INQUIRY & INVESTIGATION

Natural Selection & Variation

A Hands-On Lesson Using Bird Specimens

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In either good or bad conditions, subtle differences among individuals make a profound difference in determining life or death. We often miss this important diversity that exists *within* species in the plant and animal world, in part because of our focus on variation *among* species. Depending on environmental conditions, even fine scale differences among individuals can lead to differences in reproductive success. Without intraspecific variation in survival or reproduction, there would be no template upon which natural selection could act. However because of sexual reproduction, individuals do differ and depending on the heritability of traits, these differences lead to adaptation to conditions and evolution. Thus for students to understand evolution, they must gain an appreciation for natural variation and its role in natural selection.

In this lesson, students measure and analyze natural intraspecific variation and make predictions about the relationship between this variation and reproductive success for two traits: plumage color and bill size in birds. The central idea and procedure of this lesson on natural variation can easily be adapted for use with any plant or animal species (such as acorns, fish, plant root mass, total leaf number, or insect body size) as long as: (1) individuals vary in a measurable trait, and (2) variation in the trait has a presumed link to reproductive success. Information about how to borrow specimens from local natural history collections, as well as an online version of the lesson for teachers unable to borrow specimens, can be found at http://csip.cornell.edu/curriculum_resources/csip/ardia/.

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Background

Variation in morphology and appearance are two key characters that relate to reproductive success. While the value of a particular body size or character size depends on environmental conditions, morphology influences multiple aspects of a species' life history, such as thermoregulation and heat loss, resource needs, ability to acquire and process foods, and conspicuousness (Calder, 1996). Appearance, particularly plumage color, is linked to fitness and is intimately involved in male-male competition and female choice. I have chosen plumage color and morphology because they are important traits that can be easily quantified by students.

Assessing variation in color is appealing to students because color is a trait that is easy to quantify and has a direct link to natural selection, and because many of us have had experiences observing bright birds such as cardinals. Color in the animal world serves many purposes, some of which may be counteracting. Concealment is the first and most obvious function for many color patterns we see in nature. For example, snowshoe hares change their fur color from brown to white in the winter to match the background, and the cryptically-colored black and white zebra blends in with tall grasses on the African savanna. However, if color has evolved only for concealment, then how do we explain the conspicuousness of a bright male cardinal? The degree to which color serves multiple and contradictory functions varies across species, but the phenomenon is most common in birds. Bright coloration, despite its conspicuousness, appears to have evolved to convey information about body condition or quality from one individual to another and this idea is a central tenet of sexual selection theory (Zahavi & Zahavi, 1997).

Birds acquire some of their color from pigments collected from the environment, particularly those colors associated with sexual selection. Red, orange, and yellow colors are usually derived from carotenoids (such as occur in carrots). These compounds occur naturally in seeds and fruits, but can be scarce in the wild. Accordingly, individuals must invest time and energy in finding sufficient quantities. Because individuals differ in their ability to find and metabolize these pigments, we see a range of color variation *within* a species. It is important to note that bright coloration, on its own, is rarely directly related to survival and reproduction. Rather, bright coloration is an indicator of high quality individuals that are also good foragers and are in good health. On average, females tend to select males that have brighter plumage with the evolutionary consequence that their offspring have a bright male's foraging ability and genes. Thus, even though we might expect that bright colors make individuals more conspicuous to predators, males that are able to maintain bright plumage tend to have more offspring than do less brightly-colored males. This pattern is common in many species of birds, as well as in mammals and other vertebrates.

While there are many classic examples of morphology that are involved, like color, in sexual selection (e.g., Irish elk, widowbirds, fiddler crab), more mundane traits such as bill size appear to be a result of natural selection. A classic example of bill size and natural selection is seen among Darwin's finches on the Galápagos Islands. In normal years, Large cactus finches (*Geospiza conirostris*) with small and medium-sized bills were more successful at gathering seeds and other foods than were large-billed individuals. However, during a drought only large seeds were available and, consequently, only finches with bills larger than a certain size were able to take advantage of large seeds (Grant & Grant, 1989). *Because there was underlying diversity in bill size,* some individuals were able to survive a period of harsh conditions; interestingly, this led to evolution in the population, as there was a shift in bill size after the drought. Another classic example of the role of size variation comes from Bumpus (1899). During a severe winter, Hernan Bumpus collected 136 living and dead house sparrows (*Passer domesticus*) and compared body measurements between survivors and nonsurvivors; he found that large individuals were more likely to survive a harsh winter, suggesting that size may be tightly linked with survival under harsh conditions.

This curriculum is designed to address National Science Standard A: Science as Inquiry and Standard C: Life Sciences: Biological Evolution by examining intraspecific variation in traits believed to influence and be influenced by natural selection. Students will observe and measure variation and be stimulated to think critically about how such differences arise and the consequences of those differences. The students should: (1) see variation among individuals in a trait resulting from natural selection and (2) learn that some individuals, especially those with particular values of the trait, tend to survive and reproduce better because of that trait.

