# **A Simulation Analysis of Population Dynamics**

**Introduction:**

By now you should know the characteristics of two types of scientific studies: descriptive and experimental. Descriptive studies detect and describe patterns in nature but do not test hypotheses. Experimental studies (either comparative or manipulative) always test hypotheses. A third type of experimental study is **modeling** or **simulation analysis**. Simulation studies involve mathematically modeling populations, communities, or ecosystems to test specific hypotheses and/or to describe patterns.

As the name implies, **models** are always a simplification of nature just as are model airplanes or architectural models. Because of overwhelming complexity, a population model will never include all of the natural factors that may influence a particular population. However, if such a model includes the major factors and processes, it can be useful for making predictions and testing hypotheses. If you know a population well enough to model it and to make verifiable predictions, you probably understand a great deal about the population.

You will be completing computer exercises that will provide you with the technical skills necessary to model populations. You will first use data for the Florida scrub lizard to make predictions about the **extinction probability** of particular populations. You will start with basic **life-history** data and estimate fundamental population parameters. Then you will progress through **exponential growth**, **logistic growth**, and **stochastic models**.

The Florida scrub lizard is an endemic species of central, peninsular Florida that inhabits threatened Florida scrub habitat. As the only areas of upland and dry conditions in an otherwise swampy state, the Florida scrub is threatened by development for housing, shopping malls and orange groves. Scrub lizards serve as an indicator species and help land managers decide which properties to purchase for the purpose of maintaining a refuge of biological diversity. If we can understand the size and characteristics of scrub patches that sustain viable populations of scrub lizards, we can prioritize the formation and management of a wildlife refuge system. Modeling can help us make such management decisions.

**Skills:**

1. Use EXCEL to calculate basic parameters: For example, calculating r from life history data.
2. Use EXCEL to create discrete functions and graphs that represent continuous functions: For example, estimating exponential and logistic population growth.
3. Use EXCEL macros to create stochastic effects in deterministic functions: For example, estimating the probability of extinction.

# **Materials:**

* Access to WORD and EXCEL
* EXCEL file named *Scrub Lizard PVA*

**Exercise 1- Using EXCEL for Basic Parameter Estimates**

**Background:**

We have reviewed papers in lecture that estimate **vital rates** (survivorship and fecundity) for species. Often, vital rates depend on the age of the individual. For example, young individuals may have lower survivorship and may not reproduce at all (e.g. humans are not capable of reproducing until the age of 14-15). A **life history table** is a table that summarizes the age specific vital rates for a species. A life history table provides necessary information for estimating how populations grow, decline, fluctuate or remain the same. For example, a population’s per capita rate of increase (r) can be estimated using life history tables:

r = (lnRo)/T,

where T, the generation time = ∑xlxmx,

Ro, the net reproductive rate = Σlxmx,

X = age,

lx = the proportion surviving for age cohort x and,

mx = the average number of per capita progeny for cohort x.

**Laboratory Procedure:**

1. Open the EXCEL file named *Scrub Lizard Population Viability* available on the MOODLE site. In table 1 (the worksheet labeled *scrub lizard data*) you will find age specific survivorship and fecundity estimates for 8 different populations of scrub lizards. I have organized the data so that they are organized from smallest to largest scrub patches. I have already used this data and the calculator in table 2 (the worksheet labeled *Life Table*) to calculate r for patches g, a, f and h. You will estimate r for the remaining 4 populations.
2. Begin with patch d by entering Sj for patch d (0.15) into the S column for age 0 (cell B4). This is the estimated survival probability for all lizards in their first year in patch d. Next, enter the Sa for patch d (0.09) into the S column for age 1 (cell B5). This is the estimated survival probability for all lizards after their first year. Thus, the adult survival estimate is the same for lizards 1, 2, and 3 years old and you can enter this probability in the S column for each corresponding year (cells B6 and B7). With over 3000 lizards marked and recaptured in our study, we never found a 4 year old lizard. Therefore, we always assume that 4 year olds have 0 probability of surviving to the 5th year and you can enter a 0 in the S column for age 4 (cell B8).
3. Next, enter the fecundity data for patch d in the Mx column. Juvenile lizards (age 0) never produce progeny and you can enter 0 in the Mx column for age 0 (cell E4). Also, one year old females are smaller and produce fewer progeny than older, larger females. Our estimate for Fa1 for patch d is 4.9 and you can enter this number in the Mx column for one year olds (cell E5). Our estimate for Fa2 and Fa3 is the same (5.8) and you can enter this estimate in the Mx column for the 2 and 3 year olds (cell E6 and E7). Because we never had a 4 year old lizard, enter a 0 in the Mx column for 4 year olds (cell E8).
4. Now select the F9 key which results in the computer calculating r for patch d. Note that it does so by first calculating R0, then T, and finally r using the equations I’ve provided above. Enter the estimated r value for patch d in the lower portion of table 2.
5. Repeat steps 2-4 for patches b, e and c. For your homework, create a table in WORD and enter the patch name and estimated r for each of the patches.

