

University of Florida Center for Precollegiate Education and Training

Drowsy Drosophila:

RAPID EVOLUTION IN THE FACE OF CLIMATE CHANGE

UF UNIVERSITY of
FLORIDA

DROWSY DROSOPHILA: RAPID EVOLUTION IN THE FACE OF CLIMATE CHANGE

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Introduction

Natural selection is a central theme in biology and an important concept for student understanding of a wide variety of topics. One such topic is the ability for organisms to adapt to the increasing environmental stress predicted under contemporary global climate change. Global climate change will likely have substantial impacts on living organisms and it is critical to examine how genetic variation may either facilitate or limit the ability for organisms to adapt to global climate change through natural selection. In the present inquiry-based classroom activity, students will use a chill-coma recovery assay to compare thermal tolerance among six different lines (3 fast recovering lines and 3 slow recovering lines) of the fly *Drosophila melanogaster*. The objective of the activity is to provide students the opportunity to assess natural genetic variation in cold tolerance in *Drosophila melanogaster* and to discuss the implications for this variation to allow adaptation by natural selection to occur, thus facilitating persistence of the species despite a changing climate. Possible topics of discussion that can be used in conjunction with this activity include: genetics, evolutionary biology, conservation biology, global climate change, ecology, statistics, the scientific method, and many others, allowing this experiment to facilitate diverse teaching and learning opportunities. This activity will allow students to identify questions and concepts that guide scientific investigations, learn how to conduct a scientific investigation (including use of appropriate tools and techniques for data collection), how to use scientific technology and mathematics including a basic understanding of statistical testing and analysis, and to develop their critical thinking and communication skills

LESSON SEQUENCING GUIDE

Since the classroom teacher knows his or her students best, the teacher should decide the sequencing of lessons. The suggested sequencing guide below is based on 45 minute class periods.

	DAY 1	DAY 2	DAY 3	DAY 4	DAY 5
WEEK 1	<p>Homework Prior to Lesson One: Background Article Reading with Guided Questions</p> <p>Administer Pre-assessment (if using)</p>	<p>LESSON ONE: Winners and Losers of Climate Change</p> <p>(Debrief background reading guide, complete Winners and Losers activity with species cards/debrief)</p>	<p>LESSON TWO: Chilly Coma Assay and Evolution Investigation</p> <p>(Assay background presentation, run assay/collect raw data)</p>	<p>LESSON TWO: Chill Coma Assay and Evolution Investigation</p> <p>(Data Analysis and Lab Wrap Up Questions)</p>	<p>LESSON TWO: Chilly Coma Assay and Evolution Investigation</p> <p>(Mechanisms of Evolution Student Investigation Papers)</p>
WEEK 2	<p>LESSON TWO: (Extension) Hardy Weinberg Extension Lesson and Practice Set</p>	<p>LESSON THREE: Patterns of Natural Selection</p> <p>(Types of Selection Lesson and Practice)</p>	<p>LESSON THREE: Patterns of Natural Selection</p> <p>(Group Selection Predictions)</p>	<p>Administer Post Assessment</p>	

Vocabulary

ASSAY

investigative (analytic) procedure

CHILL COMA

the loss of mobility in insects and other ectotherms at low temperatures

CHILL COMA RECOVERY

the period of time that it takes for an insect to regain mobility after being in a chill coma

CLIMATE CHANGE

a change in global or regional climate patterns, in particular a change apparent from the mid to late 20th century onwards and attributed largely to the increased levels of atmospheric carbon dioxide produced by the use of fossil fuels.

DIRECTIONAL SELECTION

natural selection in which an extreme phenotype (i.e., phenotype either greater or lesser than the population mean) is favored over other phenotypes, causing the allele frequency to shift over time in the direction of that phenotype

DISRUPTIVE SELECTION

natural selection in which extreme forms of a trait are favored over intermediate values. Variance of the trait increases and the population is divided into two distinct groups. Over time, disruptive selection can lead to two new species

EVOLUTION

descent with modification, this includes small-scale evolution (changes in gene frequency in a population from one generation to the next) and large-scale evolution (the descent of different species from a common ancestor over many generations).

GENETIC VARIATION

variation in alleles of genes that occurs both within and among populations. Genetic variation is important because it provides the genetic material for natural selection

GLOBAL WARMING

term for the observed century-scale rise in the average temperature of the Earth's climate system and its related effects

MUTATION

change in DNA

NATURAL SELECTION

one of the basic mechanisms of evolution in which differential survival and reproduction of organisms occurs as a consequence of the characteristics of the environment

PHENOTYPIC PLASTICITY

the ability of one genotype to produce more than one phenotype in response to different environments

STABILIZING SELECTION

natural selection in which intermediate forms of a trait are favored and the extremes are selected against

NEXT GENERATION SUNSHINE STATE STANDARDS – SCIENCE

BENCHMARK	LESSON 1	LESSON 2	LESSON 3
SC.912.L.15.13 Describe the conditions required for natural selection, including: overproduction of offspring, inherited variation, and the struggle to survive, which result in differential reproductive success.		X	X
SC.912.L.15.14 Discuss mechanisms of evolutionary change other than natural selection such as genetic drift and gene flow.		X	
SC.912.L.15.15 Describe how mutation and genetic recombination increase genetic variation.		X	X
SC.912.L.17.4 Describe changes in ecosystems resulting from seasonal variations, climate change, and succession	X	X	X
SC.912.L.17.16 Discuss the large-scale environmental impacts resulting from human activity, including waste spills, oil spills, runoff, greenhouse gases, ozone depletion, and surface and groundwater pollution.	X		X
SC.912.N.1.1 Define a problem based on a specific body of knowledge	X	X	X
SC.912.N.1.3 Recognize that the strength or usefulness of a scientific claim is evaluated through scientific argumentation, which depends on critical and logical thinking, and the active consideration of alternative scientific explanations to explain the data presented.	X	X	X
SC.912.N.1.6 Describe how scientific inferences are drawn from scientific observations and provide examples from the content being studied.	X	X	X
SC.912.N.3.1 Explain that a scientific theory is the culmination of many scientific investigations drawing together all the current evidence concerning a substantial range of phenomena thus, a scientific theory represents the most powerful explanation scientists have to offer.	X	X	X

ADVANCED PLACEMENT BIOLOGY ESSENTIAL KNOWLEDGE AND SCIENCE PRACTICES (SP)

ENDURING UNDERSTANDINGS & SCIENCE PRACTICES	LESSON 1	LESSON 2	LESSON 3
Enduring Understanding 1.A: Change in the genetic makeup of a population overtime is evolution.		X	X
Enduring Understanding 1.C: Life continues to evolve within a changing environment.		X	X
Enduring Understanding 3.A: Heritable information provides for continuity of life.		X	X
Enduring understanding 4.C: Naturally occurring diversity among and between components within biological systems affects interactions with the environment.	X	X	X
Science Practice 1: The student can use representations and models to communicate scientific phenomena and solve scientific problems.	X	X	X
Science Practice 3: The student can engage in scientific questioning to extend thinking or to guide investigations within the context of the AP course.	X	X	X
Science Practice 5: The student can perform data analysis and evaluation of evidence.	X	X	X
Science Practice 6: The student can work with scientific explanations and theories.	X	X	X

NEXT GENERATION SCIENCE STANDARDS (NGSS)

	LESSON 1	LESSON 2	LESSON 3
HS-LS3-3. Apply concepts of statistics and probability to explain the variation and distribution of expressed traits in a population.		X	X
HS-LS4-4. Construct an explanation based on evidence for how natural selection leads to adaptation of populations.		X	X
HS-LS4-2. Construct an explanation based on evidence that the process of evolution primarily results from four factors: (1) the potential for a species to increase in number, (2) the heritable genetic variation of individuals in a species due to mutation and sexual reproduction, (3) competition for limited resources, and (4) the proliferation of those organisms that are better able to survive and reproduce in the environment.		X	X
HS-LS4-5. Evaluate the evidence supporting claims that changes in environmental conditions may result in: (1) increases in the number of individuals of some species, (2) the emergence of new species over time, and (3) the extinction of other species.		X	X
HS-LS4-3. Apply concepts of statistics and probability to support explanations that organisms with an advantageous heritable trait tend to increase in proportion to organisms lacking this trait.		X	X
HS-LS4-4. Construct an explanation based on evidence for how natural selection leads to adaptation of populations.			X
HS-LS2-2. Use mathematical representations to support and revise explanations based on evidence about factors affecting biodiversity and populations in ecosystems of different scales.	X		X
HS-LS2-6. Evaluate the claims, evidence, and reasoning that the complex interactions in ecosystems maintain relatively consistent numbers and types of organisms in stable conditions, but changing conditions may result in a new ecosystem.	X		X
Crosscutting Concept 1. Patterns. Observed patterns of forms and events guide organization and classification, and they prompt questions about relationships and the factors that influence them.	X	X	X
Crosscutting Concept 2. Cause and effect: Mechanism and explanation. Events have causes, sometimes simple, sometimes multifaceted. A major activity of science is investigating and explaining causal relationships and the mechanisms by which they are mediated. Such mechanisms can then be tested across given contexts and used to predict and explain events in new contexts.	X	X	X
Crosscutting Concept 7. Stability and change. For natural and built systems alike, conditions of stability and determinants of rates of change or evolution of a system are critical elements of study	X	X	X

LESSON 1

The Winners and Losers of Climate Change

VOCABULARY

CLIMATE CHANGE: a change in global or regional climate patterns, in particular a change apparent from the mid to late 20th century onwards and attributed largely to the increased levels of atmospheric carbon dioxide produced by the use of fossil fuels.

GLOBAL WARMING: term for the observed century-scale rise in the average temperature of the Earth's climate system and its related effects

PHENOTYPIC PLASTICITY: the ability of one genotype to produce more than one phenotype in response to different environments

LESSON SUMMARY

Students are assigned two articles to read for homework to prepare them for a class activity involving climate change “winners” and “losers”. In the first article students learn how climate change produces not only hotter temperatures, but also extreme weather events. In the second article students learn about phenotypic plasticity and look at several examples of genetic changes that have already occurred in species due to climate change. In class students receive a set of Climate Affected species cards and participate in an activity to predict which species populations are likely to increase (“winner”) or decrease (“loser”) in response to the current climate change trajectory.

STUDENT LEARNING OBJECTIVES

- SWBAT identify that climate change results in not only global warming but also extreme weather events and shifted seasons.
- SWBAT identify particular species that may be better suited to survive extreme climate change events (given the current change trajectory).
- SWBAT propose why organisms that display greater phenotypic plasticity would be better suited to survive climate change events.

MATERIALS

- Article: *More evidence that global warming is intensifying extreme weather*, John Abraham, The Guardian, July 2015
- Article: *Evolutionary Response to Rapid Climate Change*; Bradshaw & Holzapfel, Science 2006
- Student Page: Whiplash Weather and Phenotypic Plasticity Homework Reading Guide
- Climate Effected Species “Baseball Cards”
- Student Page: Winners and Losers of Climate Change

ADVANCE PREPARATION

- Review Referenced Resources (below)
- Print Articles (listed in materials above) — ONE copy per student
- Print Student Page-Whiplash Weather and Phenotypic Plasticity Homework Reading Guide — ONE per student
- Print Climate Effected Species “Baseball Cards”— (consider laminating for future use) — ONE set of 8 cards per group (2-4 students per group)
- Print Student Page: Winners and Losers of Climate Change — ONE per student

KEY QUESTION(S):

Why does climate change affect some species more than others?

OVERALL TIME ESTIMATE:

ONE 45 minute class period (with pre-reading homework prior to beginning the in class activity)

LEARNING STYLES:

Visual, Kinesthetic, Auditory, Cooperative



PROCEDURE AND DISCUSSION QUESTIONS WITH TIME ESTIMATES

PRIOR TO DAY ONE/HOMEWORK

1. **(1-2 MINUTES IN CLASS, ~35 MINUTES FOR STUDENTS OUTSIDE CLASS)** Assign students to read both articles: *More Evidence that Global Warming Is Intensifying Extreme Weather and Evolutionary Response to Rapid Climate Change* completing the Student Page — Whiplash Weather and Phenotypic Plasticity Homework Reading Guide as they read.

DAY ONE

1. **(3-5 MINUTES)** Verbally review the content from the homework reading the previous night, answering questions and making clarifications as necessary.
 - a. The BIG ideas for the students to come away with from the background reading are
 - i. Climate change due to global warming has resulted in extreme weather events and shifted seasons.
 - ii. Organisms that display greater phenotypic plasticity would be better suited to survive climate change events.
2. **(30-35 MINUTES)** Pass out the Student Page: *Winners and Losers of Climate Change* and one set of the Climate Effected Species “Baseball Cards” to each group.
 - a. Ensure the students understand how to use *Table 1. Trait sets associated with species’ heightened sensitivity and low adaptive capacity to climate change* in conjunction with the baseball cards to fill out the *Winners and Losers Species Matrix*.
 - i. Assist students as necessary as they complete the activity.

ASSESSMENT SUGGESTIONS

- Collect either/both Student Page(s)

EXTENSIONS

- Have students create a species awareness conservation poster to share with their peers based on question 2 from Student Page: *Winners and Losers of Climate Change*
- Class discussion using ScienceNews *Heat Turns Wild Genetic Reptiles into Functional Females*. Suggested question prompt: “If climate change continues on its current trajectory will this species be a winner or a loser? Why?”

RESOURCES/REFERENCES

Abraham, John. “More Evidence That Global Warming Is Intensifying Extreme Weather.” *TheGuardian.com*. The Guardian, 01 July 2015. Web. 01 July 2015.

Bradshaw, W. E. “CLIMATE CHANGE: Evolutionary Response to Rapid Climate Change.” *Science* 312.5779 (2006): 1477-478.

Foden, Wendy B. “Identifying the World’s Most Climate Change Vulnerable Species: A Systematic Trait-Based Assessment of All Birds, Amphibians and Corals.” *PLOS ONE*. 12 June 2013. Web. 01 July 2015.

Milius, Susan. “Heat Turns Wild Genetic Male Reptiles into Functional Females.” *Science News.*, 01 July 2015. Web. 03 July 2015.

Whiplash Weather and Phenotypic Plasticity

Reading Guide

MORE EVIDENCE THAT GLOBAL WARMING IS INTENSIFYING EXTREME WEATHER

1. How does global warming lead to extreme weather events?
2. Define “whiplash weather.” In your own words explain what it means that the trends relating climate change to severe weather the scientists write about in their paper are “statistically significant.”
3. People who don’t understand climate change sometimes point to extreme snow conditions such as the polar vortex as evidence that global warming is a myth. After reading this article how would you respond to a person who says global warming is not occurring?

EVOLUTIONARY RESPONSE TO RAPID CLIMATE CHANGE

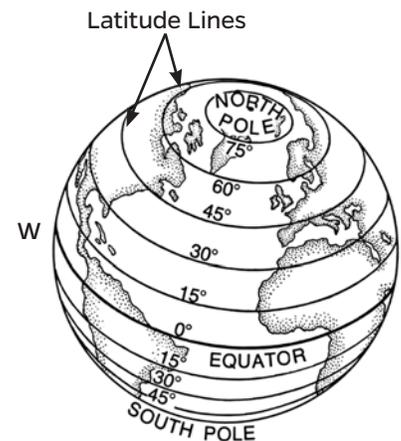
1. Differentiate between genotype and phenotype.
2. In your own words define “phenotypic plasticity” and list 3 examples of phenotypic plasticity in response to changes in climate.

3. List 3 species in which genetic changes have been observed in response to climate change.

4. Explain why the authors write that genetic changes in the observed species are the result of cues that correspond to seasonality, rather than to hotter temperatures alone.

5. Define the term “dormancy.” (You may need to look this up if you don’t know)

6. Global warming is proceeding faster in (northern, tropical) latitudes.
(circle one)



7. How has this shift affected insects at the latitudes where global warming is occurring more rapidly?

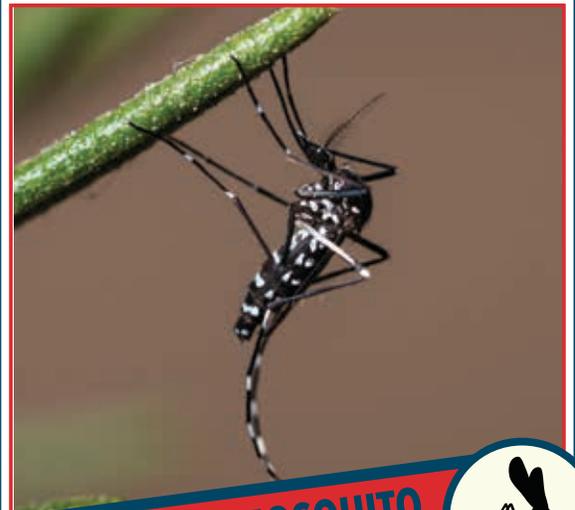
Climate Effected Species "Baseball Cards"



AFRICAN REED FROG
HYPEROLIUS ARGU



Kingdom: Animalia, Phylum: Chordata
Class: Amphibia, Order: Anura
Family: Hyperoliidae, Genus: Hyperolius



ASIAN TIGER MOSQUITO
AEDES ALBOPICTUS



Kingdom: Animalia, Phylum: Arthropoda
Class: Insecta, Order: Diptera
Family: Culicidae, Genus: Aedes



FOUR TOED LIZARD
HEMIDACTYLIUM SCUTATUM



Kingdom: Animalia, Phylum: Chordata
Class: Amphibia, Order: Caudata
Family: Plethodontidae, Genus: Hemidactylium



CORAL
MADRACIS KIRBYI



Kingdom: Animalia, Phylum: Cnidaria
Class: Anthozoa, Subclass: Hexacorallia
Order: Scleractinia, Family: Astrocoeniidae
Genus: Madracis

HABITAT: Native to tropical and subtropical regions, they are successfully adapting to cooler regions. In the warm and humid tropical regions, they are active the entire year long; however, in temperate regions they hibernate over winter. This mosquito has become a significant pest in many communities because it closely associates with humans (rather than living in wetlands), and typically flies and feeds in the daytime in addition to at dusk and dawn. The Asian Tiger mosquito is an important vector for the transmission of many viral pathogens, including the Yellow fever virus, dengue and Chikungunya fever.