The Activity

Materials

- A set of specimens or photographs for student measurement. Information on where to obtain specimens or to use high-quality photographs of museum specimens is available online at http://csip.cornell.edu/curriculum_resources/csip/ardia/.
- Color score sheet. I chose seven colors in a gradient from green to deep red. A chart can be made with free paint samples obtained from a

hardware store. While Munsell color charts are the standard reference for more precise studies, they provide too many options, leading to few individuals per color, which makes generating patterns difficult. Munsell color charts (www.munsell.com) provide a more precise way to assess color but they are expensive and difficult to use in the laboratory.

- A ruler or calipers.
- Sample figures to compare to student predictions (provided in this article).

This lesson was tested using 10 individuals of a colorful species (Scarlet Tanager, *Piranga rubra*) and 12 individuals for bill size (Red-winged Blackbird, *Agelaius phoeniceus*), each broken into two groups. The students trade their specimens among laboratory groups to allow each group to measure all individuals. For color, Northern cardinals (*Cardinalis cardinalis*), tanagers, or house finches (*Carpodacus mexicanus*) are the best candidates, as red plumage should be most variable. For body and bill size, any bird species could be used for this lesson, although using larger birds (robin-sized or bigger) will reduce measurement error because they will be easier for students to properly measure.

Time Required

Two 50-minute class periods to allow for student observations, measurement, analysis, and discussion.

Objectives

- Students will increase their awareness of the range of variation available for natural selection.
- Students will learn that differences in traits among individuals can lead to differences in survival and reproduction.
- Students will improve ability to observe and describe the natural world.
- Students will develop skills in measuring and quantifying physical traits.

Preactivity Discussion & Predictions

Start the lesson by having students describe their own observations of birds, with an emphasis on color and bill use. Ask students to make a qualitative prediction about how much variation they expect among individuals *within* a species and compare this prediction to how much variation they expect *among* species. It is suggested that students consider both closely-related species like cardinals and finches and more distantly-related species such as hawks and ducks. If time permits, short field observations of common birds at a classroom feeder or during a short excursion outside can give students additional opportunities to learn about color variation and bill size. Depending on where in the evolution unit the lesson is used, teachers can review the components of natural selection and the comparison between phenotypic and genotypic variation.

Procedure

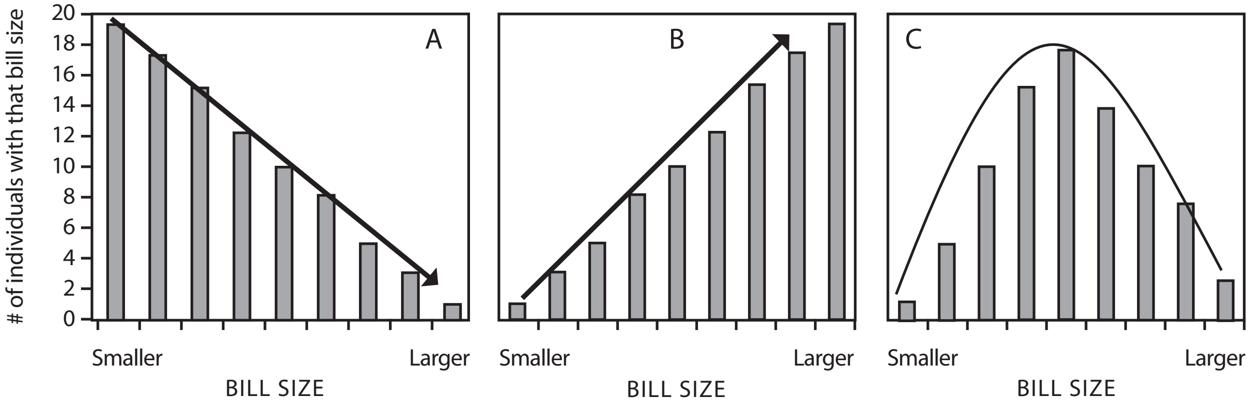
1. Give students a set of specimens that shows: a range of either color variation or bill size.
2. Ask students to describe and sketch the differences they observe among individuals. The quality of student insights is greatly improved by giving students time and encouragement to make their own observations.
3. For color, ask students to choose two to three parts of the bird body on which to make color assessments using the color chart scoring system. Guide the students through this discussion to choose aspects that make sense biologically. For example, you might ask which parts of the body are more conspicuous than others. The breast and back are both biologically relevant and easy to measure because they provide a large flat area to compare to the color templates. In addition, students will gain better understanding of measurement and experimental design if they are guided to determine their measurement protocol. For example, when color varies on the breast of a single bird, students will need to decide upon a protocol to score color. This teachable moment can allow you to explain that these sorts of decisions are inherent in scientific studies and that it is important they decide on a common protocol. Students can consider measurement options, such as whether to measure the brightest spot, the dullest spot, the center, or the average color.
4. For bill size, students should take multiple measures of bill morphology such as bill length and depth. In the same manner as color, students will benefit from guidance on how to determine the exact measurement protocol. A diagram of where to measure is posted in the supplementary materials on the lesson Web site listed earlier.

