POPULATION MODELS

Demographic Stochasticity: Roc Demographic

Terri Donovan

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In this exercise, we're going to show how you can model a population that has demographic stochasticity. And Tony already talked to you about the problem that the rocs are facing when their population size gets down to a very low number. And so we're going to try to model that by modeling the behavior and the reproductive success of individual rocs rather than the population as a whole.

So remember in the last exercises for rocs, we said that the average population had a birth rate of 1.06 rocs per breeding adult. When population size gets small, you need to think about how to model that differently than when you have very large populations and the laws of averages kicks in. And so let's set up a model where we're modeling the behavior of individuals rather than thinking about the population as a group or a unit.

Let's start our spreadsheet by entering some of the terms that Tony mentioned in his lecture. We indicated that a survey of 100 nests was done, and we recorded the number of eggs for a whole bunch of different nests. And we found that we surveyed nests, and 12 nests had 0 eggs, 70 nests had 1 egg, and 18 nests had 2 eggs. And those are our data, and that's what we're going to work with, to build this particular model. Those are the only data that we actually need. So let's make those headings and underline them, and we're going to shade those green because those are the inputs for this particular model.

So first thing we want to do is to calculate what is the probability that a nest will have 0 eggs, 1egg, or 2 eggs. And we can do that by first calculating our total sample size, which we'll do in cell B7. Simply select all of the nests that's our sample size and then move up and select the SUM function. And we see that our sample size is 100 nests.

Now we can compute the probability that a nest will have 0 eggs. The probability that a nest will have 0 eggs is simply the frequency of nests with zero eggs divided by our total sample size. And I'm going to copy this formula down, and so the reference in cell B7 must be anchored, and we'll go ahead and do that by clicking in the Formula bar and pressing the F4 function key. So there we have our probabilities. These are outputs of the model taken from the data here. I'm

going to go ahead and shade these in a color blue so that we're not confused by entering information there.

Now our goal here is to simulate the actual number of eggs that each roc has and not use the law of averages as a population-level rate. So remember populations have rates. There's a group of 100 rocs, and we calculate how many offspring they all have - we can know what's the number of offspring for that entire population. But an individual does not have a rate. An individual roc can produce 0, 1 or 2 eggs, and that's it. And so when we talk about individual-based modeling, we need to record what happens for each individual rather than for a population.

So we're going to start, by first doing a little trick that we need to do, which is to help us to identify whether an individual has 0, 1, or 2 eggs. And we're going to use this sequence of numbers here. And Tony also alluded to this in his lecture. He said if we draw a random number that's between zero and .12, then that animal's going to have 0 eggs. And, if we draw a random number between .12 all the way to .82, then the animal will produce 1 egg, and then anything over that, the animal will produce 2 eggs. And those are called **Cumulative Probabilities**. And we're going to go ahead and enter those in column D. And we're going to use - just to add up these probabilities and to cumulate them down the column - and we're going to just do that with the SUM function. And we're going to enter a sum. And we're going to start with the first cell. And we're going to go ahead and close the parentheses on that. And that might look funny, but this is, in fact, how we want to accumulate things down the column.

So this formula says: 'sum cell C4 through C4' =sum(C4:C4). We're going to start at the top with C4. So we're going to anchor that first thing. And, as we drag down this column, we can see that the Cumulative Probabilities are calculated for us. These are also outputs so, again, I'll shade those in blue. And let's go ahead and center these.

Okay, so this should look somewhat familiar to you. Let's just think about what these mean once again.

If I have an individual that's breeding and I draw a random number, what I need to do is to look up this random number in the sequence here. And, if the number is between 0 and .12, it's going to return 0 eggs. If the number is between .12 and .82, that individual will have 1 egg. And, if the number is between .82 and 1, the individual will have 2 eggs or two offspring. Now in order for this to work, I need to start my cumulation with the number 0. And I'm going to enter

that into cell D3 and shade it and center it. And this is going to be our lookup area. We're going to look up a random number within this particular **Sequence of Ordered Data**. Let's see how that looks.