**Exercise 2- Estimating population growth with an exponential growth model**

**Background:**

Although (for reasons we will discuss later) exponential population models are unrealistic, they are useful for estimating the growth potential of a species. For example, if we could imagine a population of a species with unlimited resources and no predators or pathogens, how fast would it grow?

The exponential growth rate of a population can be modeled using either the discrete equation Nt = N0ert, where:

Nt is the size of the population at time t,

N0 is the original population size, and

r is defined as above.

Alternatively, we can use the calculus (continuous) form of the model dn/dt = rN. For **discrete models**, the breeding seasons do not overlap and, often, the generations do not overlap. For **continuous models**, reproduction can occur at any time of year. We will use discrete models because, a) many organisms reproduce on a seasonal basis, b) discrete models are much easier to build using EXCEL, and c) discrete models are easier for people (students) to understand.

**Laboratory Procedure:**

1. I have already created the discrete model in the EXCEL file in table 3 (worksheet labeled *Exponential Growth*). To use this model, simply enter in the value for the two constants N0 and r and then select the F9 key to calculate the population size for the next 50 years. The calculations are automatically plotted in the corresponding figure.
2. For your homework, create a table in WORD that provides answers for the following questions:
	1. Use r for patch h (0.32) and assume a starting population of 100 lizards. What is the final population estimate at year 50? Note: instead of trying to read the estimated number from the y-axis, you can get the exact estimate by holding the cursor arrow over the top of any data point on the graph. The x (time) and y (abundance) number will be displayed in a popup.
	2. What is the final population estimate if you begin with 10 lizards?
	3. Assuming an initial population size of 100 lizards, use r for patch g (-0.48) to estimate the population size in 50 years.
	4. What is the final population size for patch g if the initial number of lizards is one billion (1,000,000,000)?
	5. If you have an initial population of 100 and an r of 0, what is the final population size?
	6. What if you have an initial population of 100 and an r of 0.1?

 **Exercise 3- Estimating population growth with a logistic model**

**Background:**

**Exponential** models (e.g. exercise 2) of population growth are useful for revealing the growth potential of a population. Populations with high growth potential will reveal a steeper exponential curve than will populations with a low growth potential. However, such models are not very realistic because they assume a population will grow indefinitely. Rarely do populations grow at a rate equal to their biological potential. Sooner or later resources (food, water, shelter, mates, etc.) become limited and a smaller proportion of individuals are able to survive, grow, and reproduce. Populations will stop growing resulting in **logistic type population** growth. The mechanisms that slow population growth include increased mortality (decreased survivorship) and decreased fecundity. Although populations may stabilize (or fluctuate in a cyclic manner) they cannot exceed the carrying capacity of the environment without experiencing extreme changes in survivorship and fecundity. We can model resource limitation by including a factor known as the **carrying capacity** (K). Carrying capacity represents the maximum population size a particular environment can support. We can incorporate carrying capacity in discrete population models by including the component K in the discrete form such that: Nt = K/1+[(K-N0)/N0]e-rt.

Although including K provides a more realistic model, it presents the problem of estimating the carrying capacity of a particular environment. In practice, this can be very difficult to do. Furthermore, carrying capacity may fluctuate across time or be influenced by factors such as patch size. Although it is intuitive to assume that larger patches have larger K’s, the difficult part is estimating how much larger. In our study of scrub lizards (Hokit et al. 1999), we observed that the lizards are very dependent on the amount of open sandy habitat within a scrub patch. Because scrub lizards are sit-and-wait predators, they need to sit at the edges of open sand, under the protective cover of shrubs, and pounce on any wayward invertebrate that travels across their patch. We were able to use infrared aerial photographs and geographic information systems (GIS) to estimate the amount of open sandy habitat in each scrub patch. The data are presented in table 1 and you will see that I have provided a regression analysis that reveals the density relationship between the amount of open sandy habitat in a patch and the estimated lizard density (number of lizards per ha). We can use this relationship to estimate carrying capacity.