Data Analysis

Once all the data have been collected, students should create a frequency histogram of at least one color variable and one bill size measure. Students should lump their bill size data into a few (preferably no more

Figure 1.

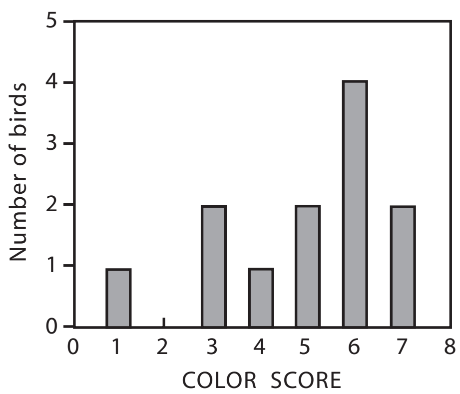
Some possible histograms of bill size distribution. As bill size increases, the number of individuals with large bills may (A) *decrease* or (B) *increase.* However, the most common form of variation is that the intermediate value is the most common and that extreme values are rare (C).



than six) categories in order to generate a pattern in their data. Some examples of how variation might be distributed are provided in Figure 1. An example from students who conducted this exercise in Rochester, New York is provided in Figure 2. Students should assess how much variation they recorded to determine if the trait is distributed evenly or skewed. For advanced classes, students could make a statistical assessment of variation such as kurtosis (a measure of skew), standard deviation, or standard error (which corrects for sample size differences). For more information on statistics, check out http://www.42explore.com/statistics.htm.

Figure 2.

Sample data from 12 Scarlet Tanager specimens measured by students at East High School, Rochester, NY.



range of colors in a group of Tanagers *and* color affects survival and reproduction, then individuals with the best value of the trait will tend to survive and reproduce better than individuals with different values of the trait.

The most effective predictions often result from discussion of prior observations, class information, and any insight students might have gained from handling the specimens. Give the students (working alone or in small groups) a blank graph with color (or bill size) on the x-axis and survival/reproduction on the y-axis. They should draw a curve or line on the graph showing how they think the ability to survive and reproduce changes as the value of the trait changes (i.e. are colorful birds more successful than less colorful birds?). At the end of the discussion, present the students with the data summarized in Figures 4 and 5 to see how their guesses match results found by researchers.

Discussion

The goal of discussion should be for students to synthesize their observations and to try to *hypothesize the relationship* between a particular value of color or bill size and natural selection (Figure 3). It is important to make the distinction between the pattern of variation that the students measured and graphed (the population-level range of variation) and the survival and reproduction value of the trait to each individual, as natural selection acts on individuals. For example, if there is a

In discussion, have the students consider two general questions:

1. What might underlie or cause the pattern of variation they have measured?
2. How might color score (or bill size) influence survival and reproduction?

Color and bill size variation arise in different ways. A bird's bill size is generally a function of its genetics and the environmental conditions it has experienced *while the bill was growing,* so that bill size would not change much over the life of an adult. Thus, simplistically, the genetics of an individual might determine the *range of possible bill sizes,* while environmental conditions during growth will determine the *actual bill size,* such as occurs with height in humans. Feather color, on the other hand, reflects current quality, because feathers are molted and regrown every year. Thus color can change multiple times over the course of an individual's life. Each trait thus conveys different information about the quality of an individual and may have a different link with the function and success of each trait.

When discussing carotenoid-based color variation such as studied here, explain the pathways by which individuals become colorful, e.g., birds must spend time and energy searching for scarce pigments and then incorporate them into their feathers and that individuals differ in the time available and their ability to find pigments. Have students brainstorm on the possible advantages and disadvantages of being colorful, such as increased attractiveness *and* increased conspicuousness to predators. For additional information, some excellent studies relating color and natural selection are Wolfenbarger (1999), Hill (1991), and McGraw et al. (2001).

Figure 3.

Some possible patterns between redness and reproductive success: As redness increases, the adaptiveness of being red can increase (A), decrease (B), or stay the same (C). Another possible pattern could be that birds with intermediate redness are the most successful (D).