Let's set up an example of an individual, and we'll call this individual 'Individual 1'. And we'll give this individual a random number. And we'll enter the random number function in cell B10. And, from that random number we need to calculate how many offspring it will have. Okay? So these are column headings. Let's go ahead and make those bold and underline those.

So let's walk our way through this. This is going to be using a **Lookup** function, and we'll go ahead and use the function key to do that. We're going to look up this individual's random number within this vector of occurrences that are ordered. We're going to find where that particular random number falls within this sequence, and then, given that result, we're going to return the number of eggs that that individual has. Let's do that with the Lookup function. Go to the Lookup function key, and this is called a Lookup function so let's go ahead and find that by typing in an "L" and then scrolling down until we find Lookup.

This particular function has two kinds of syntax. And the first one is, 'Look up a value in a lookup vector and return the result from a result vector'. And that's the one we want so select that option and press OK. And it opens up a dialogue box. So let's walk our way through this. We want to look up the random number associated with Individual 1 in this vector of Cumulative Probabilities. And remember here, the key here, is that this is a range that contains only one row or one column of text numbers or logical values and they are placed in ascending order. And once it finds where it falls within this ordered matrix here, or ordered vector, we're going to return the result in cells A4 through A6, which is the number of eggs. Press OK. And we should be able to now check to see if this function is working correctly.

So let's try it out. Our random number is .07. We find where that falls in this Array. It falls between zero and .12, and so the function is returning 0 eggs.

Let's press F9 to get a different random number. The next random number is .46. Let's look down this value. We find it falls between these two numbers. The spreadsheet's going to return the number associated with the bottom number or 1 offspring.

Let's try another one. This number is .82. We look it up in this vector. We find that it falls between .82 and .1, and so the spreadsheet's going to return that this particular individual has

two offspring.

So that's how that particular function works. And we're going to copy this down for many, many individuals, just to see if we have a population of 50 individuals. Each one having a probably of 0 eggs as .12 and a probability of 1 egg as .7 and a probability of 2 eggs as .18.

What would those individuals have, in terms of offspring? And remember, with any kind of individual-based model we're actually measuring, not a population average, but what is the outcome for that individual. So in terms of births, an individual can produce 0, 1 or 2 offspring. And those are the answers we're dealing with. And, if we were looking at survival, an individual could either live or die. So we're not talking about rates for a population - we're talking about the actual performance of an individual.

Now in order for me to copy this down, the first thing I need to do is to anchor parts of this formula because I'm always going to be referencing these two vectors. And so let's go ahead and put absolute references on the particular cells used in this formula, and then press OK.

And let's simulate 50 different individuals. So we'll start a sequence from 1 and 2, and let's drag that all the way down to 50. If you're ambitious, you can drag it down to 100 or more. And then let's give a random number to each of those individuals and copy the number of offspring that those individuals have. So grab both cells B10 and C10, and then grab the Fill handle and pull it down.

And now I am doing some **demographic modeling with demographic stochasticity**. Every single individual in the population has a random number, and we are using this random number to give us a result of how many offspring each produces.

In order for us to model the roc population, we're going to use another trick. And we're going to cumulate how many offspring there are by entering the word Cumulative Offspring. And we're going to use a formula similar to what we had done previously. We're simply going to tally how many offspring there are - if the population consists of 1 individual, if the population consists of 2 individuals, if the population consists of three individuals. So let's go ahead and use a SUM function, and we'll start that tally and anchor the first reference within that particular formula. Press the Enter button, and then drag it down.
So let's now refresh ourselves quickly by reviewing what this actually means. If our population had one individual and, by chance, its random number was close to 0 and it produced no

offspring, then the offspring for that population was 0. If our population consisted of 5 individuals, each of them reproducing with demographic stochasticity, according to this set of random numbers. Here are the number of offspring produced by each of those 5 individuals, and the cumulative total is calculated as 3. Individual one produced 0 . Individual two produced 0 offspring. Individuals three, four, and five each produced 1, and so our Cumulative Offspring is 3. If our population had 10 individuals, then for each of those individuals, cumulating across them we have 10 offspring. And we're going to use this grid right here to help us track the dynamics of roc populations as we model them individually. So let's do that now.