DIET: Like other mosquito species, only the females require a blood meal to develop their eggs. Males and females feed on nectar and other sweet plant juices.

REPRODUCTION: The female lays her eggs near water typically near a stagnant pool. However, any open container containing water will suffice for larvae development, even with less than an ounce of water in. It can also breed in running water, so stagnant pools of water are not the mosquitos' only breeding sites.

HABITAT: Near water in rather dense savannas of eastern Africa from southernmost, coastal Somalia to coastal South Africa. H. ARGUS is a widely distributed lowland species which thrive in a variety of annual temperature ranges and are found in ponds and temporary pools in savanna, shrubland and grassland.

DIET: Prey consists mainly of a variety of insects. Predators include various fish, birds, snakes, terrapins, spiders and other frogs.

REPRODUCTION: They produce freshwater dependent aquatic larvae that have short maximum dispersal differences.

HABITAT: This rare species is only found in the northern and central Indian Ocean and southwest Pacific. This species occurs in most reef environments and prefers low-light areas.

DIET: Dependent on heat-intolerant Zooxanthellae for energy (food).

REPRODUCTION: *Madracis kirbyi* has a very slow growth rate and the age of first maturity of most reef building corals is typically three to eight years old. Based on average sizes and growth rates, scientists assume that average generation length is 10 years.

HABITAT: Four toed lizards belong to a family of lungless salamanders and are native to Eastern North America. They survive within a narrow precipitation range as they must keep their skin wet in order to effectively breathe through it. Four toed lizards only live in sphagnum bogs, grassy areas surrounding beaver ponds and forests rich with mosses.

DIET: Small invertebrates, such as spider, worms, ticks, springtails, ground beetles and other insects.

REPRODUCTION: Mating occurs in terrestrial areas throughout the fall months. In early spring the females nest on land, along the banks of small ponds (a microhabitat requirement). After the 4–6 week embryonic period, the larvae hatch and make their way to the adjacent pond (thus the species has short maximum dispersal distances). Compared to other amphibians lungless lizards have a slow turnover of generations.



FANTAIL WARBLERS
GENUS *CISTICOLA*



Kingdom: Animalia, Phylum: Chordata
Class: Aves, Order: Passeriformes
Family: Cisticolidae, Genus: Cisticola



COMMON COQUI
ELEUTHERODACTYLUS COQUI



Domain: Eukaryotic, Kingdom: Animalia
Phylum: Chordata, Class: Amphibia
Order: Anura, Family: Leptodactylidae
Genus: Eleutherodactylus



FINGERED POISON FROGS
MANNOPHYRNE TRINITATIS



Kingdom: Animalia, Phylum: Chordata
Class: Amphibia, Order: Anura
Family: Aromobatidae, Genus: Mannophryne



HORNBILLS
BUCEROTIDAE FAMILY



Kingdom: Animalia, Phylum: Chordata
Class: Aves, Order: Bucerotiformes
Family: Bucerotidae

HABITAT: Coquí is the common name for a genus that includes 17 species in Puerto Rico. The species is named for the loud call the males make at night. Many species are found only within a small habitat on just one island and have narrow temperature and precipitation niches.

DIET: Feed primarily upon arthropods.

REPRODUCTION: Eggs hatch directly into small frogs, completely bypassing the tadpole stage. Most species are characterized by parental behaviors, such as egg-guarding by either the male or female parent. Young do not usually travel very far from the location they hatch.

HABITAT: The genus contains about 45 species and the majority live in tropical and subtropical regions of Africa. A variety of open habitats are occupied. These include wetlands, moist or drier grasslands, open or rocky mountain slopes, and human-modified habitats such as road verges, weedy areas or pasture.

DIET: *Cristicolas* eat a wide variety of insects. The parasitic weaver is a specialist parasite of *cisticolas* and is negatively affected by climate change.

REPRODUCTION: Females build their pouch nest suspended within a clump of grass. The average clutch is about 4 eggs, which take about 2 weeks to hatch. Two broods a year occur in many regions. Females can sometimes breed in their first year.

HABITAT: Hornbills (Bucerotidae) are a family of birds found in tropical and subtropical Africa and Asia. Many species have small ranges and hornbills tend to be territorial.

DIET: The Hornbill family is omnivorous, feeding on fruit and small animals.

REPRODUCTION: They are monogamous breeders nesting in natural cavities in trees and sometimes cliffs. After breeding, the female uses regurgitated food, droppings, and mud to seal the opening of the tree hollow until only a small slit remains. She lays her eggs and sits on them while the male flies back and forth bringing her food.

HABITAT: *M. trinitatis* is endemic to (found only in) Trinidad, where they are concentrated mainly in the Northern and Central Ranges. Fingered poison tree frogs have both narrow temperature and precipitation niches.

DIET: Adults feed on small insects and arthropods. Juvenile animals may feed on small *Drosophila* (flies). The tadpoles are herbivorous and feed on leaf litter and algae.

REPRODUCTION: Females deposit small clutches of eggs in terrestrial nests. After hatching, one of the parents transports the tadpoles to a small water body (a microhabitat requirement), where they complete their development to metamorphosis. Compared to other amphibians fingered poison frogs have a slow turnover between generations.

Winners and Losers of Climate Change

INSTRUCTIONS: Use Table 1 and Figure 2 from the collaborative study entitled *Identifying the World's Most Climate Change Vulnerable Species: A Systematic Trait-Based Assessment of all Birds, Amphibians and Corals* to complete the Species Vulnerability Matrix.

TABLE 1. TRAIT SETS ASSOCIATED WITH SPECIES HEIGHTEN SENSITIVITY AND LOW ADAPTIVE CAPACITY TO CLIMATE CHANGE.

SENSITIVITY
<p>a. Specialised habitat and/or microhabitat requirements As climate change-driven environmental changes unfold, species that are less tightly coupled to specific conditions and requirements are likely to be more resilient because they will have a wider range of habitat and microhabitat options available to them. Sensitivity is further increased for species with several life stages, each requiring different habitats or microhabitats (e.g., water-dependent larval amphibians). We note, however, that this does not hold in all cases, and extreme specialization may allow some species to escape the full impacts of climate change exposure (e.g., deep sea fishes).</p>
<p>b. Environmental tolerances or thresholds (at any life stage) that are likely to be exceeded due to climate change Species with physiological tolerances that are tightly coupled to specific environmental conditions (e.g., temperature or precipitation regimes, water pH or oxygen levels) are likely to be particularly sensitive to climatic changes (e.g., tropical ectotherms) [37,38]. However, even species with broad environmental tolerances may already be close to thresholds beyond which physiological function quickly breaks down (e.g., drought tolerant desert plants [39]).</p>
<p>c. Dependence on environmental triggers that are likely to be disrupted by climate change Many species rely on environmental triggers or cues to initiate life stages (e.g., migration, breeding, egg laying, seed germination, hibernation and spring emergence). While cues such as day length and lunar cycles will be unaffected by climate change, those driven by climate and season may alter in both their timing and magnitude, leading to asynchrony and uncoupling with environmental factors [40] (e.g., mismatches between advancing spring food availability peaks and hatching dates [41]). Climate change sensitivity is likely to be compounded when different sexes or life stages rely on different cues.</p>
<p>d. Dependence on interspecific interactions that are likely to be disrupted by climate change Climate change driven alterations in species' ranges, phenologies and relative abundances may affect their beneficial inter-specific interactions (e.g., with prey, pollinators, hosts and symbionts) and/or those that may cause declines (e.g., with predators, competitors, pathogens and parasites). Species are likely to be particularly sensitive to climate change if, for example, they are highly dependent on one or few specific resource species and are unlikely to be able to substitute these for other species [42].</p>
<p>e. Rarity The inherent vulnerability of small populations to Allee effects and catastrophic events, as well as their generally reduced capacity to recover quickly following local extinction events, suggest that many rare species will be more sensitive to climate change than common species. Rare species include those with very small population sizes, as well as those that may be locally abundant but are geographically highly restricted.</p>
LOW ADAPTIVE CAPACITY
<p>f. Poor dispersal ability: <u>Intrinsic dispersal limitations:</u> Species with low dispersal rates or low potential for long distance dispersal (e.g., land snails, ant and raindrop splash-dispersed plants) have lowest adaptive capacity since they are unlikely to be able to keep up with a shifting climate envelope. <u>Extrinsic dispersal limitations:</u> Even where species are intrinsically capable of long distance or rapid dispersal, movement and/or successful colonisation may be reduced by low permeability or physical barriers along dispersal routes. These include natural barriers (e.g., oceans or rivers for terrestrial species), anthropogenic barriers (e.g., dams for freshwater species) and unsuitable habitats or conditions (e.g., ocean currents and temperature gradients for marine species). Species for which no suitable habitat or 'climate space' is likely to remain (e.g., Arctic ice-dependent species) may also be considered in this trait set.</p>
<p>g. Poor evolvability: Species' potential for rapid genetic change will determine whether evolutionary adaptation can result at a rate sufficient to keep up with climate change driven changes to their environments. Species with low genetic diversity, often indicated by recent bottlenecks in population numbers, generally exhibit lower ranges of both phenotypic and genotypic variation. As a result, such species tend to have fewer novel characteristics that could facilitate adaptation to the new climatic conditions. Since direct measures of species' genetic diversity are few, proxy measures of evolvability such as those relating to reproductive rates and outputs, and hence the rate at which advantageous novel genotypes could accumulate in populations and species [43], may be useful. Evidence suggests that evolutionary adaptation is possible in relatively short timeframes (e.g., 5 to 30 years [44]) but for most species with long generation lengths (e.g., large animals and many perennial plants), this is likely to be too slow to have any serious minimising effect on climate change impacts.</p>

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SPECIES VULNERABILITY MATRIX: Check any of the following boxes for each species if the factor is contributing negatively towards the species continued success given the current impact of climate change. Column “e. rarity” has been completed for you, for all 8 species.

	a. specialized habit	b./c. environmental tolerances/dependence on environmental triggers	d. interspecific interaction dependence	e. rarity	f. poor dispersal ability	
African Reed Frog						
Asian Tiger Mosquito						
Four Toed Lizard				x		
Coral				x		
Fantail Warbler						
Common Coqui				x		
Fingered Poison Frogs				x		
Hornbill						

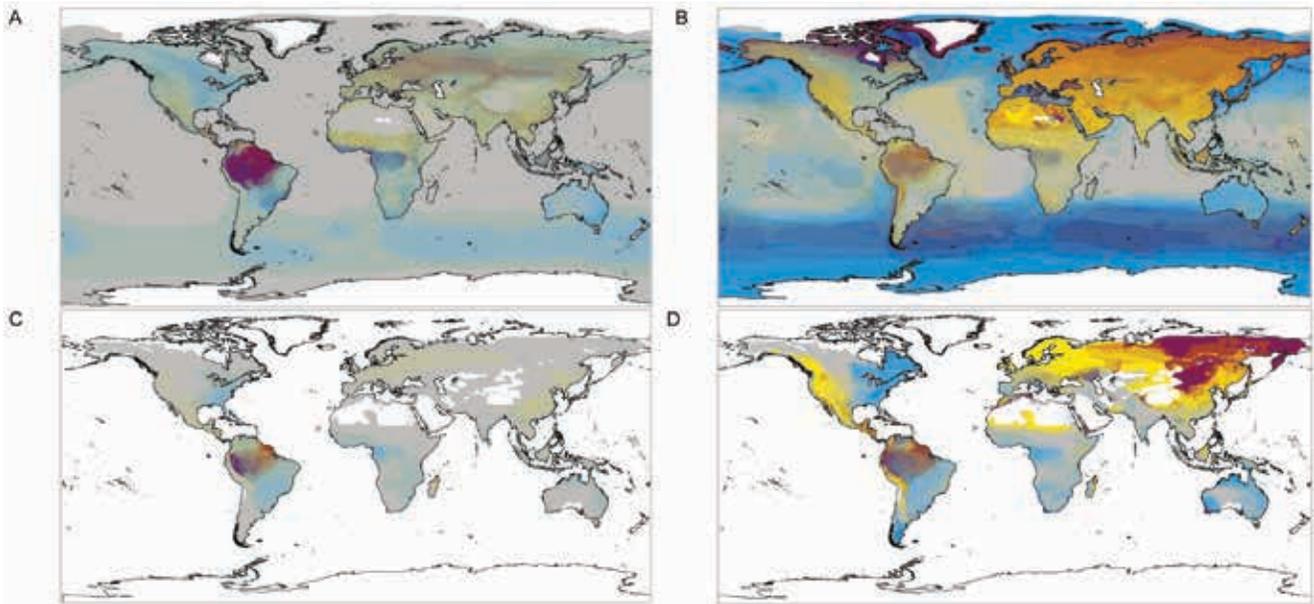
POST ACTIVITY QUESTIONS:

1. Calculate the total risk factor for each species by adding the number of checked boxes. Write this number into the matrix as a new right hand column. Order the species based on highest to lowest vulnerability below.

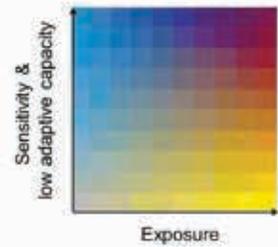
2. Any species with 3 or more check marks in the matrix above is considered a “loser” in response to climate change. Did any of the species categorized as “loser” surprise you? What about the “winners”? Why?

3. Using your completed matrix, Table 1 and the map provided on the next page (Figure 2), which region of the world is in the greatest need for biology conservation inventions, given the current climate change trajectory? Support your claim with specific evidence from the activity.

FIGURE 2. CONCENTRATIONS OF CLIMATE CHANGE VULNERABLE SPECIES.



NOTE: Regions on the map containing species which exhibit sensitivity, low adaptive capacity and high exposure are shaded in maroon.



Winners and Losers of Climate Change

INSTRUCTIONS: Use Table 1 and Figure 2 from the collaborative study entitled *Identifying the World’s Most Climate Change Vulnerable Species: A Systematic Trait-Based Assessment of all Birds, Amphibians and Corals* to complete the Species Vulnerability Matrix.

TABLE 1. TRAIT SETS ASSOCIATED WITH SPECIES HEIGHTEN SENSITIVITY AND LOW ADAPTIVE CAPACITY TO CLIMATE CHANGE.

