BIOL 208 – POPULATION AND COMMUNITY BIOLOGY

EVOLUTION LAB

Objectives

- To develop an understanding of the primary factors that affect the evolution of a species.
- Demonstrate the biological and environmental selection factors that influence evolution through natural selection.
- Simulate how changes in bird beak size and other characteristics of finch populations influence the evolution of finches and their population numbers.

Getting Started

Week 1 – We will first view a video entitled ***"What Darwin Never Saw."*** This excellent video, produced by Bill Curtis, will provide important background for understanding the experiments involving the evolution of beak size in Darwin's finches. Next, Professor Abrahamson will introduce you to the ***Evolution Lab* simulation model** and allow you and your partner time to conduct several experiments. Be sure to bring the *Evolution Lab* manual and the user name and password that accompanied the *Evolution Lab* bundled with your Smith & Smith textbook. This manual provides valuable background, objectives, and assignment information for our 2-week project.

Write up for week 1 due at the start of lab next week. Remember to submit an electronic copy to SafeAssign via Blackboard before coming to lab.

You need to establish your account with our textbook's companion lab site. Go to http://www.biologylab.awlonline.com/ to establish your username and password for the *Evolution Lab* web site.

Week 2 – We will begin with a presentation on ***"Galápagos: Islands in Time"*** by Professor Abrahamson. Next, you and your partner will continue assignments using the *Evolution Lab* simulation model.

Write up for week 2 due at the start of the Cladistics lab. Remember to submit an electronic copy to SafeAssign via Blackboard.

Background

The *Evolution Lab* includes seven projects focused on the evolution of beak size (i.e., the depth of the beak) in the medium-ground finch (*Geospiza fortis*). You will investigate how numerous factors affect the depth of the beak by manipulating various biological parameters (initial beak size, heritability of beak size, variation in beak size, clutch size, and population size) and two environmental parameters (precipitation and island size). By altering these parameters, you can "design experiments" to infer for yourself how these various factors affect evolution.

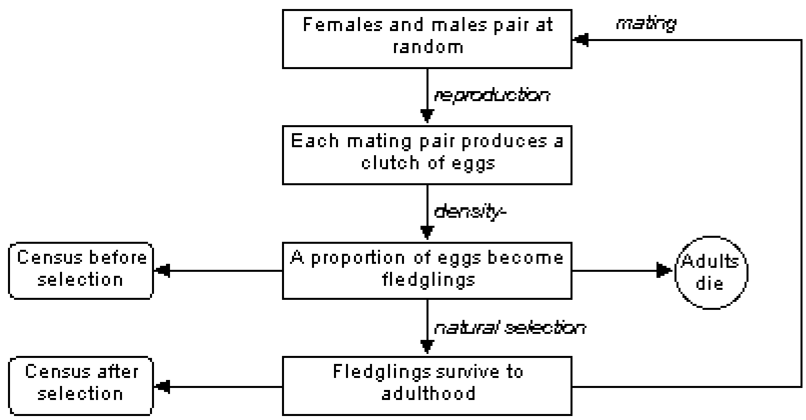
The Model

The model is quite straightforward and is based on Peter and Rosemary Grant's work that was featured in the video *What Darwin Never Saw.* Small populations of medium-ground finches occur on two different hypothetical islands – "Darwin Island" and "Wallace Island" where they feed on seeds produced by plants. Three sizes of seeds are available to the finches:

1. Plants that do best under **wet conditions** produce **small, soft seeds** – finches having small beaks best exploit this category of seed. When wet conditions predominate, small seeds dominate and finches with small beaks have a higher survival rate.
2. Plants that perform best under **moderate precipitation** conditions produce **intermediate-sized, hard seeds** – finches with intermediate-sized beaks optimally handle this category of seed. At intermediate

rainfall levels, a mixture of the three seed types are found, with intermediate-sized seeds most abundant; birds with medium-sized beaks survive best under these environmental conditions.

3. Plants that dominate during **drought** conditions produce **large, hard seeds** – finches possessing large beaks that are able to crack and open hard seeds best use this category of seed. When conditions are dry, hard seeds dominate and natural selection favors finches with large beaks.