We're interested in simulating a population from the year 1000 all the way to the year 2000, sticking with our increments of 100 years. So we'll start a series that begins with 1000, and we'll go ahead and enter the year 1100, and then copy that down until we get to the year 2000. Because, after all, that's what the caliph is most interested in.

And what we're interested in recording is the number of rocs that are living in each of those time periods. We said that our first population in the year 1000 drops down catastrophically to 5 rocs. And we're interested now in projecting how the population will project over time and what that ending number will be in the year 2000. And so this is an example of a model that's going to include demographic stochasticity.

Let me go ahead and underline the column headings. And so let me just talk you through how we could set this up. We start off with a population of rocs, and there's 5 of them in the year 1000. I want to grab new random numbers - a new set of random numbers for that particular century - and then those 5 individuals are represented by these numbers here. Those 5 individuals, according to this set of random numbers, produced a total of 6 offspring. And so we want the number 6 to go right there. I'm going to go ahead and enter the number 6 just for the sake of demonstration.

Then, in the next time step, we want to set new random numbers. The new random numbers pertain to those new individuals in the next century, and those are 6 individuals. And those 6 individuals cumulatively produced 6 offspring, and so that number would go there. So that's the basic idea of how our population model is going to be working. Now we don't want to do this tediously step-by-step. And one of the values of computers is to have the computer do all that work for you.

So let's go ahead and enter the word Year t in cell F6. And we're going to start with the number 5, and we'll enter Year t + 1 in cell F7. And that's what we're going to be calculating.

So let's go ahead and wipe this out. And right here we need a formula that's going to say, 'If I started with 5 individuals, what's my population size going to be in the next year?'

Can you think of a formula that might do that?

There is a really nice formula in Excel that's called the **VLOOKUP** function. Very similar to the Lookup function that we used, but this is for a group of contiguous data. And V stands for vertical. And we'll show you how that works right now.

So go up to your Insert function key, and we're going to be looking for the VLOOKUP. Sso type in the letter 'V'. And then scroll down until you find it - there it is. And this particular function has number of different Arrays, different arguments, that need to be entered into the function itself.

The first argument is the Lookup value, and what we want to do is look up the population size. The next argument says, 'Well, where's the table where you want to look this thing up in?' And we want to look it up in this table over here. This table that begins with cells A10 and drop it all the way down to your 50th animal. So our whole table is in the Table array from A10 to D59.

Now the thing about the VLOOKUP function is, this value needs to be in the first column of this table. And so when it finds cell 5, it's going to find the number 5, and then we want it to return how many offspring those 5 individuals had. And so we need to return the value in the first, second, third, fourth column. And that's our fourth column index, and that goes right there.

The Range lookup is the final argument in this function. And we'd enter the word True or False in this particular argument. And, if we want to find an exact match, we need to enter the word 'False', and so I'll enter that now.

So you can see from this particular example if our population starts at 5 individuals in the Year t, we then find the number 5 here, and then we say how many individuals were cumulatively produced by those 5 individuals and return that number. Press OK when you're finished. And we get our answer in cell G7.

Now every time you press Enter or Calculate, these new random numbers will be calculated, and so your answers might change. So if I start off with 5 individuals and I press F9 and get new random numbers - watch the result here in cell G7. And that is demographic stochasticity

at work. It's the random chance that individuals will vary in what their reproductive effort is, or their reproductive success. And it's including a random number function that lets us know that not every animal will do well. Some will produce 0 eggs, some will produce 1, some will produce 2, but it's a random draw according to these Cumulative Probabilities that we have in D3 through D6.

Okay, the next thing we want to do now is use this set of values here to go ahead and fill out our population projection. And we're going to do that by using a macro.

So what we have here is a sequence of years from 1000 to 2000, and we start off with 5 rocs in the year 1000, and our goal is to know how populations will change through time. And so we start off with this entry here [G10] - I've also entered it up here [G6]. We're going to let those 5 individuals reproduce. Each of them has a random number, and, given that sequence of random numbers, they each produce offspring. The cumulative number of offspring is then given right here, which is depicted in cell G7. And what we want to do is to record a macro that will take that information and pop it down into the next generation. And then also record that number here [G6] to the Year t, so that the generation after that can also be computed.