SENSITIVITY
<p>a. Specialised habitat and/or microhabitat requirements As climate change-driven environmental changes unfold, species that are less tightly coupled to specific conditions and requirements are likely to be more resilient because they will have a wider range of habitat and microhabitat options available to them. Sensitivity is further increased for species with several life stages, each requiring different habitats or microhabitats (e.g., water-dependent larval amphibians). We note, however, that this does not hold in all cases, and extreme specialization may allow some species to escape the full impacts of climate change exposure (e.g., deep sea fishes).</p>
<p>b. Environmental tolerances or thresholds (at any life stage) that are likely to be exceeded due to climate change Species with physiological tolerances that are tightly coupled to specific environmental conditions (e.g., temperature or precipitation regimes, water pH or oxygen levels) are likely to be particularly sensitive to climatic changes (e.g., tropical ectotherms) [37,38]. However, even species with broad environmental tolerances may already be close to thresholds beyond which physiological function quickly breaks down (e.g., drought tolerant desert plants [39]).</p>
<p>c. Dependence on environmental triggers that are likely to be disrupted by climate change Many species rely on environmental triggers or cues to initiate life stages (e.g., migration, breeding, egg laying, seed germination, hibernation and spring emergence). While cues such as day length and lunar cycles will be unaffected by climate change, those driven by climate and season may alter in both their timing and magnitude, leading to asynchrony and uncoupling with environmental factors [40] (e.g., mismatches between advancing spring food availability peaks and hatching dates [41]). Climate change sensitivity is likely to be compounded when different sexes or life stages rely on different cues.</p>
<p>d. Dependence on interspecific interactions that are likely to be disrupted by climate change Climate change driven alterations in species’ ranges, phenologies and relative abundances may affect their beneficial inter-specific interactions (e.g., with prey, pollinators, hosts and symbionts) and/or those that may cause declines (e.g., with predators, competitors, pathogens and parasites). Species are likely to be particularly sensitive to climate change if, for example, they are highly dependent on one or few specific resource species and are unlikely to be able to substitute these for other species [42].</p>
<p>e. Rarity The inherent vulnerability of small populations to Allee effects and catastrophic events, as well as their generally reduced capacity to recover quickly following local extinction events, suggest that many rare species will be more sensitive to climate change than common species. Rare species include those with very small population sizes, as well as those that may be locally abundant but are geographically highly restricted.</p>
LOW ADAPTIVE CAPACITY
<p>f. Poor dispersal ability: Intrinsic dispersal limitations: Species with low dispersal rates or low potential for long distance dispersal (e.g., land snails, ant and raindrop splash-dispersed plants) have lowest adaptive capacity since they are unlikely to be able to keep up with a shifting climate envelope. Extrinsic dispersal limitations: Even where species are intrinsically capable of long distance or rapid dispersal, movement and/or successful colonisation may be reduced by low permeability or physical barriers along dispersal routes. These include natural barriers (e.g., oceans or rivers for terrestrial species), anthropogenic barriers (e.g., dams for freshwater species) and unsuitable habitats or conditions (e.g., ocean currents and temperature gradients for marine species). Species for which no suitable habitat or ‘climate space’ is likely to remain (e.g., Arctic ice-dependent species) may also be considered in this trait set.</p>
<p>g. Poor evolvability: Species’ potential for rapid genetic change will determine whether evolutionary adaptation can result at a rate sufficient to keep up with climate change driven changes to their environments. Species with low genetic diversity, often indicated by recent bottlenecks in population numbers, generally exhibit lower ranges of both phenotypic and genotypic variation. As a result, such species tend to have fewer novel characteristics that could facilitate adaptation to the new climatic conditions. Since direct measures of species’ genetic diversity are few, proxy measures of evolvability such as those relating to reproductive rates and outputs, and hence the rate at which advantageous novel genotypes could accumulate in populations and species [43], may be useful. Evidence suggests that evolutionary adaptation is possible in relatively short timeframes (e.g., 5 to 30 years [44]) but for most species with long generation lengths (e.g., large animals and many perennial plants), this is likely to be too slow to have any serious minimising effect on climate change impacts.</p>

doi:10.1371/journal.pone.0065427.t001

SPECIES VULNERABILITY MATRIX: Check any of the following boxes for each species if the factor is contributing negatively towards the species continued success given the current impact of climate change. Column “e. rarity” has been completed for you, for all 8 species.

	a. specialized habit	b./c. environmental tolerances/dependence on environmental triggers	d. interspecific interaction dependence	e. rarity	f. poor dispersal ability	“Total Score” students will add this column in analysis question 1
African Reed Frog					x	1
Asian Tiger Mosquito						0
Four Toed Lizard	x	x		x	x	4
Coral	x	x	x	x	x	5
Fantail Warbler						0
Common Coqui	x	x		x	x	4
Fingered Poison Frogs	x	x		x		3
Hornbill	x	x			x	3

POST ACTIVITY QUESTIONS:

1. Calculate the total risk factor for each species by adding the number of checked boxes. Write this number into the matrix as a new right hand column. Order the species based on highest to lowest vulnerability below.

See matrix above.

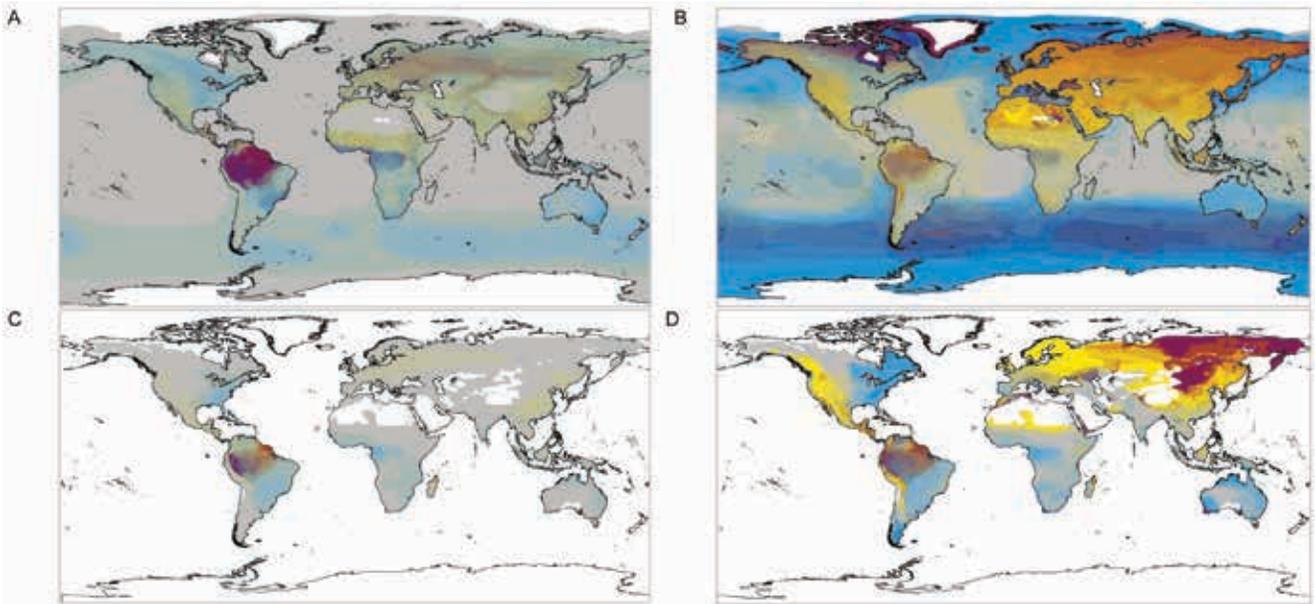
2. Any species with 3 or more check marks in the matrix above is considered a “loser” in response to climate change. Did any of the species categorized as “loser” surprise you? What about the “winners”? Why?

Student responses will vary.

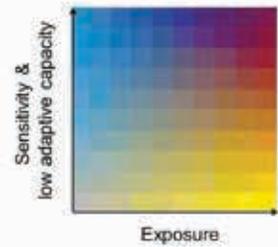
3. Using your completed matrix, Table 1 and the map provided on the next page (Figure 2), which region of the world is in the greatest need for biology conservation inventions, given the current climate change trajectory? Support your claim with specific evidence from the activity.

Student responses will vary.

FIGURE 2. CONCENTRATIONS OF CLIMATE CHANGE VULNERABLE SPECIES.



NOTE: Regions on the map containing species which exhibit sensitivity, low adaptive capacity and high exposure are shaded in maroon.



LESSON 2

CHILL COMA ASSAY AND EVOLUTION INVESTIGATION

VOCABULARY

CHILL COMA: the loss of mobility in insects and other ectotherms at low temperatures

CHILL COMA RECOVERY: the period of time that it takes for an insect to regain mobility after being in a chill coma

ASSAY: investigative (analytic) procedure

EVOLUTION: descent with modification, this includes small-scale evolution (changes in gene frequency in a population from one generation to the next) and large-scale evolution (the descent of different species from a common ancestor over many generations).

NATURAL SELECTION: one of the basic mechanisms of evolution in which differential survival and reproduction of organisms occurs as a consequence of the characteristics of the environment

MUTATION: change in DNA

GENETIC VARIATION: variation in alleles of genes that occurs both within and among populations. Genetic variation is important because it provides the genetic material for natural selection

LESSON SUMMARY

In this two day lesson, with an optional third day exploring the Hardy-Weinberg Principle to quantify evolutionary change in a population, students will have the opportunity to run the Chill Coma Recovery Assay with live *Drosophila melanogaster* specimens as an engaging introduction before further exploring the mechanisms of evolutionary change in a population, specifically in response to climate change. In Part I of this lesson students will perform a hands on lab procedure; use statistical analysis both on pen and paper, as well as using computer-based spreadsheets in Microsoft Excel; before exploring the mechanisms of evolution via supported self-investigation in Part II. Part III of the lesson is the optional Hardy-Weinberg activity that will further deepen student understanding of biostatistics, including both instruction and practice using the Hardy-Weinberg equations as well as additional application of the Chi-Squared statistical test.

STUDENT LEARNING OBJECTIVES

- SWBAT identify mechanisms of evolution
- SWBAT relate laboratory data to scientific phenomenon
- SWBAT understand the importance of genetic variation in evolution
- SWBAT create graphs and mathematically analyze data collected from an experiment

KEY QUESTION(S):

Is there potential for natural selection to act upon cold coma recovery in *Drosophila melanogaster*?

OVERALL TIME ESTIMATE:

THREE 45 minute class periods (with optional 4th day for Hardy-Weinberg application)

LEARNING STYLES:

Visual, Kinesthetic, Auditory, Cooperative



CHILL COMA RECOVERY TIME ASSAY BACKGROUND:

The fly *Drosophila melanogaster* has proven to be a successful model for examining organismal thermotolerance and responses to temperature extremes and fluctuations. *Drosophila melanogaster* originated in Africa and ancestral populations were thus presumably adapted to a tropical climate (David and Capy 1988). Beginning approximately 2-3 million years ago, *D. melanogaster* successfully moved out of Africa into a wide variety of climates and habitats, including spreading throughout the north and south temperate zones in both eastern and western hemispheres of the globe (David and Capy 1988). These globally invasive populations have adapted to local environmental conditions and exhibit specific patterns of thermal tolerance and resistance, with tropical species adapted to a warmer climate and temperate species adapted to a more variable climate, as evident from latitudinal clines in allele frequencies at specific genes as well as thermotolerance traits (David and Capy 1988). Several studies have shown evidence that populations in temperate environments display tolerance to high and low temperatures, resulting from seasonal variation in weather conditions, whereas tropical populations are generally intolerant to extreme temperature fluctuations due to the environmental stability of the tropical environment (David and Capy 1988, Hoffman et al. 2003). Studies have shown that there is a significant relationship between latitude and chill-coma recovery time among *Drosophila* species in which tropical species tend to have longer chill-coma recovery times while temperate species have shorter recovery times (Gibert et al. 2001, Overgaard et al. 2011).

At low temperatures, insects and other ectotherms lose their mobility; this is called a chill coma. The temperature at which chill coma is induced varies by species, but for *D. melanogaster*, all populations lose mobility when exposed to 0°C for more than 5 minutes (Gibert et al. 2001). Once brought back to higher temperatures (> 20°C), the insect will recover and resume their normal behavior and activities. Chill-coma recovery time is the period of time that it takes for an insect to regain mobility. A standard assay for measuring chill-coma recovery time is to put vials of flies in ice (0°C) for a certain period of time (e.g., 3 hours) and then measure the length of time it takes for the insect to resume normal behaviors (standing, walking, flying, etc.) (David et al. 1998). This simple assay is valuable to researchers because it requires little in the way of equipment, it can be conducted on large numbers of individuals, and it is useful in assessing differences in thermotolerance between species or between populations of a single species (Overgaard et al. 2011, Sinclair et al. 2012). In the following experiment, students will use this assay to compare chill-coma recovery times in six different lines (3 high resistance/fast recovery lines and 3 low resistance/slow recovery lines) of *Drosophila melanogaster* produced from isofemale lines, which are lines established from separate wild-caught gravid females. Isofemale lines are useful for studying genetic variation because genetic variation becomes fixed within each of these lines but varies clearly between lines, allowing the heritability of particular traits to be measured, analyzed, and compared among isofemale lines with different genetic backgrounds (David et al. 2005). These isofemale lines are derived from the *Drosophila melanogaster* Genetic Reference Panel (Mackay et al. 2012), a set of 192 fully genome-sequenced inbred and genetically homogeneous lines that capture natural genetic variation in cold tolerance and other traits.

Adapted from *Classroom Activity: Illustrating the Concept of Natural Genetic Variation in Traits as a Key Component of Evolution by Natural Selection: Thermotolerance in Drosophila melanogaster flies and Natural Selection in the Face of Contemporary Climate Change*

MATERIALS

- Student Page: Chill Coma Assay Procedure and Data Analysis
- Lab Introduction/Background PowerPoint with Teacher Script
- Data Analysis Excel Template
- Chill Coma Lab Materials:
 - o 6 Fly Lines — (See details in Hahn Manuscript, referenced below)
 - o Petri Dish Halves (tops and bottoms can be used) — 1 dish per pair of students
 - o Forceps — 1 per student pair
 - o Eppendorf tube (or other small container) of either ethanol or isopropyl alcohol — 1 per pair of students
 - o Ice and ice bucket/small cooler
 - o Timer/stopwatch

PART II

- Student Page: What Can Cold Flies Tell Us About Evolution?

PART III (EXTENSION)

- Student Page: Measuring Evolution with Hardy-Weinberg

ADVANCE PREPARATION

- Review Background Materials
- Prep Fly Lines, as described in the Hahn Manuscript, referenced below —
NOTE: This may take ~2 weeks advanced fly rearing
 - a. Day of Lab: also prep the necessary number of petri dishes, forceps, and alcohol vials
- Print Student Page: Chill Coma Assay Procedure and Data Analysis
- Print Student Page: What Can Cold Flies Tell Us About Evolution?
- Print Student Page: Measuring Evolution-Hardy-Weinberg Practice Problems

OBTAINING APPROPRIATE *DROSOPHILA* FOR THE CHILL COMA ASSAY

- **Option One:** Directly order any of the recommended lines (~\$15 per stock) from the Bloomington *Drosophila* Stock Center at Indiana University (<http://flystocks.bio.indiana.edu>).
- **Option Two:** The laboratory of Dr. Dan Hahn can send you starters of each of the fast and slow recovering stocks if available. Please allow at least two weeks for the starters to be grown and shipped. You can then grow up as many *Drosophila* as needed for your classes.

The most sustainable option is number one which allows teachers (and students) to work with the handling and rearing of *Drosophila*. *Drosophila* are an excellent model organism for many biological and environmental learning activities.

THE CARE AND KEEPING OF *DROSOPHILA*

Great electronic guide on *Drosophila*:

<http://blogs.rochester.edu/larracuenta/wp-content/uploads/2016/01/CarolinaDrosophilaManual0001.pdf>

The main *Drosophila* page from Carolina Biological:

<http://www.carolina.com/life-science/genetics/drosophila-fruit-fly-genetics/10419.ct>

Teachers can easily order instant food and supplies for rearing including bottles, vials, etc. from them. Alternatively, supplies can be purchased from Genessee Scientific (<https://geneseesci.com>).

PROCEDURE AND DISCUSSION QUESTIONS WITH TIME ESTIMATES

DAY ONE

1. **(8-10 MINUTES)** Show the provided PPT lesson (using the provided teacher script) to set the stage for the chill coma assay.
2. **(3-5 MINUTES)** Distribute the Student Page: Chill Coma Assay Procedure and Data Analysis
 - a. Read through the procedure with the students, ensuring they understand the process. A few tips to emphasize when working with the flies:
 - i. The students should NOT observe the flies so closely as to be breathing on the dishes (the warmth of their breath will cause the flies to exit the chill coma too quickly)
 - ii. A fly is considered “recovered” when it can right itself from its back or side unto all six legs steadily. The fly may take a few steps, but do not let it bump into a neighboring fly, because that might rouse the neighbor too soon.

3. (~20 MINUTES) Pass out fly lines and any other lab materials that students have not collected yet (petri dish, alcohol tube, forceps, timer). Circulate as students perform the assay. NOTE: Some lines may take as long as 20 minutes for all of the flies to recover from the chill coma.
4. (10-15 MINUTES) As students finish collecting the chill coma recovery data instruct them to clean up and begin the data analysis section of the lab packet.

DAY TWO:

1. (20-25 MINUTES) Debrief/correct any errors from the individual student data analysis from the previous day and instruct students to enter their fly line data in the provided Data Analysis Excel Template.
 - a. Use the Mean Recovery Time Graph to lead a discussion on variance emphasizing the error bar overlap.
2. (20 MINUTES) Provide students time to answer the related analysis questions in the Student Page: Chill Coma Assay Procedure and Data Analysis.
 - a. (Optional) Debrief the questions as a group and/or collect as a formative assessment.

DAY THREE

1. (20-30 MINUTES) Distribute copies of the Student Page: What Can Cold Flies Tell Us About Evolution? to each student and circulate, assisting as necessary, as they read and analyze the information provided about the mechanisms of evolution.
2. (10-15 MINUTES) Debrief and emphasize important points about the mechanisms of evolution. (Use the provided teacher key to assist)

(OPTIONAL) DAY FOUR

1. (10-15 MINUTES) Distribute copies of the Student Page: Measuring Evolution with Hardy-Weinberg. Review the background material as a class, providing as many sample practice problems as necessary (see references for further materials on instruction Hardy-Weinberg)
2. (~30 MINUTES) Instruct the students to begin work on the practice problems, circulating and assisting as necessary.