For example, note that patch h has an estimated 84.3 ha of open sandy habitat. We can enter 84.3 into our regression equation for x and calculate lizard density to be about 108 per ha. We can multiply this density by the total area of patch h (about 278 ha) and get an estimated carrying capacity of 30,102. This is the estimated maximum number of lizards patch h can support.

**Laboratory Procedure:**

1. Use the logistic model in table 4 (worksheet labeled *Logistic Model*) to help answer the following questions. Create a table in Word that lists the answers to each of the following questions:
	1. Using data for patch h and an initial population size of 100, does patch h reach K within 50 years?
	2. How many years does it take for patch h to reach carrying capacity if the initial population size is 10,000?
	3. Using the data for patch e and an initial population size of 10,000, does the population reach carrying capacity in 50 years?
	4. What happens when using data for patch b and an initial size of 100?

**Exercise 4- Modeling populations with stochastic fluctuations**

**Background:**

All of the models we have used until now have had two glaring assumptions: a) environmental conditions remain constant and b) the growth rate of the population (Ro or r) is fixed with respect to individuals. For example, if Ro = 1, on average every individual will produce one offspring and our models assume that all individuals produce one offspring. But we know that some individuals may produce one, others produce two, and still others produce zero, which average out to one offspring per individual. Furthermore, we assume constant environmental conditions and we know environmental conditions can vary from time period to time period. Thus, carrying capacity (K) can fluctuate over time. In short, our models have been **deterministic**. Given a particular set of values for an equation, you will get the same number for abundance no matter how often you do the calculation. To make our models a bit more realistic, we may wish to include random fluctuations and produce a stochastic model. **Stochastic models** include chance fluctuation in either the environmental conditions or the demographic properties of individuals.

**Population viability analysis** (or PVA) is a simulation technique that estimates the probability of a particular population going extinct. PVA uses stochastic population models and **Monte Carlo** simulation techniques that result in hundreds or even thousands of simulations used to estimate the probability of extinction. Practically impossible before computers, PVA is now a standard technique used to assess the persistence of populations.

**Laboratory Procedure:**

1. In the EXCEL file named *Scrub Lizard PVA* (available on MOODLE), I have created a model that includes chance fluctuations in r. To be able to use this model, we must have multiple measurements of r so that we can calculate a mean r and standard deviation. To get multiple measures of r, we could measure r over many years for individual cohorts and then calculate a mean and standard deviation. However, our scrub lizard study was conducted within 2.5 years and a mean r over 2 years of data would be useless. Instead, we can calculate multiple r’s separated geographically, one for each scrub patch as you did in exercise one above.
2. Going back to the EXCEL file labeled *Scrub Lizard Logistic*. To the bottom right of table 2 you should see estimates of mean r and standard deviation for the 4 largest patches and for the 4 smallest patches. Also, there should be a mean and standard deviation for all patches combined. These are the values we will use for this exercise. For each year in the simulation, the computer randomly selects an r value that is plus or minus the standard deviation of r. Most of the selected r values will be close to the mean, but not all.
3. Because the model is stochastic, the results from one 50 year simulation may not necessarily be the same for another 50 year simulation. We need to use Monte Carlo simulation techniques to be able to estimate the most probable outcome. **Monte Carlo** simulation gets its name from similar estimation techniques used to predict gambling outcomes. The method employs the technique of running multiple stochastic simulations (hundreds or even thousands) and then averaging the results. I have constructed our model so that it runs each 50 year simulation 100 times. Thus, the computer must calculate population size for each year of the a 50 year simulation using a randomly selected r value for each year and repeat each year simulation 100 times resulting in 5000 estimates of r.
4. Because of space limitations on table 5, I have created a separate figure (worksheet labeled *PVA figure*) for the 100 simulations. After running each of the simulations, check the figure so you can more easily visualize what the computer is doing within each simulation. You should see a total of 100 lines plotted in the figure.
5. For each simulation, we are ultimately interested in estimating the probability that a population will survive or go extinct within a particular time interval (50 years in our case). Thus, at the top of table 5 you will see a value labeled *p(extinction)*. This is the estimated probability that a particular population will go extinct. This type of modeling is called **population viability analysis** (PVA) because we are estimating the chance that a population will still be viable after 50 years.
6. For your homework, create a table in WORD that answers the following questions using the PVA model.
7. Using an initial population size of 10, what is the probability of extinction for a scrub lizard population in an average sized “large” patch of scrub habitat?
8. What is the probability of extinction for a scrub lizard population in an average sized “small” patch of scrub habitat?
9. Using the mean r and standard deviation for all patches, what is the probability of extinction for a patch the same size as patch b (i.e. same carrying capacity)?
10. What about the same question for patch e?