Evolution Lab is an "individual-based" **stochastic** (i.e., chance-influenced) simulation model. Each "bird" is represented by its gender and beak size. As diagrammed in the adjacent figure, females and males mate, mating pairs form clutches of eggs, eggs become fledglings, and fledglings survive to become the next population of adult birds. The **generations** in our model are considered **discrete** – that is, the parents die before their offspring reproduce (this is a simplification as finches don't do this in nature). Each generation is "sampled" at two points in time: before and after selection occurs. **Population size** refers to the number of breeding birds before selection.

At the start of the simulation a seed distribution is determined from the level of precipitation. The parameter p is used to determine the proportions of soft, intermediate, and hard seeds and p is inversely proportional to the rainfall. The proportions of soft, intermediate, and hard seeds are given by p^2, $2pq$, and q^2, respectively, where $q = 1 - p$. Although this formula evokes the Hardy-Weinberg Equilibrium model, there are no genes or alleles in the *Evolution Lab* simulation.

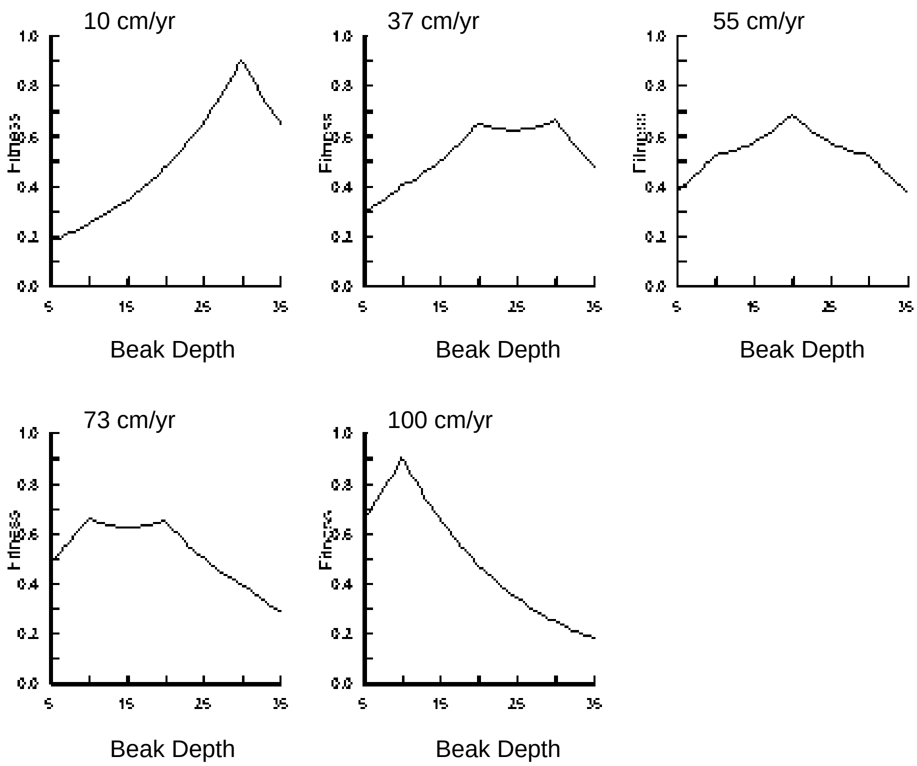
Each bird is challenged by natural selection and its **probability of survival** is determined by the **seed-size distribution** and the bird's **beak size**. Thus, each bird has a fitness component that represents its survival probability on each type of seed. Mating and reproduction in which each female bird is randomly paired with a male bird to produce a clutch of eggs follow selection. Birds that do not find mates (because of an unequal sex ratio) do not reproduce. For each mating pair, the number of eggs in their clutch is taken from a Poisson probability distribution with a mean value equal to the clutch size parameter that you chose. If it survives, each egg will produce a bird with a beak size that is determined by the parents' mean beak size and the mean beak size of the population before selection according to the **heritability value, h^2**, you've selected. If $h^2 = 0$, then the mean beak size of the offspring will equal, on average, the mean beak size of the parental population before selection. If beak size has an $h^2 = 1$, then the mean beak size of a clutch of eggs will equal, on average, the "midparent value."