ASSESSMENT SUGGESTIONS

- Collect either/all Student Page(s)

ADDITIONAL TEACHER RESOURCES

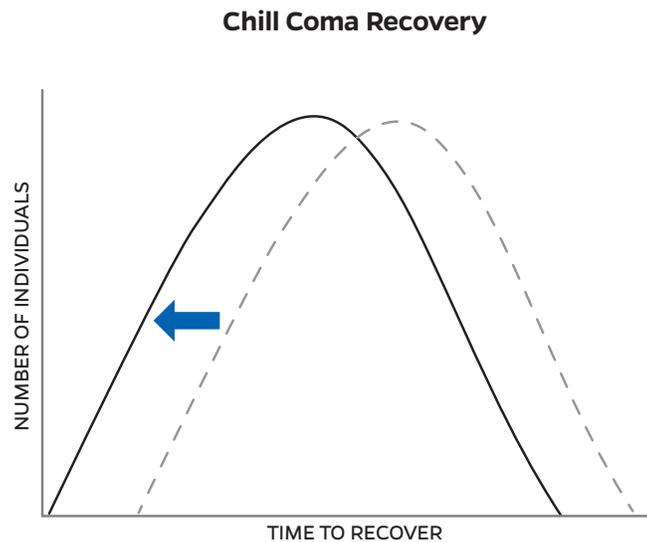
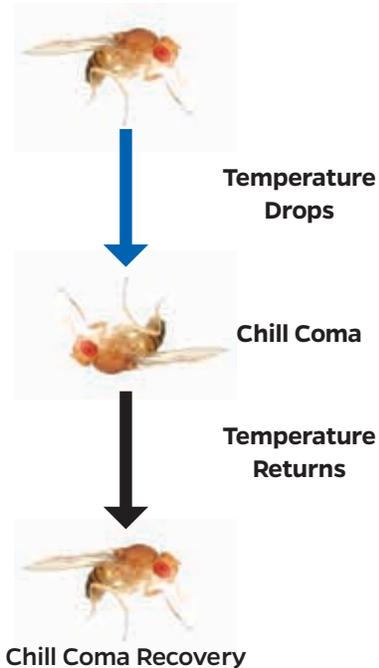
- Hardy-Weinberg Instructional Video: “Bozeman Science: Hardy-Weinberg Equation” <https://youtu.be/oEBNom3K9cQ>
- Additional Hardy-Weinberg Practice Set: “National Math + Science Hardy-Weinberg Equilibrium Problems” (with Key) <http://www.houstonisd.org/cms/lib2/TX01001591/Centricity/Domain/5363/Hardy%20Weinberg%20Problem%20Set%20KEY.pdf>
- Chi Squared Instructional Video: “Bozeman Science: Chi-squared Test” <https://youtu.be/WXPBoFDqNVk>

REFERENCES

Hahn, Daniel A. “Classroom Activity: Illustrating the Concept of Natural Genetic Variation in Traits as a Key Component of Evolution by Natural Selection: Thermotolerance in *Drosophila melanogaster* flies and Natural Selection in the Face of Contemporary Climate Change.” (under review). Available upon request from dahahn@ufl.edu.

Student Protocol: Chill Coma Assay

YOUR MISSION: Determine whether there is sufficient genetic variation in a population of *Drosophila melanogaster* fruit flies for directional selection of cold tolerance to occur.



PROCEDURE:

1. Collect your assigned vials from the ice bucket and/or instructor.
2. Tap your flies into a petri dish (one per line if you were assigned multiple lines) being careful that the flies are not touching one another.
 - a. If flies are touching, very gently push them away from one another by using the forceps.
3. Once the flies have been placed in the petri dishes, immediately start your stopwatch.
4. Observe your flies and record the time that each fly recovers on the data sheet. **Recovery is defined as when a fly can stand up on all of its legs.**
5. Once a fly is recovered, immediately pick the fly up with forceps and place it into the provided waste vial (containing ethanol or isopropyl alcohol) so the recovered fly is not accidentally recorded more than once. *Be careful not to touch any of the non-recovered flies*
6. Continue until each fly has been recorded as recovered or is verified as dead by the instructor.

DATA COLLECTION WORKSHEET

Vial ID*: _____

Recorded Recovery Time	
Record the time that each fly recovers. Ex: 6 mins 35 secs	
#	Time
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	

Converted Recovery Time	
Convert time to decimal form by dividing the seconds by 60. Ex: 6 mins 35 secs = 6.58 minutes (35/60= 0.58)	
#	Time
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	

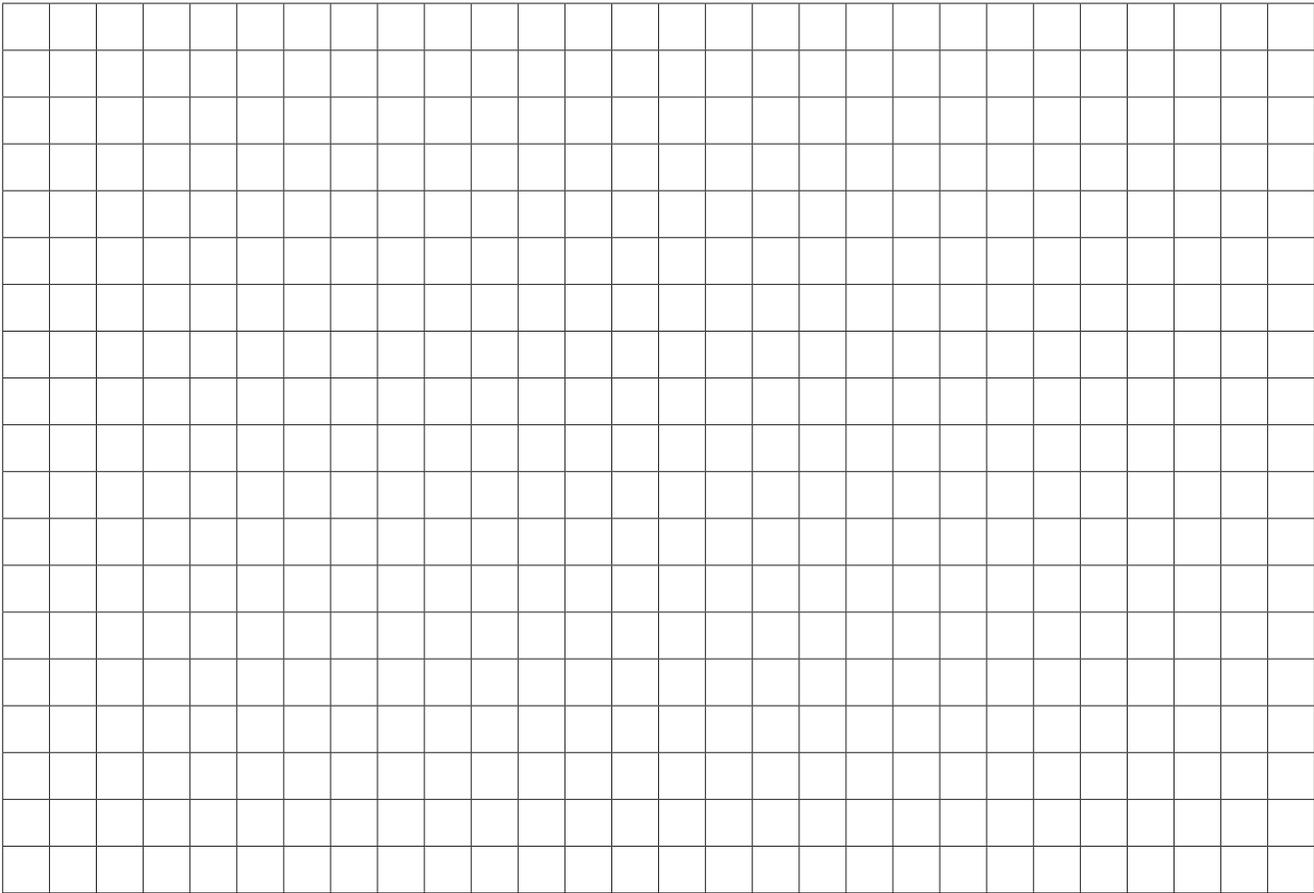
DATA ANALYSIS

Mean: _____ Std Dev: _____ SEM (95% confidence): _____

Upper Error Limit: _____ Lower Error Limit: _____

*If another group has the same vial ID (and thus fly line) complete your data analysis using the data points from both groups

Create an appropriate graph, including 95% confidence error bars, on the axis provided below.



ANALYSIS QUESTIONS

1. What type of graph did you construct? Why did you choose this type?
2. Which fly line demonstrated the most rapid recovery time? The slowest recovery time?
3. Which fly lines demonstrated the most significant difference in recovery time? Justify your answer using the lab data.
4. State at least 3 possible sources of error related to data collection in this assay. Suggest a way to correct for each error.

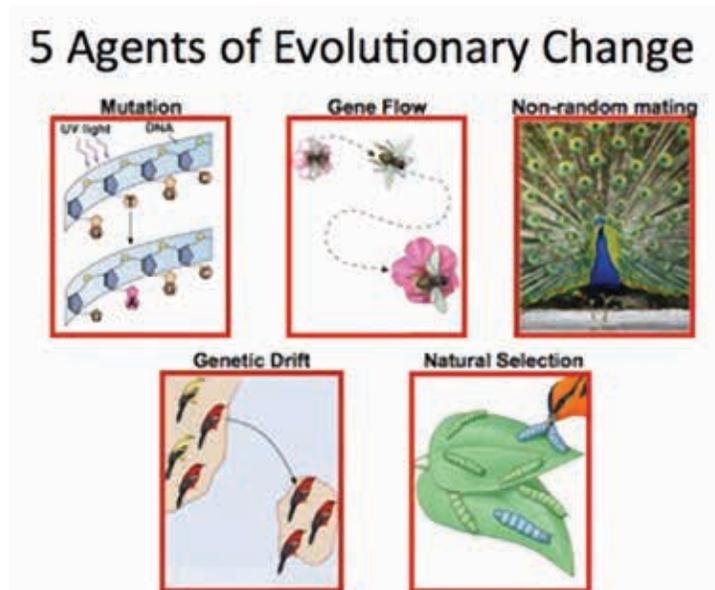
What Can Cold Flies Tell Us About Evolution?

INTRODUCTION: From the data you collected in the Chill Coma Assay it is clear that some strains of *Drosophila melanogaster* recover more rapidly from exposure to cold events than others. Considering what you learned about climate change and “whiplash weather” events it appears that it would be advantageous to be a fly from one of the strains that recovers most rapidly. Let’s explore how populations of organisms adapt over time in response to changes in their environment.

By examining the history of life on earth a frequently observed pattern is that organisms with traits that confer an advantage in response to environmental pressures survive and reproduce more frequently than those with less favorable traits. This is known as natural selection and is one of the 5 mechanisms of evolutionary change. The following is a summary of the processes that drive evolution:

First we must consider the question: what is evolution? The most basic definition from a cellular biologist’s perspective is: Evolution is a change in gene (allele) frequencies over time.

What drives these changes?



While all of these agents of change drive evolution, we will focus on natural selection. For natural selection to occur the following conditions must be met:

1. There must be variation within the population.
2. This variation is genetically inherited
3. This variation leads to differential reproduction

LET'S REVIEW WHAT YOU JUST LEARNED:

1. Explain what it means for genetic variation to be present in a population.
2. Which population has more genetic variation? Explain your answer.
Population 1: A research strain of flies which are inbred specifically for the homozygous recessive white eye color allele or
Population 2: Wild type fruit fly collected from a North Carolina Farmer's market.
3. Explain differential reproduction in your own words.
4. Why is it important that variation be heritable?

WHAT CAUSES THIS GENETIC VARIATION IN THE FIRST PLACE?

GOOD QUESTION. That's where the other 4 agents of change come into play, resulting in various allele frequencies within an interbreeding population (species).

- **MUTATIONS** cause changes to the DNA (the alleles) and possibly to the expressed protein and thus phenotype of the organism.
- **GENE FLOW** increases variation when organisms emigrate into a new area or immigrate out of an existing one, thus changing the allele frequency of that population's gene pool.
- **NON-RANDOM MATING** (or sexual selection)- Sexual selection acts on an organism's ability to obtain, or successfully copulate, with a mate. Those individuals who successfully mate more often, due to their desirable sexual traits (a thick, bushy mane on a male lion or long, brilliant tail feathers of a male peacock) will pass on the alleles for these sex related genes in greater frequency than those individuals who have less "attractive" sex features and thus reproduce less.
- **GENETIC DRIFT** - alternations in the allele frequencies of a population due to change. No selective pressure is involved in genetic drift; it is due to random chance and occurs in all populations.

GREAT! SO....WHAT DOES ALL THIS MEAN?

Well, when you consider all the agents of evolutionary change you are analyzing an organism's fitness. Fitness is a handy concept because it lumps everything that matters to natural selection (survival, mate-finding, reproduction) into one idea. **THE FITTEST INDIVIDUAL IS NOT NECESSARILY THE STRONGEST, FASTEST, OR BIGGEST.** A genotype's fitness includes its ability to survive, find a mate, produce offspring — and ultimately leave its genes in the next generation.

YOU TRY IT:

1. Would it be possible for a population of flies with no mutation, gene flow, non-random mating, or genetic drift to undergo natural selection? Explain why or why not.

2. Do the following examples best describe mutation, gene flow, nonrandom mating or genetic drift?
 - a. Female hornbills prefer males with larger beaks as mates. _____
 - b. The DNA of a fingered tree frog changes as a result of exposure to UV radiation from the sun. _____
 - c. A few individuals of common Coquí are isolated from the larger population by a new road (a chance event). As a result the allele frequencies in the small isolated population begin to change significantly from the allele frequencies in the original larger population. _____
 - d. Asian tiger mosquitoes are expanding their ranges. As a result individuals are frequently leaving a population to travel further north. These individuals do not return to the original population. _____

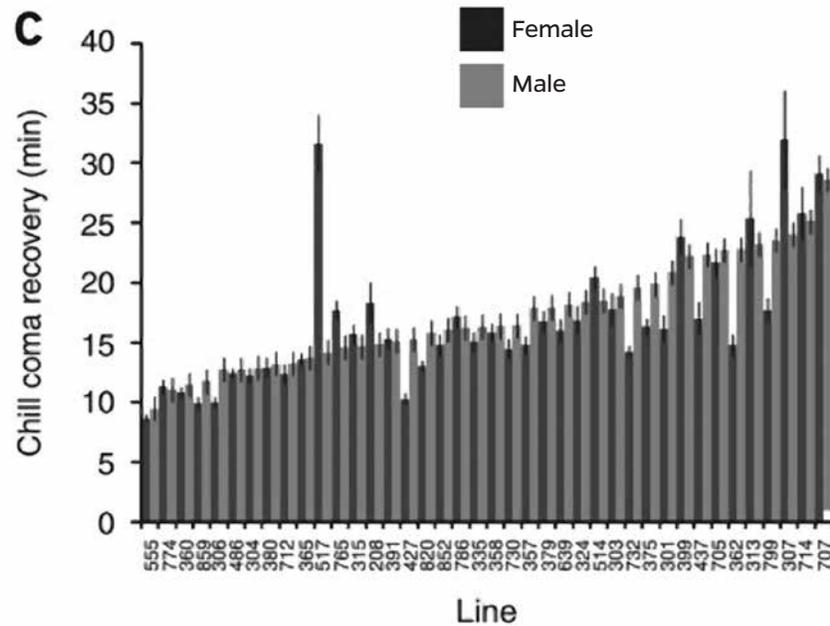
3. Assuming that all the traits contributing to the results below are genetically controlled, which member of a population of Fantail Warblers is most evolutionarily fit? One that _____
 - a. lives 12 years, produces 36 eggs, 19 hatch and reproduce.
 - b. lives 14 years, produces 26 eggs, 14 hatch and reproduce.
 - c. lives 7 years, produces, 24 eggs, 21 hatch and reproduce.
 - d. lives 5 years, produces 23 eggs, 18, hatch and reproduce.
 - e. lives 17 years, produces 20 eggs, 20 hatch and reproduce.

Explain your answer:

THINKING BACK TO THE LAB DATA:

1. Given what you now know about evolution, propose why the different strains of flies you observed have different chill coma recovery times.
2. How can you tell if there is genetic variation within this population using the results from your assay?
3. If you were going to conduct future research, which of the lines you conducted the assay on would you be most interested in studying and why?
4. Why is it likely that chill coma recovery time would be a trait that natural selection acts upon?

5. You explored 6 different lines of flies, but in reality there are nearly 600 lines. 40 are displayed below.



a. Given the above information, why is collaboration important in science?

b. Using the complete data set provided above suggest an additional research question you could investigate.