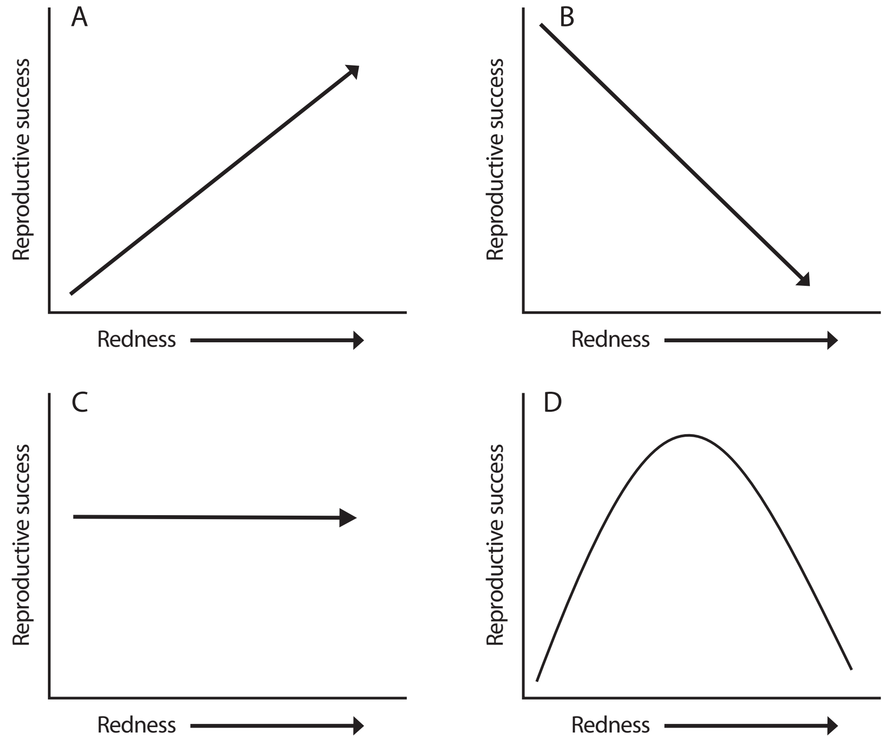


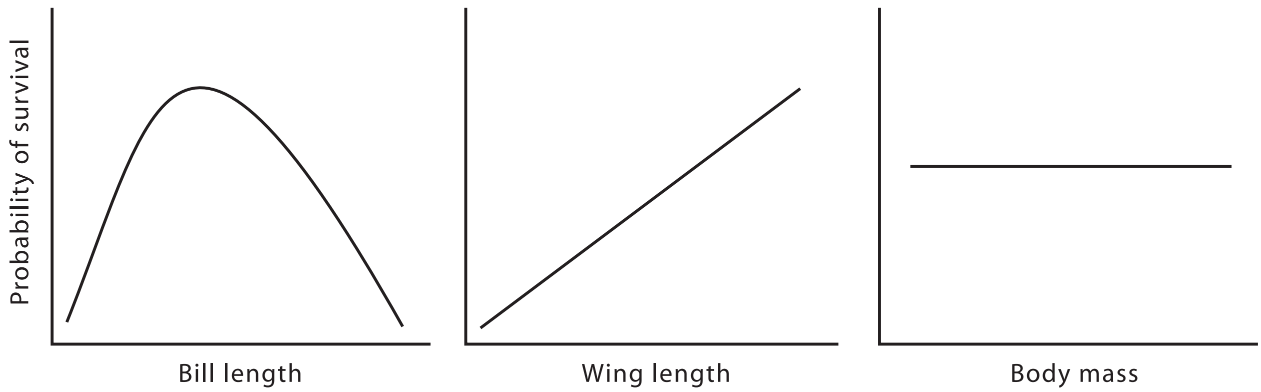
Figure 4.

The relationship between plumage coloration and reproduction in Northern cardinals and house finches. Figures derived from Wolfenbarger (1999) and Hill (1991).

In Northern cardinals, the general trend is that bright males tend to raise more nestlings than do less bright males.

Bright male house finches tend to make more feeding visits to nests than do dull male house finches.

Figure 5.
The relationship between body and bill size and survival in birds. Derived from Smith (1990).



In evaluating bill size, students should consider the relative advantages of having an extreme vs. intermediate bill size and when each might be favored. They should also consider what conditions favor extreme vs. intermediate bill sizes. If conditions were benign, would there be much selection on bill size? If conditions were harsh, how would the strength of selection change? They might also consider what the long-term consequences are of population-level variation if environmental conditions change over time. Another possible discussion could contrast how color and bill size influence natural selection differently. For example, color might relate more to the probability of mating, while bill size might influence probability of surviving. For more information on morphology, see Alatalo and Lundberg (1986), and Smith (1990).

Assessment Strategy

Both content and skill can be assessed to measure student learning. Student understanding of content can be evaluated using the worksheet (posted with the online version of this lesson) or quizzes. Evaluation of students' measurements, attention to detail, graphs, and the depth and breadth of observations of the specimens can be used to measure laboratory skills.

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