Not every egg produces a fledgling. If this was true, the population would either continue to grow geometrically or would quickly go extinct. Population growth is density-dependent via the linking of the probability that an egg produces a fledgling to the size of the parental population that is feeding the young birds. Thus, the probability that an egg hatches and survives to become a fledgling decreases exponentially with an increase in the size of the parental population. The **carrying capacity** (maximum population size) is proportional to island size, which is determined by you.

Fitness Landscapes

Precipitation, through its effects on seed-size distribution, determines how the survival probabilities vary with beak size. This interaction creates "fitness landscapes" for the various levels of precipitation as shown in the figure below. At the lowest rainfall extreme (10 cm/year), for example, only hard seeds are produced and large beak depths are optimal. When rainfall is intermediate to the extremes (55 cm/year), the intermediate beak size is favored. Similarly, when high rainfall occurs, small beak depths are favored. However, when only one seed type is available, the maximum possible survival probability is below the theoretical maximum of 100%.

Precipitation levels exist that produce a balance of seed types such that a small **"fitness plateau"** can be achieved. This is the case for rainfall levels of 37 cm/year and 73 cm/year as seen in the adjacent figure. Each plateau has a shallow valley with adaptive beaks near the edges of the plateau. Two populations started on different sides of the trough will move in opposite directions. Populations started in the center of the trough will move in either direction at random, depending on stochastic events. This can provide examples of **disruptive selection** and "founder effects."



Your Assignments

Work in pairs during hypothesis generation and testing and to discuss the simulation outcomes with your partner. Details of what to do for each assignment are found on in the *Evolution Lab* manual and on the *Evolution Lab* web page. **Please do the assignments in the following order**:

Week 1 –

- Assignment 1 – "The influence of precipitation on beak size and population number"
- Assignment 4 – "Effect of island size"
- Assignment 6 – "Extinction"

WRITE UP FOR WEEK 1:

A write-up of each week's assignments is due at the following week's lab meeting time. These write-ups must be done **individually and independently** but are based on your discussions with your partner, and with other groups in the case of exercise #7, which is completed in the second week of this two-week lab project. The heading of your write-up must include the name of your partner in addition to your own name.

Your write up should use the labeling for questions as indicated below (e.g., 1A, 1B, 1C, 1Da, 1Db,…4A, etc.). Lab write-ups must be typed.

Assignment 1 – Influence of precipitation on beak size and population number

In assignment 1, you ran two experiments – the first experiment explored the simple relationship between beak size and population number and the second examined the effect of precipitation on beak size and population number.

To help you understand the first experiment, consider that the value of a given beak size to an individual finch is determined by the sizes and hardness of seeds available. That is, beak size is an **adaptation** that enables consumption of particular seeds. Thus, finch fitness is determined by the relationship of beak size to seed availability (as in the figure above).

A. State your hypothesis for how beak size will affect population numbers.

B. As beak size approached the optimum size for the conditions on a given island, what happened to the number of finches in an island's population?

C. What happened to beak size on Darwin Island compared to Wallace Island over time (examine the histograms)? What does this pattern suggest about beak-size adaptation and the availability of seeds?

D. State your three hypotheses for (a) how a decrease in precipitation will affect beak size over time, (b) how a decrease in precipitation will affect finch-population size over time, and (c) how an increase in precipitation will affect beak size over time.

E. Based on the plots of mean beak size over time, was your first hypothesis in D confirmed – If yes, why? And if not, why not? If not, provide a reformulated hypothesis.

F. Based on the plots of population numbers over time, was your second hypothesis in D confirmed – If yes, why? And if not, why not? If not, provide a reformulated hypothesis.

G. Based on the plots of mean beak size over time, was your third hypothesis in D confirmed – If yes, why? And if not, why not? If not, provide a reformulated hypothesis.

H. Why when you decreased precipitation might you expect an initial decrease in finch-population numbers and subsequently an increase in population size?

I. Why did you see slightly different results each time you reran an experiment?

Assignment 4 – Effect of Island Size (Carrying Capacity and Genetic Drift)

In assignment 4, you altered island size, which changed the **carrying capacity** (maximum number of organisms from a given population that an environment can support) of the island. Thus, here we explored the influence of island size on the carrying capacity of finches. Recognize that there are two components to carrying capacity – (a) the availability of necessary resources and (b) the ability of the species in question to exploit the available resources.