6. While you observed differences in chill coma recovery time, the exact mechanism is currently unknown. Use your knowledge of experimental design to write a procedure investigating one of the following:

- The effect of different times that flies are kept on ice to assess how varying the time of exposure to physiological stress influences recovery time.
- The role of age on recovery times to evaluate how organisms differ in their ability to handle physiological stress as they age.
- The role of developmental temperature on the expression of cold tolerance to determine if rearing temperature affects later resistance to cold stress.

Measuring Evolution With The Hardy-Weinberg Principle

INTRODUCTION: We have examined genetic variation within one species of *Drosophila* (fruit fly). Could this genetic drive evolution and ultimately speciation? (the lineage-splitting event that produces two or more separate species). Is there a way to quantify these genetic changes through time? The answer to both of the above questions is “YES!” thanks to the widely used Hardy-Weinberg Principle. Read the following to investigate more about this principle:

THE HARDY-WEINBERG PRINCIPLE

Developed in the early 20th century by Godfrey Hardy, a mathematician, and Wilhelm Weinberg, a physician, the Hardy-Weinberg equations serve as a null hypothesis model; meaning that if a population's allele frequencies equal the variables in the Hardy-Weinberg equations the population is NOT experiencing any changes in allele frequencies and thus is not undergoing evolution. This population would be referred to as being in Hardy-Weinberg Equilibrium.

To be in Hardy-Weinberg Equilibrium, a population must exhibit the following conditions:

1. very large population size (no genetic drift)
2. no migration (no gene flow in or out)
3. no mutation (no genetic change)
4. random mating (no sexual selection)
5. no natural selection (every genotype is equally fit)

The Hardy-Weinberg Principle consists of two equations: one applies directly to alleles, while the other is used to measure genotypes:

$$p + q = 1$$

p= frequency of the dominant allele

q= frequency of the recessive allele

$$p^2 + 2pq + q^2 = 1$$

p^2 = frequency of the homozygous dominant genotype

$2pq$ = frequency of the heterozygous genotype

q^2 = frequency of the homozygous recessive genotype

GREAT! SO, WHAT DOES THAT MEAN FOR AN ACTUAL POPULATION OF ORGANISMS?

Thus, if the allele frequencies of particular gene are measured in a population, using the Hardy-Weinberg equations we can determine if the population is in Hardy Weinberg Equilibrium for that particular gene (aka, not evolving) or if the population is NOT in equilibrium, then it is exhibiting signs of evolution, due to as evidenced by a change in the allele frequency. This can be accomplished by comparing the allele values calculated using the Hardy-Weinberg equations to the allele frequencies measured in the wild population.

For example if the calculated frequency of the p allele (dominant allele) is determined to be 0.7 for a given gene in a particular population, and the calculated frequency of the q allele is 0.3 for the same gene, then $0.7 + 0.3 = 1$ at one generation. If the same allele frequencies are observed in the population in future generations then this population is in Hardy-Weinberg equilibrium; therefore the population does not have significant changes in allele frequency (compared to the calculated values) for that gene and thus is not evolving. However, if the allele frequencies change substantially from one generation to another generation in the future (one or more generations later), then evolution is occurring in that population. Although many people think of evolution as only a slow process, it can occur quickly in some circumstances. For example, evolution can happen in as little as 1-2 generations!

READY TO PUT THE PRINCIPLE TO WORK?

The exact genetic mechanism for recovery from the chill coma phenomenon is not yet known in *Drosophila melanogaster*, however for the purposes of this exercise, and all the following practice problems, let's assume it's controlled by a single, completely dominant gene named Chilly. The dominant allele displays rapid chill coma recovery time and homozygous recessive individuals display a slower chill coma recovery.

1. In a sampled population of *Drosophila melanogaster* of 250 individuals, 192 recover from chill coma rapidly. Determine the p and q values for this population.
2. In the same population described in question one, what percentage of flies are heterozygous for the Chilly gene?
3. A larger population of *Drosophila melanogaster* is sampled and out of 2020 individuals, 392 recover slowly from chill coma. Determine the number of individuals that are homozygous dominant, heterozygous and homozygous recessive.
4. In a small population of flies the expected allele frequencies are $p = 0.6$ and $q = 0.4$. When the population is analyzed the actual frequencies observed are $p = 0.8$ and $q = 0.2$. Give at least two possible reasons why the observed and expected frequency did not match.

5. As described in question 4, often the expected and observed allele frequencies DO NOT match, since the Hardy-Weinberg equilibrium equations serve only as a null hypothesis. Further statistical analysis must be done to determine if the differences between observed and expected values are significant (p value of 0.5 or less) enough to warrant further investigation. Run a Chi Squared analysis (a chart has been provided to help you organize the analysis), given the following information to determine if the population of flies should be more closely studied for evidence of evolution.

a. In a population of 300 flies, 260 display the dominant phenotype. Determine the number of expected individuals for all three genotypes and record them in the table below.

b. The population of flies is sampled and the p value is determined to be 0.9. Determine the number of observed individuals for all three genotypes and record them in the table below.

Genotype/Phenotype	Observed (o)	Expected (e)	(o-e)	(o-e) ² /e
				$\chi^2 =$

c. How many degrees of freedom do you have? _____

d. Use the Chi Squared Table below to determine the P value. _____

CHI-SQUARE TABLE								
Degrees of Freedom								
p	1	2	3	4	5	6	7	8
0.05	3.84	5.99	7.82	9.49	11.07	12.59	14.07	15.51
0.01	6.64	9.32	11.34	13.28	15.09	16.81	18.48	20.09

e. Interpret the P value as it relates to these data. Explain the significance in terms of evolution.

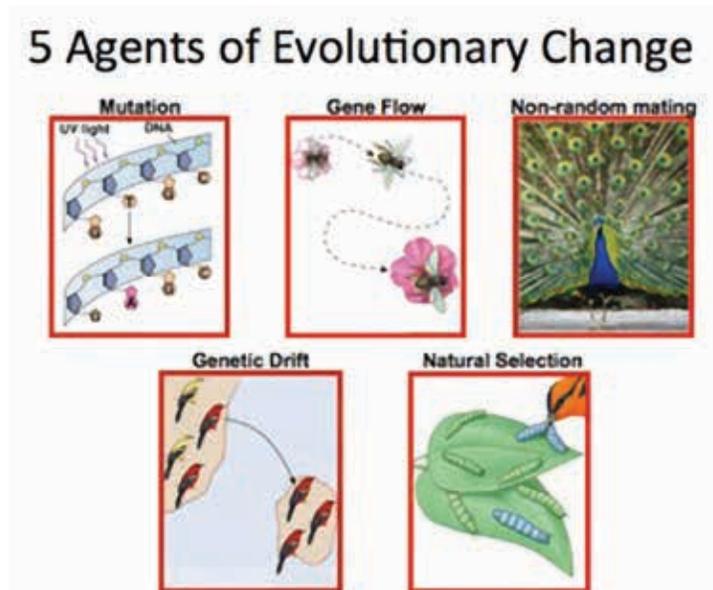
What Can Cold Flies Tell Us About Evolution?

INTRODUCTION: From the data you collected in the Chill Coma Assay it is clear that some strains of *Drosophila melanogaster* recover more rapidly from exposure to cold events than others. Considering what you learned about climate change and “whiplash weather” events it appears that it would be advantageous to be a fly from one of the strains that recovers most rapidly. Let’s explore how populations of organisms adapt over time in response to changes in their environment.

By examining the history of life on earth a frequently observed pattern is that organisms with traits that confer an advantage in response to environmental pressures survive and reproduce more frequently than those with less favorable traits. This is known as natural selection and is one of the 5 mechanisms of evolutionary change. The following is a summary of the processes that drive evolution:

First we must consider the question: what is evolution? The most basic definition from a cellular biologist’s perspective is: Evolution is a change in gene (allele) frequencies over time.

What drives these changes?



While all of these agents of change drive evolution, we will focus on natural selection. For natural selection to occur the following conditions must be met:

1. There must be variation within the population.
2. This variation is genetically inherited
3. This variation leads to differential reproduction

LET'S REVIEW WHAT YOU JUST LEARNED:

1. Explain what it means for genetic variation to be present in a population.

Individuals within the population will have different allele frequencies, which may or may not display as differences in phenotype as well. AKA the individuals ARE NOT genetically identical.

2. Which population has more genetic variation? Explain your answer.

Population 1: A research strain of flies which are inbred specifically for the homozygous recessive white eye color allele or

Population 2: Wild type fruit fly collected from a North Carolina Farmer's market.

Population 2, because we are assuming they would not be genetically identical, since they were collected from the wild and are not manipulated in the laboratory.

3. Explain differential reproduction in your own words.

Some individuals have greater reproductive success than others; those individuals with greater reproductive success will contribute more of their genes to gene pool of the following generations.

4. Why is it important that variation be heritable?

It is important that the genetic variation (especially those traits that are advantageous) be passed on to the next generation (or inherited).

WHAT CAUSES THIS GENETIC VARIATION IN THE FIRST PLACE?

GOOD QUESTION. That's where the other 4 agents of change come into play, resulting in various allele frequencies within an interbreeding population (species).

- **MUTATIONS** cause changes to the DNA (the alleles) and possibly to the expressed protein and thus phenotype of the organism.
- **GENE FLOW** increases variation when organisms emigrate into a new area or immigrate out of an existing one, thus changing the allele frequency of that population's gene pool.
- **NON-RANDOM MATING** (or sexual selection)- Sexual selection acts on an organism's ability to obtain, or successfully copulate, with a mate. Those individuals who successfully mate more often, due to their desirable sexual traits (a thick, bushy mane on a male lion or long, brilliant tail feathers of a male peacock) will pass on the alleles for these sex related genes in greater frequency than those individuals who have less "attractive" sex features and thus reproduce less.
- **GENETIC DRIFT** - alternations in the allele frequencies of a population due to change. No selective pressure is involved in genetic drift; it is due to random chance and occurs in all populations.

GREAT! SO....WHAT DOES ALL THIS MEAN?

Well, when you consider all the agents of evolutionary change you are analyzing an organism's fitness. Fitness is a handy concept because it lumps everything that matters to natural selection (survival, mate-finding, reproduction) into one idea. **THE FITTEST INDIVIDUAL IS NOT NECESSARILY THE STRONGEST, FASTEST, OR BIGGEST.** A genotype's fitness includes its ability to survive, find a mate, produce offspring — and ultimately leave its genes in the next generation.

YOU TRY IT:

1. Would it be possible for a population of flies with no mutation, gene flow, non-random mating, or genetic drift to undergo natural selection? Explain why or why not.

No, because the described population above is exhibiting all the traits required for Hardy-Weinberg equilibrium and would not be experiencing evolutionary events. (OR: There would not be any genetic variation for natural selection to act upon.)

2. Do the following examples best describe mutation, gene flow, nonrandom mating or genetic drift?

- a. Female hornbills prefer males with larger beaks as mates. *Nonrandom mating*
- b. The DNA of a fingered tree frog changes as a result of exposure to UV radiation from the sun. *Mutation*
- c. A few individuals of common Coquí are isolated from the larger population by a new road (a chance event). As a result the allele frequencies in the small isolated population begin to change significantly from the allele frequencies in the original larger population. *Genetic drift*
- d. Asian tiger mosquitoes are expanding their ranges. As a result individuals are frequently leaving a population to travel further north. These individuals do not return to the original population. *Gene flow*

3. Assuming that all the traits contributing to the results below are genetically controlled, which member of a population of Fantail Warblers is most evolutionarily fit? One that _____

- a. lives 12 years, produces 36 eggs, 19 hatch and reproduce.
- b. lives 14 years, produces 26 eggs, 14 hatch and reproduce.
- c. lives 7 years, produces, 24 eggs, 21 hatch and reproduce.*
- d. lives 5 years, produces 23 eggs, 18, hatch and reproduce.
- e. lives 17 years, produces 20 eggs, 20 hatch and reproduce.

Explain your answer:

The bird described in choice c has the most reproductively successful offspring, thus its alleles are more frequently found in the gene pool.

THINKING BACK TO THE LAB DATA:

1. Given what you now know about evolution, propose why the different strains of flies you observed have different chill coma recovery times.

If the chill coma response phenomenon is genetic, then the different lines represent genetic variation for that trait.

2. How can you tell if there is genetic variation within this population using the results from your assay?

Based on the statistical analysis, those lines with significant genetic variation will NOT show any overlap in their 95% confidence error bars.

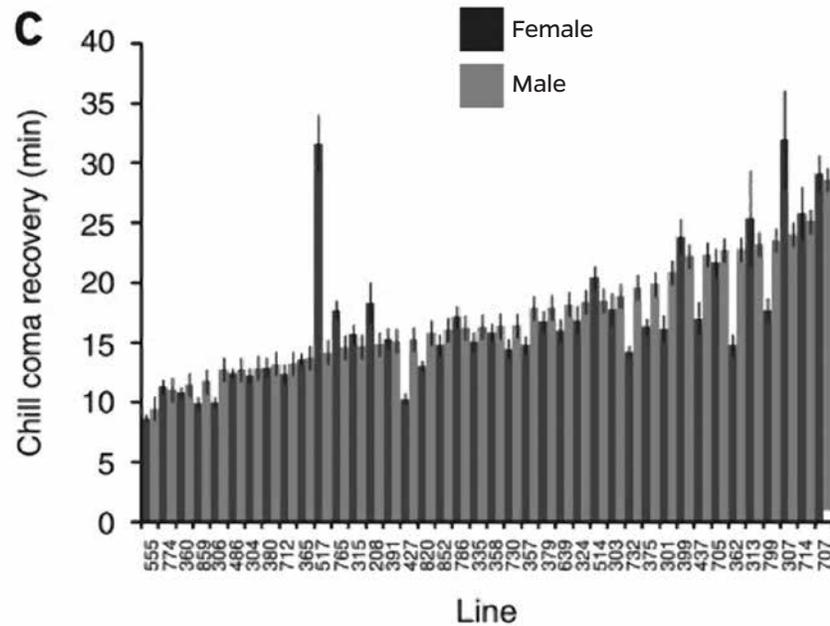
3. If you were going to conduct future research, which of the lines you conducted the assay on would you be most interested in studying and why?

Student answers will vary, but ideally students will choose the line with the fastest response time, since those individuals would likely survive current climate change patterns more successfully than a slow recovery line.

4. Why is it likely that chill coma recovery time would be a trait that natural selection acts upon?

Fly populations that have a rapid chill coma recovery time would be more likely to survive rapidly changing climates/whiplash weather events and thus experience differential reproduction, passing on the advantageous alleles to the next generation, compared to a population with slow chill coma recovery time.

5. You explored 6 different lines of flies, but in reality there are nearly 600 lines. 40 are displayed below.



a. Given the above information, why is collaboration important in science?

Student answers will vary, but ideally they will discuss the large number of lines, the logistics of such a large study, etc.

b. Using the complete data set provided above suggest an additional research question you could investigate.

Student answers will vary but may include:

Why is there a difference between male and females of the same line?

Why is line 517 so different from the other lines?

6. While you observed differences in chill coma recovery time, the exact mechanism is currently unknown. Use your knowledge of experimental design to write a procedure investigating one of the following:

a. The effect of different times that flies are kept on ice to assess how varying the time of exposure to physiological stress influences recovery time.

b. The role of age on recovery times to evaluate how organisms differ in their ability to handle physiological stress as they age.

c. The role of developmental temperature on the expression of cold tolerance to determine if rearing temperature affects later resistance to cold stress.

Student answers will vary, but should include clear IV and DV, controls, constants, replication, duration of experiment, data collection consideration, etc.

Measuring Evolution With The Hardy-Weinberg Principle

INTRODUCTION: We have examined genetic variation within one species of *Drosophila* (fruit fly). Could this genetic drive evolution and ultimately speciation? (the lineage-splitting event that produces two or more separate species). Is there a way to quantify these genetic changes through time? The answer to both of the above questions is “YES!” thanks to the widely used Hardy-Weinberg Principle. Read the following to investigate more about this principle:

THE HARDY-WEINBERG PRINCIPLE

Developed in the early 20th century by Godfrey Hardy, a mathematician, and Wilhelm Weinberg, a physician, the Hardy-Weinberg equations serve as a null hypothesis model; meaning that if a population’s allele frequencies equal the variables in the Hardy-Weinberg equations the population is NOT experiencing any changes in allele frequencies and thus is not undergoing evolution. This population would be referred to as being in Hardy-Weinberg Equilibrium.

To be in Hardy-Weinberg Equilibrium, a population must exhibit the following conditions:

1. very large population size (no genetic drift)
2. no migration (no gene flow in or out)
3. no mutation (no genetic change)
4. random mating (no sexual selection)
5. no natural selection (every genotype is equally fit)

The Hardy-Weinberg Principle consists of two equations: one applies directly to alleles, while the other is used to measure genotypes:

$$p + q = 1$$

p= frequency of the dominant allele

q= frequency of the recessive allele

$$p^2 + 2pq + q^2 = 1$$

p^2 = frequency of the homozygous dominant genotype

$2pq$ = frequency of the heterozygous genotype

q^2 = frequency of the homozygous recessive genotype

GREAT! SO, WHAT DOES THAT MEAN FOR AN ACTUAL POPULATION OF ORGANISMS?