So in order for us to do this, we need to use a macro, and so go to your View tab, and then select Macro / Record Macro. Give your macro a name. And let's call this ‘Population Dynamics’, or ‘Population Simulation’. Whatever you want to call it is fine. And I'm going to add a button to the spreadsheet because I can never remember the shortcut key.
Okay. Now any clicks that we make or any entries that we make on our spreadsheet will be faithfully recorded by the macro. And, what we need to do in this particular case is - because everything is controlled by these random numbers and because every time you press an entry within Excel the spreadsheet calculates - the first thing we need to do is to change how the spreadsheet calculates its information. And you can do that by going up to the Formulas tab. And then scrolling over to the Calculation Options and changing it from automatic to manual. And what that does is, it requires you to press F9 in order to have the spreadsheet calculate. And this is required because otherwise we'll end up out of sequence with what we're simulating.

The first step then actually is to press F9, to get a whole set of new random numbers. We start off with 5 animals. We let those five animals reproduce. They each produce offspring

according to the random number that they're associated with, and we find that those 5 animals produced 6 offspring. Your numbers will look different than mine, no doubt.

What we want to do is select that number in cell Year t+1. And go up to the Copy function, it's on the home page. Select Copy and then drop down to the word rocs in cell G9. And then go over to the Find and Select button. And we're going to Find the next blank cell within this particular column. It's within a Sheet, and make sure that this Search: By Columns option is selected. And then select Find Next. Keep this cell blank because we're interested in finding a blank cell. It drops down to the next blank cell. Then we press Close. And now we want to paste that number 6, and so go up to the Paste, drop it down, and select the Paste Values option. We're not done yet. Now we need to say we're at time 6. And so we're going to let this be Year t. And so select cell G6, and paste that number 6 in one more time by pasting its values. And that's basically it. Go back up to the View tab. Go to Macros / Stop Recording.

Okay? Now I'm going to go ahead and add a little smiley face to run my macro for me. So click on the Insert and then a Shape. And you can choose any old shape that you want. And put it on your paper, or on your spreadsheet. And then right-click on that, then assign that a particular macro. We called that Population Simulation. Press OK. And now, when we press on the smiley face, the macro will run, and we'll be able to run the results for many different generations over time. So let's just see how this works.

Now I'm at year 6. I find those 6 animals should get a brand new set of random numbers, let's do that. Those 6 animals produced 7 offspring. And so that number was calculated right there [G7]. And the number 7 was copied here [G12]. And it was also placed immediately into cell G6 So, it happens very quickly. Let's run it again.

Now we have 7 individuals. It's going to record new random numbers. New random numbers - we had a population of 7. We drop down to those 7 animals, and we find that those 7 animals produced 7 offspring. And so that number was recorded, and the next time step is recorded right here [G6] as well. So that's basically how our macro runs. And we can go ahead and press our smiley face through time. And we end up with 10 individuals for that particular simulation.

Now it would be wise for us to do this many, many times. Let's go ahead and wipe this result out and run our population again. We're going to start with 5 animals. And what I want to do is go back and have the Calculate key switched back to automatic calculation. So we do that in Formulas and set our calculation back to automatic. Remember, in the macro, the first thing it's going to do is to turn it to manual calculation so you don't need to worry about that.

So let's go ahead. We've started off with 5. I've pressed F9 now. In the next time step I've got 7 animals, and that number is going to go there [G11]. So let's go ahead and just run your macro one more set of times. And, in that particular set of sequence, we ended up with 6 rocs. Let's try it one more time. Delete your animals. Have your starting population be in Year t, and run your macro. And this time we ended up with 6 animals.

What you need to do with any of these stochastic runs is to do this many, many times, and each time you want to record your final result. And that allows you to get a sense for what the variation in these final numbers might be. You certainly don't want to run this kind of model one time and report back to the caliph that the answer will be 6. Because there's so much stochasticity involved.

That's what we're really interested in is - if, we really have only 5 rocs, could there be a possibility that the roc population would go extinct? And what is that population? Can we put a number on that extinction probability?

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