A. State your hypotheses (a) to predict what effect an increase in island size will have on finch populations, and (b) how finch-population size will affect beak sizes.

B. What was the effect of increasing island size on finch-population size?

C. What was the effect of increasing island size on finch-beak size?

D. How did the patterns differ on smaller versus larger islands (hint: If the graphs of beak size and/or population size appear more "ragged," there's more **genetic drift** [random variation] occurring)?

E. What influences did decreases in clutch size, variance, heritability, as well as increased precipitation have in reversing the increases in beak size and population numbers observed on the larger island?

Assignment 6 – Extinction

Here, you considered what conditions can lead to extinction of a finch population. Because extinction depends on **stochastic effects** (chance effects), you need to rerun experiments several times to see such stochastic events.

A. Decreases in which variables led to extinction, why?

B. What two variables were most important for determining extinction (hint: one variable is an attribute of the finches and one is an attribute of the environment)?

C. How did genetic variance and heritability influence extinction?

Week 2 –

- Assignment 2 – "Modes of natural selection"
- Assignment 5 – "Variance"
- Assignment 7 – "Influence of heritability, h^2"
  For assignment 7, expand your group beyond yourself and your partner by including another pair of lab mates in the generation of hypotheses, simulation runs, and discussions).
- Assignment 3 – "Effect of clutch size" (number of eggs per nesting)

WRITE UP FOR WEEK 2:

Assignment 2 – Modes of Natural Selection (Directional, Stabilizing, and Disruptive)

This assignment explores a somewhat more complicated phenomenon and the observed effects can be subtle – as a consequence you must critically evaluate your results as you respond to the following questions. R should be calculated year-by-year, that is, calculate R for yr 1 to yr 2, then yr 2 to yr 3, and so forth. Once you have the R values for the first ten years calculate a mean of these values. Then perform a similar series of calculations for the last 10 years.

A. What type of natural selection (i.e., directional, stabilizing, disruptive) occurred on Wallace versus Darwin Island after you altered precipitation on Wallace Island to 50 cm/yr and precipitation on Darwin Island to 0 cm/yr? Explain why this occurred.

B. Explain how average R (the difference in mean beak size from one generation to the next) differed during the first 10 yrs of the simulation versus the last 10 yrs for populations on both islands. If the rate of change differed between the two time intervals, explain why.

C. Was there a difference in the finch-population sizes on the two island – if so, explain the reason for these differences?

Assignment 5 – Genetic Variance

This assignment explores the role of genetic variance in a population's ability to evolve.

A. State your hypothesis for how genetic variance affects population numbers – explain the connection between decreased or increased genetic variance and the capacity of an organism to adapt to environmental changes.

B. What happened when you increased variance on Darwin Island to near 2.0, decreased variance on Wallace Island to 0.1, and created drought on both islands?

C. What does this experiment suggest about how adaptation may prevent a population from going extinct?

Assignment 7 – Influence of Heritability

This assignment examines the role of heritability in a population's ability to evolve.

A. State your hypothesis for how low or high heritability affects the rate of evolutionary change.

B. Did your results confirm your hypothesis? What effect did heritability have on the rate of evolution and why does it have this influence?

C. Consider your results from experiments exploring variance as well as heritability. Do changes in variance and heritability have similar or different effects on the rate of beak evolution?

D. Can differences in heritability between the finch populations on the two islands be overcome by changes in the amount of genetic variance within the populations? If so, why? If not, why not?

Assignment 3 – Effect of Clutch Size (number of eggs/nesting)

We saved this assignment for last because it explores a complicated phenomenon and because the observed effects are subtle – you will need to examine replicate runs of your experiments to critically evaluate your results. Keep in mind that small clutch sizes keep population sizes small and that small populations have more genetic drift (stochastic effects).

A. By comparing replicate runs, you should have noticed that sometimes the mean beak size of finches on Darwin and Wallace Islands diverge and at other times beak sizes evolved in the same direction – all with the same starting conditions. Explain why the populations tend to move "off the cusp" at 25 mm (hint: look back at the figure on page 3)?

B. What type of natural selection (e.g., directional, stabilizing, or disruptive) is depicted when the beak sizes on Darwin and Wallace Islands diverge?

C. What do these results suggest about the role of stochastic effects (chance) in evolution?