Thus, if the allele frequencies of particular gene are measured in a population, using the Hardy-Weinberg equations we can determine if the population is in Hardy Weinberg Equilibrium for that particular gene (aka, not evolving) or if the population is NOT in equilibrium, then it is exhibiting signs of evolution, due to as evidenced by a change in the allele frequency. This can be accomplished by comparing the allele values calculated using the Hardy-Weinberg equations to the allele frequencies measured in the wild population.

For example if the calculated frequency of the p allele (dominant allele) is determined to be 0.7 for a given gene in a particular population, and the calculated frequency of the q allele is 0.3 for the same gene, then $0.7 + 0.3 = 1$ at one generation. If the same allele frequencies are observed in the population in future generations then this population is in Hardy-Weinberg equilibrium; therefore the population does not have significant changes in allele frequency (compared to the calculated values) for that gene and thus is not evolving. However, if the allele frequencies change substantially from one generation to another generation in the future (one or more generations later), then evolution is occurring in that population. Although many people think of evolution as only a slow process, it can occur quickly in some circumstances. For example, evolution can happen in as little as 1-2 generations!

READY TO PUT THE PRINCIPLE TO WORK?

The exact genetic mechanism for recovery from the chill coma phenomenon is not yet known in *Drosophila melanogaster*, however for the purposes of this exercise, and all the following practice problems, let's assume it's controlled by a single, completely dominant gene named Chilly. The dominant allele displays rapid chill coma recovery time and homozygous recessive individuals display a slower chill coma recovery.

1. In a sampled population of *Drosophila melanogaster* of 250 individuals, 192 recover from chill coma rapidly. Determine the p and q values for this population.

$$q^2 = 58/250$$

$$q = 0.48$$

$$p = 0.52$$

2. In the same population described in question one, what percentage of flies are heterozygous for the Chily gene?

$$\text{Heterozygous} = 2pq = 2 (.52) (.48) = 0.50$$

3. A larger population of *Drosophila melanogaster* is sampled and out of 2020 individuals, 392 recover slowly from chill coma. Determine the number of individuals that are homozygous dominant, heterozygous and homozygous recessive.

$$q^2 = 392/2020$$

$$\text{homo dom} = p^2 = (0.56)^2 * 2020 = 633 \text{ individuals}$$

$$\text{hetero dom} = 2pq = 2(0.56)(0.44) * 2020 = 995 \text{ individuals}$$

$$q = 0.44$$

$$\text{homo rec} = q^2 = (0.44)^2 * 2020 = 372 \text{ individuals}$$

$$p = 0.56$$

4. In a small population of flies the expected allele frequencies are p = 0.6 and q = 0.4. When the population is analyzed the actual frequencies observed are p = 0.8 and q = 0.2. Give at least two possible reasons why the observed and expected frequency did not match.

Student answers will vary. Any of the above "Hardy-Weinberg Conditions" and/or the population is exhibiting evolution via changes in allele frequency are acceptable answers.

5. As described in question 4, often the expected and observed allele frequencies DO NOT match, since the Hardy-Weinberg equilibrium equations serve only as a null hypothesis. Further statistical analysis must be done to determine if the differences between observed and expected values are significant (p value of 0.5 or less) enough to warrant further investigation. Run a Chi Squared analysis (a chart has been provided to help you organize the analysis), given the following information to determine if the population of flies should be more closely studied for evidence of evolution.

a. In a population of 300 flies, 260 display the dominant phenotype. Determine the number of expected individuals for all three genotypes and record them in the table below.

$$q^2 = 40/300 \quad \text{homo dom} = p^2 = (0.63)^2 * 300 = 119 \text{ individuals}$$

$$p = 0.63 \quad \text{hetero dom} = 2pq = 2(.63)(.37) * 300 = 140 \text{ individuals}$$

$$q = 0.37 \quad \text{homo rec} = q^2 = (0.37)^2 * 300 = 41 \text{ individuals}$$

b. The population of flies is sampled and the p value is determined to be 0.9. Determine the number of observed individuals for all three genotypes and record them in the table below.

$$p = 0.90 \quad \text{homo dom} = p^2 = (0.90)^2 * 300 = 242 \text{ individuals}$$

$$q = 0.10 \quad \text{hetero dom} = 2pq = 2(0.90)(0.10) * 300 = 54 \text{ individuals}$$

$$\text{homo rec} = q^2 = (0.10)^2 * 300 = 3 \text{ individuals}$$

Genotype/Phenotype	Observed (o)	Expected (e)	(o-e)	(o-e) ² /e
CC / quick recovery	242	119	124	129.2
Cc / quick recovery	54	140	-86	52.8
cc/ slow recovery	3	41	-38	35.2
				X² = 217.2

c. How many degrees of freedom do you have? **2**

d. Use the Chi Squared Table below to determine the P value. **less than 0.01**

CHI-SQUARE TABLE								
Degrees of Freedom								
p	1	2	3	4	5	6	7	8
0.05	3.84	5.99	7.82	9.49	11.07	12.59	14.07	15.51
0.01	6.64	9.32	11.34	13.28	15.09	16.81	18.48	20.09

e. Interpret the P value as it relates to these data. Explain the significance in terms of evolution.

A p value of less than 0.01 means that there is less than a 1% probability that the difference in observed vs expected is due solely to random chance. Thus we can assume that this population is NOT in Hardy-Weinberg equilibrium and is undergoing changes in allele frequency due to evolution events.

LESSON 3

Patterns of Natural Selection

VOCABULARY

IRECTIONAL SELECTION: natural selection in which an extreme phenotype (i.e., phenotype either greater or lesser than the population mean) is favored over other phenotypes, causing the allele frequency to shift over time in the direction of that phenotype

STABILIZING SELECTION: natural selection in which intermediate forms of a trait are favored and the extremes are selected against

DISRUPTIVE SELECTION: natural selection in which extreme forms of a trait are favored over intermediate values. Variance of the trait increases and the population is divided into two distinct groups. Over time, disruptive selection can lead to two new species

LESSON SUMMARY

In this one-day lesson students will first learn about three types of natural selection: directional, stabilizing and disruptive selection. Next, students complete a practice set with different population scenarios and predict what kind of natural selection the population will undergo. As a conclusion to the lesson, students work in groups to identify how a real population of organisms might respond to climate change induced changes in their environments. Each group draws a graph and writes predictions on a white board. The group information is presented to the entire class and the students fill in a graphic organizer listing problems created by climate change and possible adaptations in response to those problems.

STUDENT LEARNING OBJECTIVES

- SWBAT differentiate between direction, stabilizing, and disruptive selection
- SWBAT predict what kind of selection might occur in a species in response to changes in the environment due to climate change

MATERIALS:

- Student Page: Patterns of Natural Selection
- Student Page: Guided Notes Outline
- Student Page: Natural Selection in the Face of Climate Change – Species Fact Sheets
- 6 White Boards and Markers (one for each group)

BACKGROUND INFORMATION:

See first page of student worksheet.

ADVANCE PREPARATION:

- Print Student Page: Patterns of Natural Selection - ONE copy per student
- Student Page: Guided Notes Outline- ONE copy per student
- Student Page: Natural Selection in the Face of Climate Change — Species Fact Sheets (consider laminating for future use) — ONE set (each group of 2-4 students will get ONE sheet)

KEY QUESTION(S):

What types of natural selection might occur as a result of climate change?

OVERALL TIME ESTIMATE

ONE 45 minute class period

LEARNING STYLES

Visual, auditory, and kinesthetic



PROCEDURE AND DISCUSSION QUESTIONS WITH TIME ESTIMATES

1. **(10-12 MINUTES)** Pass out the Part I Student Worksheet. Review the key features of natural selection from the activity “What Can Cold Flies Teach Us About Evolution.” Discuss the three types of natural selection on the first page with the class. Have students complete the four practice problems.
2. **(10-15 MINUTES)** Pass out one whiteboard, markers and ONE Student Page: Natural Selection in the Face of Climate Change-Species Fact Sheets to each group. Instruct students to create a graph on their whiteboard showing the frequency of one trait of the species on their card that might be affected by climate change. Students should draw one line representing the current trait frequencies and then add a second line showing how that trait might be acted upon by evolution to help the species survive the challenges posed by climate change (see teacher answer key for examples). Students should also write a 1-2 sentence summary of how the climate change issue on the card could result in the pattern of natural selection depicted in their graph. Inform students that they will have 10 minutes to create their graph and prepare a summary of the species information and climate change challenge to the entire class.
3. **(20- 25 MINUTES)** Pass out ONE student-guided note sheet to EACH student. Fill out the definition of climate change together as a class. Groups should take turns showing the graphs they created and explain how climate change is affecting their species and how their species could potentially evolve to become better suited to future environmental conditions created by climate change. Then each group of students should add one statement to the “climate change challenge” box and one statement to the “As a result of Climate Change Natural selection would favor...” box.
4. **(5-10 MINUTES)** Conclude the class with a discussion on the limits of evolutionary adaptability. Make sure to emphasize that many species will NOT be able to evolve in response to climate change and face serious risk of extinction.

ASSESSMENT SUGGESTIONS:

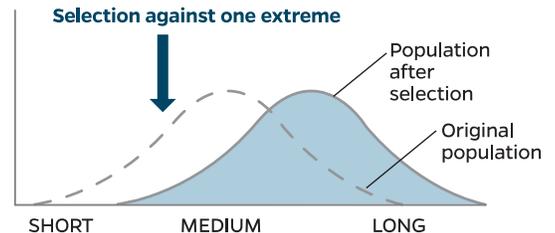
- Collect either/both Student Page(s)

Patterns of Natural Selection

DIRECTIONAL SELECTION: Natural selection in which an extreme phenotype is favored over other phenotypes, causing the alleles causing that phenotype to be favored and shift over time in the direction of that phenotype.

Example: Prior to the industrial revolution in England the peppered moth had light coloration and lived on trees covered with light colored lichen. This provided camouflage against predatory birds. There were a few dark individuals in the population, but they were usually eaten by birds. However, once the industrial revolution began the light-colored lichens covering the trees were killed by sulfur dioxide emissions from the new factories. Without the light background of the trees, the light moths were more visible to birds and now the dark moths had a camouflage advantage. In 1848, the dark moths comprised 1% of the population and by 1959 they represented ~90% of the population.

DIRECTIONAL SELECTION

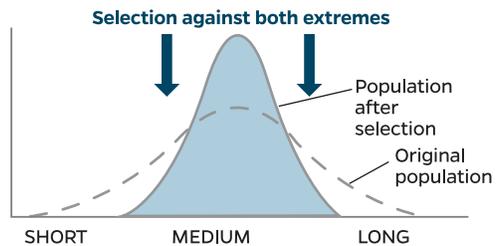


FOR: one extreme trait
AGAINST: the other extreme

STABILIZING SELECTION: Natural selection in which intermediate forms of a trait are favored and more extreme values are selected against.

Example: Human birth weight has undergone stabilizing selection. Babies of low weight lose heat more quickly and get ill from infectious diseases more easily, whereas babies of large body weight are more difficult to deliver through the pelvis. Infants of a more medium weight have the greatest survival.

STABILIZING SELECTION

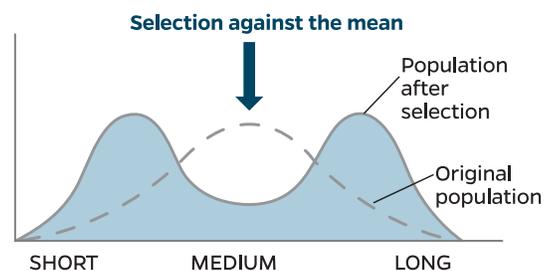


FOR: moderate traits
AGAINST: both extremes

DISRUPTIVE SELECTION: Natural selection in which extreme forms of a trait are favored over intermediate values. Variance of the trait increases and the population becomes divided phenotypically into two distinct groups. Over time, disruptive selection can lead to formation of two new species (speciation).

Example: A population of mice lives in a desert habitat with both sand and black volcanic rocks. The mice with black fur are able to hide from predators amongst the black rocks, and the mice with lighter fur are able to hide from predators in the sand. The mice with intermediate fur, however, stand out in all areas of the habitat, and thereby suffer greater predation. Natural selection would favor both light and dark colored mice, but select against mice of intermediate color.

DISRUPTIVE SELECTION



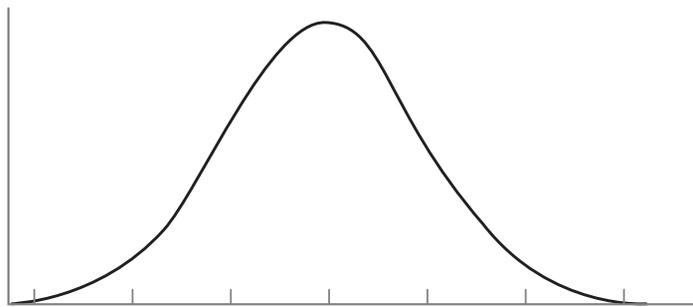
FOR: both extremes
AGAINST: moderate traits

PRACTICE PROBLEMS

INSTRUCTIONS: For each of the following scenarios assume each population has continuous variation in the traits described below, the traits are genetically inherited and there is a great deal of genetic diversity in the populations. Initially assume the distribution of trait values in the population starts out in a normal distribution. Predict which pattern of natural selection would be most likely to occur based on the information provided. Draw the new populations in a different color on the graphs provided. Label both axes.

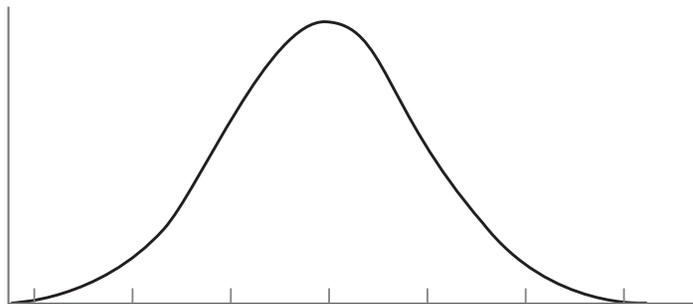
1. Fantail Warblers are birds that live in subtropical regions of Africa. The parasitic weaver (a lice like organism) is a specialist parasite of Fantail Warblers. However, parasite populations are declining due to climate change. Previously the birds with thicker feathers (which required more energy to produce) were more resistant to the parasitic weaver. As the effects of climate change increase what type of pattern of natural selection would we expect to see in the fantail warbler population with respect to feather thickness?

Type of Selection _____



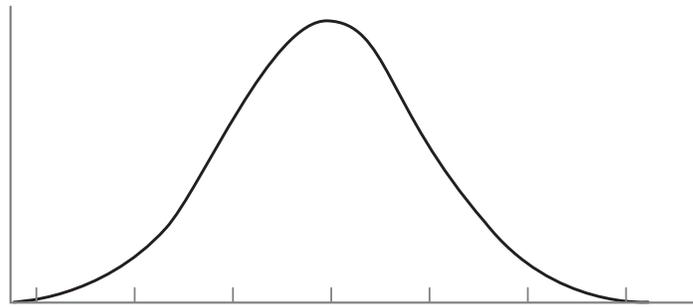
2. A large population of southern yellow tailed hornbills is living in the Kalahari Desert. There are small amounts of rainfall and the summer temperature is very high. Yellow-billed hornbills are monogamous and will live in breeding pairs or small family groups. When they begin their courtship the male will feed the female for up to a month by bringing her small bits of food in his mouth. Females are attracted to males with richly pigmented feathers and less likely to choose a male with dull colored feathers. However, if the males have richer pigment they have trouble regulating their body temperature in warmer temperatures and often don't survive to adulthood. As the effects of climate change increase what type of pattern of natural selection could we expect to see in the southern yellowtail hornbill population with respect to amount of pigment in males?

Type of Selection _____



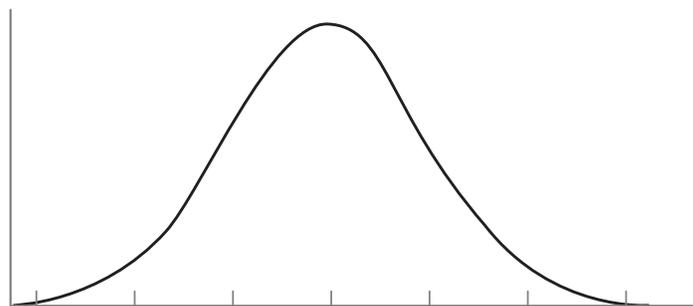
3. Fingered Poison Frogs are endemic to Trinidad. Females deposit small clutches of eggs in terrestrial nests. After hatching in July, one of the parents transports the tadpoles to a small water body, where they complete their development to metamorphosis. Suppose that due to changing climate conditions small bodies of water are only readily available during certain months of the year. Fingered Poison Frogs in southern Trinidad begin to only produce offspring during the spring months (April and May) and Fingered Poison Frogs in Northern Trinidad only produce offspring during the fall (September-October). What type of pattern of natural selection would we expect to see Trinidad's Fingered Poison Frogs population with respect to time of reproduction?

