, seedlings shrivel up and die before they can put down strong roots."

The region, including nearby Joshua Tree National Park, has not reached average precipitation rates of about 4 inches in several years. So far this year, it's gotten 1.71 inches of rain.

If warmer, drier conditions continue in the coming decades, scientific modeling suggests the trees will lose 90% of their current range in the 800,000-acre park by the end of the century.

With funding from federal wildlife officials, Barrows is trying to find ways to assess the effects of climate change on Joshua trees and the many species they shelter: yucca moths, skipper butterflies, termites, ants, desert night lizards, kangaroo rats and 20 species of birds including Scott's orioles, ladder-backed woodpeckers and great horned owls.

There is more at stake than the fate of the park's estimated 2.5 million Joshua trees, said biologist Rebecca R. Hernandez, a post-doctoral fellow at UC Berkeley. "Beyond its importance as a critical refuge for desert species, the Joshua tree is a cultural signature of California's desert landscape," Hernandez said.

Joshua trees, which grow in the Mojave Desert and nowhere else, have become mainstays for movies, fashion shoots, advertising campaigns and wedding ceremonies. The one that adorned the cover of U2's 1987 album "The Joshua Tree" became a pilgrimage site for fans from around the world until it was blown over by strong winds in 2000.

The species scientists know as Yucca brevifolia isn't actually a tree; it's a succulent. Joshua trees grow to 40 feet high, live more than 200 years and bloom sporadically. In 2013, extensive stands were festooned with yellow and white bell-shaped blossoms that drew tourists eager to take in the scenery before the bloom wilted in the harsh desert sun.

They were named for the biblical figure Joshua by members of a band of Mormons traveling through the Cajon Pass back to Utah in 1857. They imagined the trees as shaggy prophets, their outstretched limbs pointing the way to their promised land.

During the 1980s, development in desert boom towns such as Lancaster and Palmdale replaced about 200,000 Joshua trees with housing tracts and shopping centers. Many more were removed over the last decade to make way for renewable energy facilities.

In the 1990s, moist El Niño conditions triggered explosive growth of exotic grasses among the trees. Feeding off nitrogen-laden smog wafting in from Los Angeles, the grasses have established themselves, leaving Joshua tree forests vulnerable to large-scale brush fires such as one that charred 14,000 acres in 1999.

Now, the biggest threat is climate change, which most of the trees may not be able to overcome. The globe's average temperature is expected to rise roughly by an additional 5 degrees to 7 degrees Fahrenheit by the end of the century, scientists say.

Computer models depicting the distribution of suitable habitat after a roughly 5-degree Fahrenheit rise show Joshua trees retaining just 2% to 10% of their current range, according to studies led by Barrows and published in the scientific journal Biological Conservation.

"Since they grow for about 200 years, we won't see massive die-offs in our lifetime," park Superintendent David Smith said. "But we will see less recruitment of new trees."

In a collaborative effort launched this year, the park, the U.S. Fish and Wildlife Service and a research team led by Barrows organized the first long-term project designed to monitor the Joshua trees' responses to climate change and drought.

The data, collected with help from volunteer citizen scientists from the nonprofit group Earthwatch, will create baseline information to help guide conservation decisions as Joshua trees retreat to cooler and wetter higher elevations. The group has also established monitoring stations to gauge changes in the distributions of Joshua trees and species they support.

Will the region have to change its name one day to, say, "Creosote National Park"?

"Nah," Barrows said with a smile. "There's still going to be enough Joshua trees around here and there."

Barrows scanned the drought-stricken Joshua tree woodlands for signs of new life. Minutes later, he spotted a knee-high bouquet of dagger-like leaves.

"Look here, a baby," he said, smiling down on the Joshua tree he estimated was about 10 to 15 years old. "Will it survive? Depends on how much rain we get."

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