Type of Selection _____

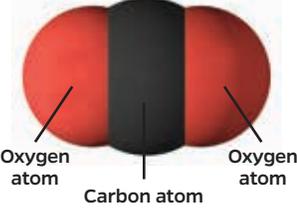
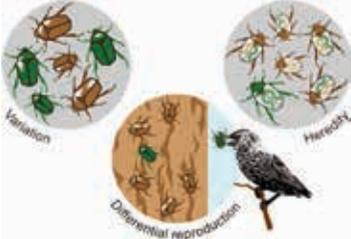


4. A study was conducted on *Pocillopora damicornis*, a coral widely distributed in the Indo-Pacific. The study measured changes in reproductive timing associated with increased seawater temperature. In this study, the effect of increased seawater temperature on the timing of planula (free swimming coral larvae) release was examined during the lunar cycles of March and June 2012. Twelve brooding corals were removed from Hobihu reef in Nanwan Bay, southern Taiwan and placed in 23°C and 28°C controlled temperature treatment tanks. For both temperatures, the timing of planulation was found to be plastic, with the high temperature treatment resulting in significantly earlier peaks of planula release compared to the low temperature treatment. This suggests that temperature alone can influence the timing of larval release in *pocillopora damicornis* in Nanwan Bay. What pattern of natural selection would we expect to see in the *pocillopora damicornis* population if ocean temperatures continue to increase?

Type of Selection _____



CLIMATE CHANGE:

Problems Created By Climate Change	As a Result of Climate Change Natural Selection Would Favor
<p data-bbox="337 380 597 401">Carbon Dioxide Molecule</p>  <p data-bbox="321 552 391 600">Oxygen atom</p> <p data-bbox="402 590 521 611">Carbon atom</p> <p data-bbox="548 552 618 600">Oxygen atom</p>	 <p>The diagram illustrates the three components of natural selection: Variation (shown with different colored beetles), Heredity (shown with a tree and its offspring), and Differential reproduction (shown with a bird and its offspring).</p>

Limitations to Evolutionary Adaptability:

- 1)
- 2)

LESSON 3 | SPECIES 1

Species: *Lepus americanus* (Snowshoe Hare)

SPECIES INFORMATION

Snowshoe hares are forest-dwellers that prefer the thick cover of brushy undergrowth. They are primarily a northern species that inhabit boreal forests and can range as far north as the shores of the Arctic Ocean. Hares are a bit larger than rabbits, and they typically have taller hind legs and longer ears. Snowshoe hares have especially large, furry feet that help them to move atop snow in the winter.

Snowshoe hares feed on plants such as, grass, ferns and leaves. Their main predators include lynx, foxes, coyotes, raptors and birds of prey. Young hares are frequently eaten by red squirrels. Most hares live less than a year because of predators.

One defense against predators is that snowshoe hares have a snow-white winter coat that turns brown when the snow melts each spring. It takes about ten weeks for the coat to completely change color. Hares switch color in the spring and fall in response to light, when the days get longer or shorter. However, if the snow comes late, the result is white hare on brown ground. Unfortunately the hares still think they are camouflaged and act like predators can't see them and are usually eaten.

CLIMATE CHANGE CHALLENGE

Hares are consistently molting (changing color) at the same time, year after year. However, due to climate change the snowfall comes later and melts earlier resulting more and more times when hares are mismatched with the environment.



A white snowshoe hare against a brown background makes the animal easy prey.

Information from: <http://www.npr.org/2013/09/08/220188619/climate-change-leaves-hares-wearing-the-wrong-colors>

LESSON 3 | SPECIES 2

Species: *Icterus galbula* (Baltimore Orioles)

SPECIES INFORMATION

Baltimore Orioles spend summer and winter in entirely different geographic ranges. From early April to late May, flocks arrive in eastern and central North America to breed. These breeding grounds range from Louisiana (31°N) to Canada (50°N) where they prefer open woodland, forest edges, river banks, and small groves of trees. They will also forage for insects and fruits in brush and shrubbery during this time. Post breeding season they begin to migrate to wintering grounds ranging from Florida (25°N) to the Caribbean (15°N). This migration season can begin as soon as July, where they will remain until the next breeding season.

CLIMATE CHANGE CHALLENGE

Due to climate change the Baltimore Orioles limited North American summer breeding range may shrink. Warming will likely harm vegetation that birds rely on for nesting and food in the southern part of the breeding grounds.



Information from: http://www.allaboutbirds.org/guide/Baltimore_Oriole/lifehistory and <http://climate.audubon.org/birds/balori/baltimore-oriole>

LESSON 3 | SPECIES 3**Species: *Spheniscus magellanicus* (Magellanic penguin)****SPECIES INFORMATION**

The Magellanic penguin is a South American penguin, breeding in coastal Argentina, Chile and the Falkland Islands. Magellanic penguins feed in the water, preying on cuttlefish, squid, krill, and other crustaceans.

Magellanic penguins mate with the same partner year after year. The male reclaims his burrow from the previous year and waits to reconnect with his female partner. The females are able to recognize their mates through their call alone. Both the male and female penguins care for their young, taking turns incubating the eggs and feeding their chicks.

CLIMATE CHANGE CHALLENGE

Weather records show that there is more rainfall and more severe storms occurring in Magellanic penguin breeding grounds. Warmer air temperatures mean not only hotter weather, but also more evaporation from the Atlantic, which puts more moisture in the air and thus creates wetter storms. Juvenile penguins are dying of hypothermia after heavy rain. Chicks are covered in down. Their juvenile plumage doesn't come in to protect them at all until they are older than 40 days.



Magellanic penguins strut their stuff on the rocky shoreline of Argentina's Punta Tombo, home to the largest colony of the birds in the world.

Information from: <http://www.wcs.org/saving-wildlife/birds/magellanic-penguin.aspx> and <http://www.npr.org/2014/01/30/268908419/changing-climate-in-argentina-is-killing-penguin-chicks>

LESSON 3 | SPECIES 4

Species: Pacific Northwest Shellfish

SPECIES INFORMATION

In North America we eat a few different varieties of bivalves including clams, mussels, oysters, and scallops.

Oysters are filter feeders, drawing water in over their gills through the beating of cilia. Suspended plankton and particles are trapped in the mucus of a gill, and from there are transported to the mouth, where they are eaten, digested, and expelled. Oysters usually reach maturity in one year. They are protandric meaning during their first year they spawn as males by releasing sperm into the water. However, as they grow over the next two or three years and develop greater energy reserves, they spawn as females by releasing eggs.

Scallops are found in all of the world’s oceans and are primarily “free-living”. Many species are capable of rapidly swimming short distances and even of migrating across the ocean floor. The scallop family is unusual in that some members of the family are dioecious (males and females are separate), while others are simultaneous hermaphrodites (both sexes in the same individual), and a few are protoandrous hermaphrodites (males when young then switching to female).

CLIMATE CHANGE CHALLENGE

As levels of CO₂ continue to rise some of the CO₂ is absorbed by the ocean. When CO₂ combines with water it produces carbonic acid and results in ocean acidification. The Vancouver Aquarium has recorded a steady decrease in water pH in the Pacific Northwest waters, from an average of around 8.1 until 1974 to levels as low as 7.2 in recent years. Acidic waters make it harder for oyster and scallop larvae to form their hard shells. Thinner, more fragile shells make them vulnerable to predators and diseases.



KBCS/BELLVUE/SEATTLE/FICKR

A geoduck (long neck clam) farm near Totten Inlet, Washington.

Information from: <http://www.nature.com/nclimate/journal/v5/n3/full/nclimate2508.html> and <http://www.washingtonpost.com/news/energy-environment/wp/2015/02/24/climate-change-is-really-bad-news-if-you-like-oysters-scallops-and-clams/>

LESSON 3 | SPECIES 5**Species: *Rana cascadae* (Cascades Frog)****SPECIES INFORMATION**

Cascades frogs (aka the “chuckle frog”) live in the mountains of the Northwest and thrive in alpine wetlands fed by melting snow. Cascades frogs spend most of the year beneath dozens of feet of snow. But for a few months in the summer, the frogs come to warm sunny ponds produced from snowmelt to feed and mate. Females can only breed once a year. A single female will lay up to 425 eggs at a time, but very few tadpoles will live past their first year. The eggs hatch within eight to 20 days, which immediately begins the “larval period.” Their larval period lasts 80 to 95 days.

Most frogs reach their full size after three years, after which they become fertile and can begin mating. Adults appear to use the same breeding sites for several years. Larvae are thought to be primarily benthic feeders (organisms who obtain energy from the consumption of sedimentary material) and adults are thought to consume a variety of invertebrate prey and will occasionally consume other frogs and tadpoles.

CLIMATE CHANGE CHALLENGE

The Pacific Northwest has lost about 50 percent of its snowpack over the last 50 years. With less snowpack and hotter summers, more egg sacks and tadpoles (aka the larval stage) are stranded out of water and die.



Information from: <http://www.npr.org/2013/08/07/209892263/climate-change-could-spell-final-chuckle-for-alpine-frog>

LESSON 3 | SPECIES 6

Species: *Calidris canutus* (Red Knot)

SPECIES INFORMATION

Red Knots make one of the longest yearly migrations of any bird, flying more than 9,300 miles from south to north every spring; they repeat the trip in reverse every autumn. Red Knots concentrate in huge numbers at traditional staging grounds during migration. Delaware Bay is an important staging area during spring migration, where the Red Knots feed on the eggs of spawning horseshoe crabs. It is estimated that nearly 90 percent of the entire population of the Red Knot subspecies *C. rufa* can be present on the bay in a single day.

CLIMATE CHANGE CHALLENGE

The horseshoe crabs and the birds have to arrive at the same time if the Red Knots are going to make it to the Arctic to nest. This timing is critical since the birds need the energy from consuming the horseshoe crab's eggs to finish the migration. Warming water temperatures could prompt the crabs to lay eggs before the birds arrive. Climate change could throw this critical meeting out of sync. In addition, rising seas and bigger storms are washing away the beaches where the horseshoe crabs come to mate.



At high tide thousands of mating horseshoe crabs gather along the water's edge. Migrating red knots roughly double their body weight in 10 days of gorging on the crabs' fatty eggs.

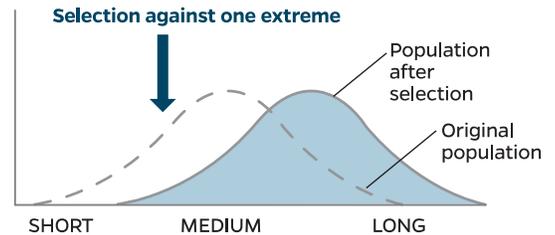
Information from: <http://www.npr.org/2014/07/28/319092192/shifts-in-habitat-may-threaten-ruddy-shorebirds-survival>

Patterns of Natural Selection

DIRECTIONAL SELECTION: Natural selection in which an extreme phenotype is favored over other phenotypes, causing the alleles causing that phenotype to be favored and shift over time in the direction of that phenotype.

Example: Prior to the industrial revolution in England the peppered moth had light coloration and lived on trees covered with light colored lichen. This provided camouflage against predatory birds. There were a few dark individuals in the population, but they were usually eaten by birds. However, once the industrial revolution began the light-colored lichens covering the trees were killed by sulfur dioxide emissions from the new factories. Without the light background of the trees, the light moths were more visible to birds and now the dark moths had a camouflage advantage. In 1848, the dark moths comprised 1% of the population and by 1959 they represented ~90% of the population.

DIRECTIONAL SELECTION

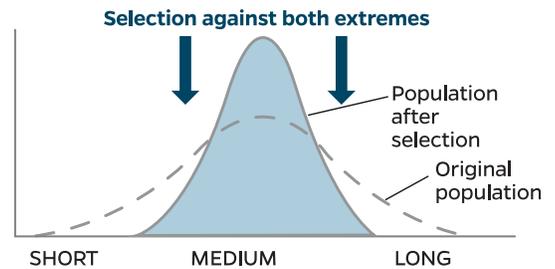


FOR: one extreme trait
AGAINST: the other extreme

STABILIZING SELECTION: Natural selection in which intermediate forms of a trait are favored and more extreme values are selected against.

Example: Human birth weight has undergone stabilizing selection. Babies of low weight lose heat more quickly and get ill from infectious diseases more easily, whereas babies of large body weight are more difficult to deliver through the pelvis. Infants of a more medium weight have the greatest survival.

STABILIZING SELECTION

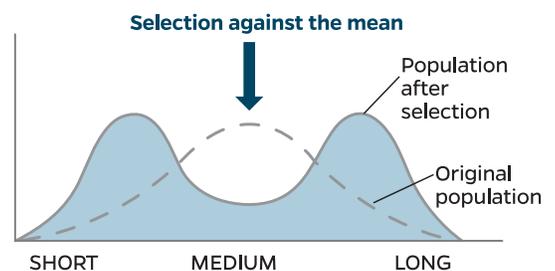


FOR: moderate traits
AGAINST: both extremes

DISRUPTIVE SELECTION: Natural selection in which extreme forms of a trait are favored over intermediate values. Variance of the trait increases and the population becomes divided phenotypically into two distinct groups. Over time, disruptive selection can lead to formation of two new species (speciation).

Example: A population of mice lives in a desert habitat with both sand and black volcanic rocks. The mice with black fur are able to hide from predators amongst the black rocks, and the mice with lighter fur are able to hide from predators in the sand. The mice with intermediate fur, however, stand out in all areas of the habitat, and thereby suffer greater predation. Natural selection would favor both light and dark colored mice, but select against mice of intermediate color.

DISRUPTIVE SELECTION



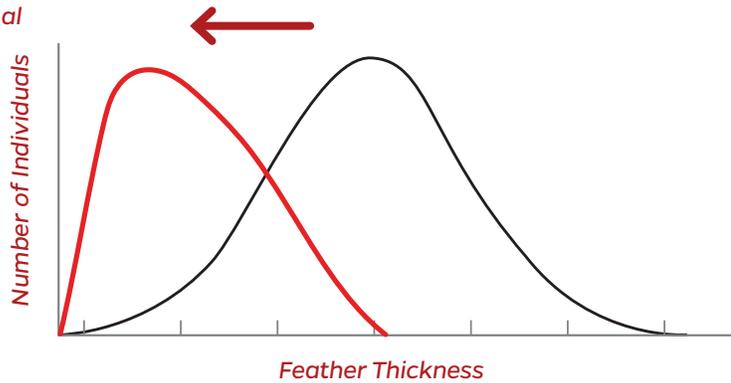
FOR: both extremes
AGAINST: moderate traits

PRACTICE PROBLEMS

INSTRUCTIONS: For each of the following scenarios assume each population has continuous variation in the traits described below, the traits are genetically inherited and there is a great deal of genetic diversity in the populations. Initially assume the distribution of trait values in the population starts out in a normal distribution. Predict which pattern of natural selection would be most likely to occur based on the information provided. Draw the new populations in a different color on the graphs provided. Label both axes.

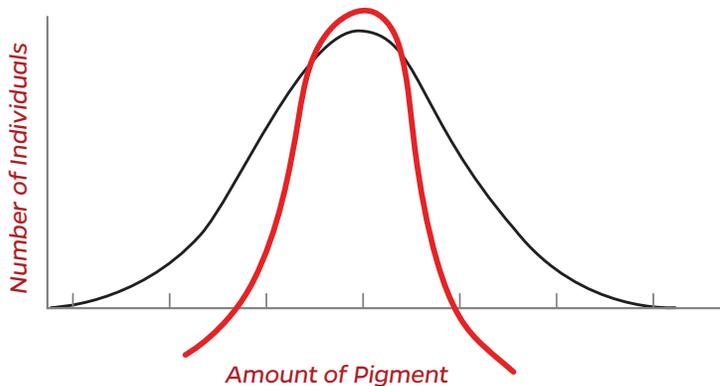
1. Fantail Warblers are birds that live in subtropical regions of Africa. The parasitic weaver (a lice like organism) is a specialist parasite of Fantail Warblers. However, parasite populations are declining due to climate change. Previously the birds with thicker feathers (which required more energy to produce) were more resistant to the parasitic weaver. As the effects of climate change increase what type of pattern of natural selection would we expect to see in the fantail warbler population with respect to feather thickness?

Type of Selection *Directional*



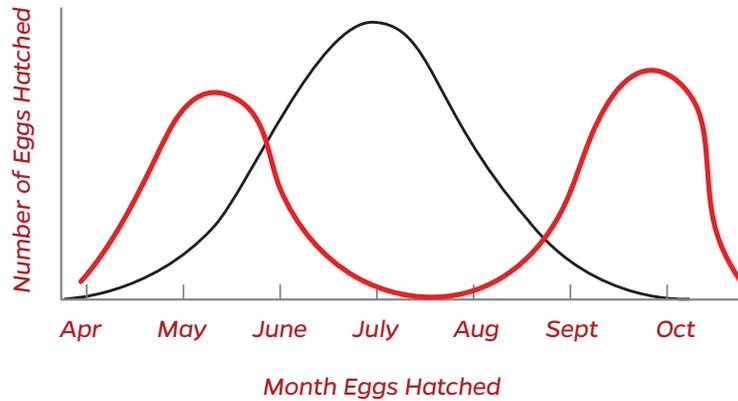
2. A large population of southern yellow tailed hornbills is living in the Kalahari Desert. There are small amounts of rainfall and the summer temperature is very high. Yellow-billed hornbills are monogamous and will live in breeding pairs or small family groups. When they begin their courtship the male will feed the female for up to a month by bringing her small bits of food in his mouth. Females are attracted to males with richly pigmented feathers and less likely to choose a male with dull colored feathers. However, if the males have richer pigment they have trouble regulating their body temperature in warmer temperatures and often don't survive to adulthood. As the effects of climate change increase what type of pattern of natural selection could we expect to see in the southern yellowtail hornbill population with respect to amount of pigment in males?

Type of Selection *Stabilizing*



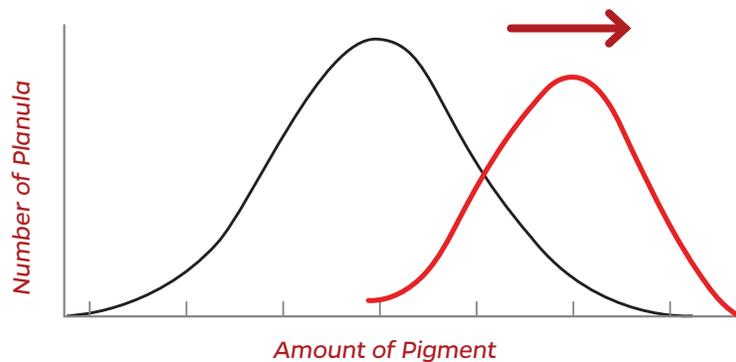
3. Fingered Poison Frogs are endemic to Trinidad. Females deposit small clutches of eggs in terrestrial nests. After hatching in July, one of the parents transports the tadpoles to a small water body, where they complete their development to metamorphosis. Suppose that due to changing climate conditions small bodies of water are only readily available during certain months of the year. Fingered Poison Frogs in southern Trinidad begin to only produce offspring during the spring months (April and May) and Fingered Poison Frogs in Northern Trinidad only produce offspring during the fall (September – October). What type of pattern of natural selection would we expect to see Trinidad’s Fingered Poison Frogs population with respect to time of reproduction?

Type of Selection *Disruptive*

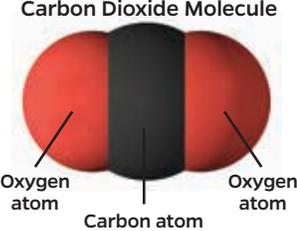


4. A study was conducted on *pocillopora damicornis*, a coral widely distributed in the Indo-Pacific. The study measured changes in reproductive timing associated with increased seawater temperature. In this study, the effect of increased seawater temperature on the timing of planula (free swimming coral larvae) release was examined during the lunar cycles of March and June 2012. Twelve brooding corals were removed from Hobihu reef in Nanwan Bay, southern Taiwan and placed in 23°C and 28°C controlled temperature treatment tanks. For both temperatures, the timing of planulation was found to be plastic, with the high temperature treatment resulting in significantly earlier peaks of planula release compared to the low temperature treatment. This suggests that temperature alone can influence the timing of larval release in *pocillopora damicornis* in Nanwan Bay. What pattern of natural selection would we expect to see in the *pocillopora damicornis* population if ocean temperatures continue to increase?

Type of Selection *Directional*



CLIMATE CHANGE: a change in global or regional climate patterns; attributed largely to the increased levels of atmospheric carbon dioxide produced by the use of fossil fuels.

Problems Created By Climate Change	As a Result of Climate Change Natural Selection Would Favor*
<p style="text-align: center;">Carbon Dioxide Molecule</p>  <p style="text-align: center;">Oxygen atom Carbon atom Oxygen atom</p> <ol style="list-style-type: none"> 1. Acclimation strategies become out of sync with changing seasons 2. Breeding ranges may shrink 3. More rainfall and severe storms due to increased evaporation from warmer temperatures 4. Ocean acidification occurs when CO₂ is absorbed by the ocean and creates carbonic acid 5. Loss of snowpack in mountainous regions 6. Food sources may be out of sync with migration patterns 	 <ol style="list-style-type: none"> 1. Snowshoe hares that turn white later in the winter and/or turn brown earlier in the spring 2. Baltimore Orioles that expand their range to higher latitude during the breeding season 3. Juvenile Magellanic Penguins with more fat (to avoid hypothermia) and/or that develop adult feathers earlier in life 4. Shellfish with thicker shells 5. Cascades tadpoles with a shorter larval period and/or are more resistant to desiccation 6. Red knots that can find other food sources and/or arrive earlier in Delaware so arrival is synced with horseshoe crab egg laying

Limitations to Evolutionary Adaptability:

- 1) There may not be enough (or any) genetic variation in the population for a given trait
- 2) A population may not be able to evolve fast enough (especially organisms with longer generation times) to keep up with the pace of climate change **, ***

*Teacher's Note: Point out to students that these are all examples of directional selection.

**Teacher's Note: Point out to students that if an organism cannot adapt to a changing environment it is in danger of extinction.

*** Teacher's Note: This would also be a good place to remind students that evolution is NOT goal oriented and does NOT produce "perfect" organisms.

Natural Selection in the Face of Climate Change — Key

*** Please note students may come up with different traits that natural selection may act on. These are just possible answers. ***

SPECIES 1 - SNOW SHOE HARE

Climate Change Issue

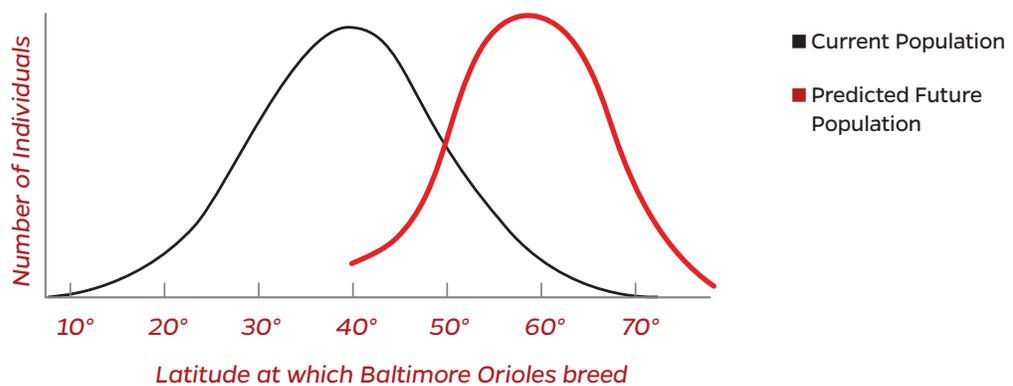
Snow doesn't come until later in the winter. Snowshoe hares that turn white later in the winter and/or turn brown earlier in the spring are camouflaged more effectively because they don't stand out to predators.



SPECIES 2 - BALTIMORE ORIOLES

Climate Change Issue

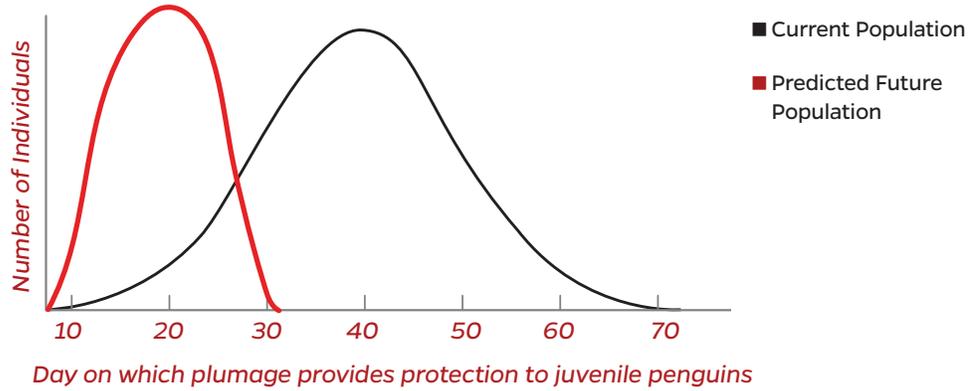
Baltimore Orioles that shift their summer range north so they can find enough food and the correct habitat for breeding as temperature rises and deciduous trees move north.



SPECIES 3 - MAGELLANIC PENGUIN

Climate Change Issue

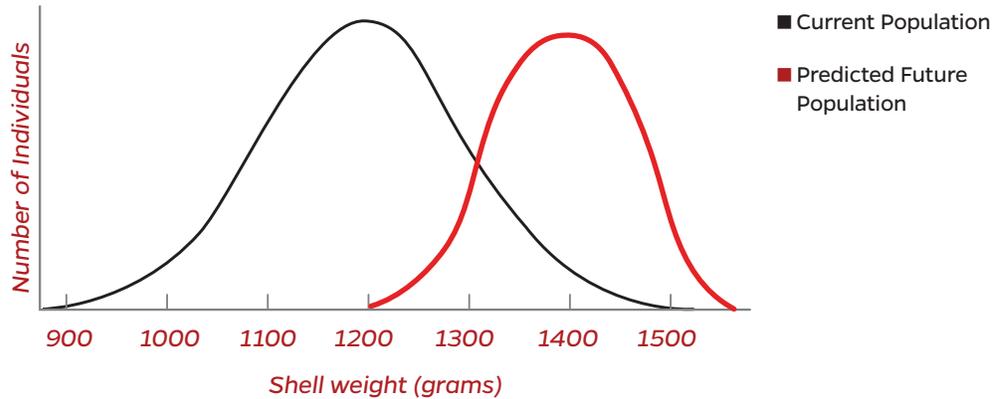
More rainfall and severe storms due to increased evaporation from warmer temperatures select for juvenile penguins that are protected by adult plumage earlier.



SPECIES 4 - PACIFIC NORTHWEST SHELLFISH

Climate Change Issue

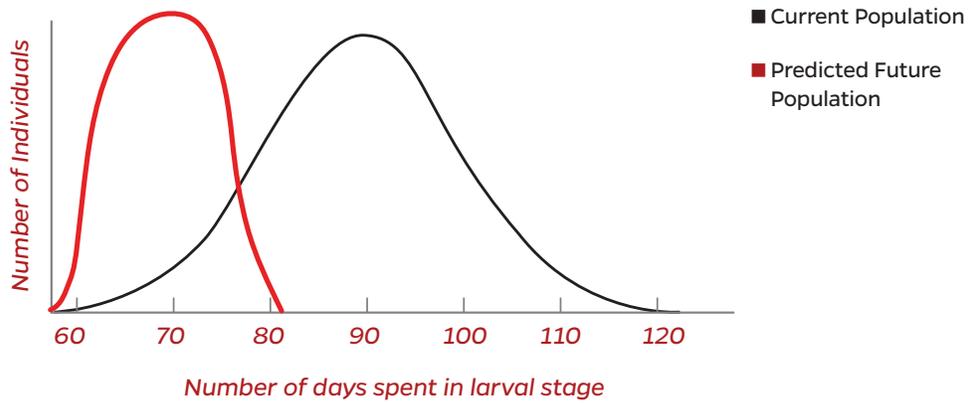
Ocean acidification selects for shellfish that can form successful shells by despite low pH. (The issue with ocean acidification is with mollusks not being able to sequester the calcium carbonate to form shell material when they are growing.)



SPECIES 5 - CASECADES FROG

Climate Change Issue

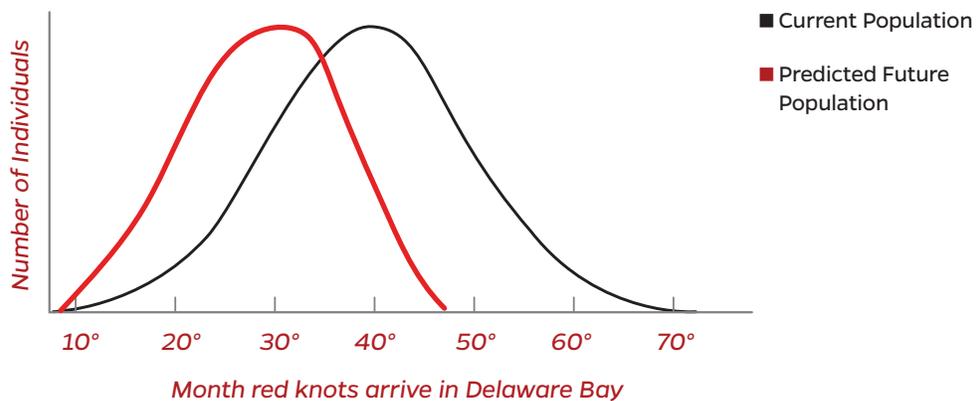
Since there is less snowpack and therefore water is available for a shorter time, Cascades tadpoles with a shorter larval period would be selected for.



SPECIES 6 - RED KNOT

Climate Change Issue

Horseshoe crabs may begin to lay eggs, an important food source for red knots, earlier in the year. Natural selection may select for red knots that arrive earlier in Delaware so arrival is synced with horseshoe crab egg laying.



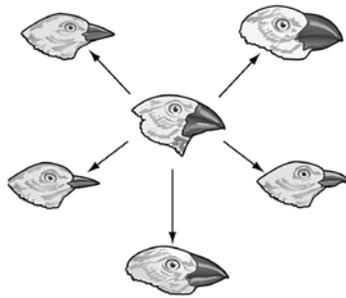
PRE/POST UNIT ASSESSMENT AND SURVEY

PART I INSTRUCTIONS: ANSWER THE FOLLOWING BASED ON YOUR CURRENT KNOWLEDGE

1. Which of the following is the best example of natural selection?

- a) The lifespan of a chimpanzee is extended to 60 years in captivity.
- b) The population size of giraffes changes over time as a result of immigration.
- c) The bone density of a human increases significantly as a result of participation in sports.
- d) The average toxin level in a poisonous frog population increases over many years in response to high predation.

2. The diagram below shows many finch species that originated from a single ancestral finch species in the Galapagos Islands. Each species of finch feeds on a unique type of food.



Which of the following statements best explains why many different finch species originated from the single ancestral species?

- a) Populations adapted to environmental pressures.
- b) Recessive traits in populations were eliminated over time.
- c) Individuals acquired unique characteristics during their lifetimes.
- d) Random mutations caused some individuals to have harmful traits.

3. Features that increase the likelihood of survival and reproduction by an organism in a particular environment are called

- a) genes.
- b) alleles.
- c) mutations.
- d) adaptations.

4. The genetic contribution of an individual's genotype to succeeding generations, compared with that of other individuals in the population, is known as

- a) variation.
- b) microevolution.
- c) macroevolution.
- d) evolutionary fitness.

5. Which of the following is NOT an example of change due to climate change?

- a) Fruit flies with a shorter chill coma recovery time produce more offspring than those flies with a longer chill coma recovery time.
- b) Light colored mice are preyed upon by hawks less frequently than dark colored mice, living in a light colored sand desert.
- c) Mosquitoes with a short reproductive life cycle rapidly adapt to increasing global temperatures.
- d) Southern dwelling birds expand their habitat ranges north as global temperatures increase.

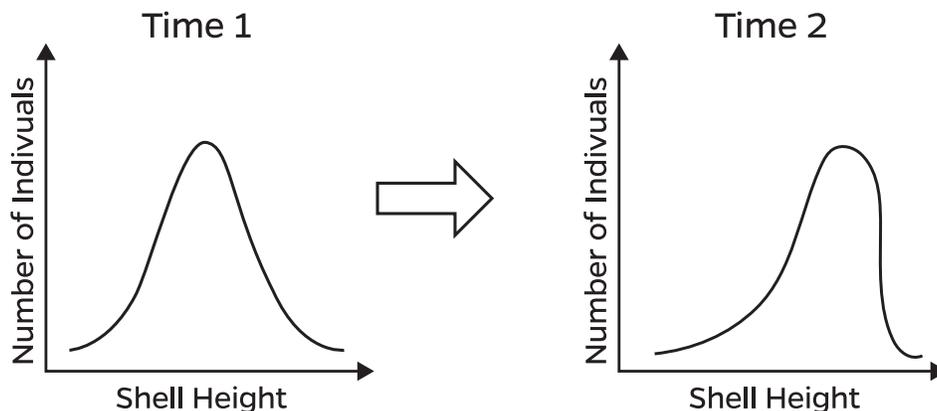
For questions 6-8, pick the correct effect caused by global climate change from the provided pair of statements:

6. Increased global mean temperatures
 Decreased global mean temperatures
7. Increased volume of water stored in the polar ice caps
 Increased severe weather events
8. Decreased severe weather events
 Decreased average winter temperatures

9. A species that lacks the genetic variation necessary to adapt to a changing environment is more likely to

- a) develop many mutated cells.
- b) become extinct over time.
- c) develop resistance to disease.
- d) become less genetically diverse.

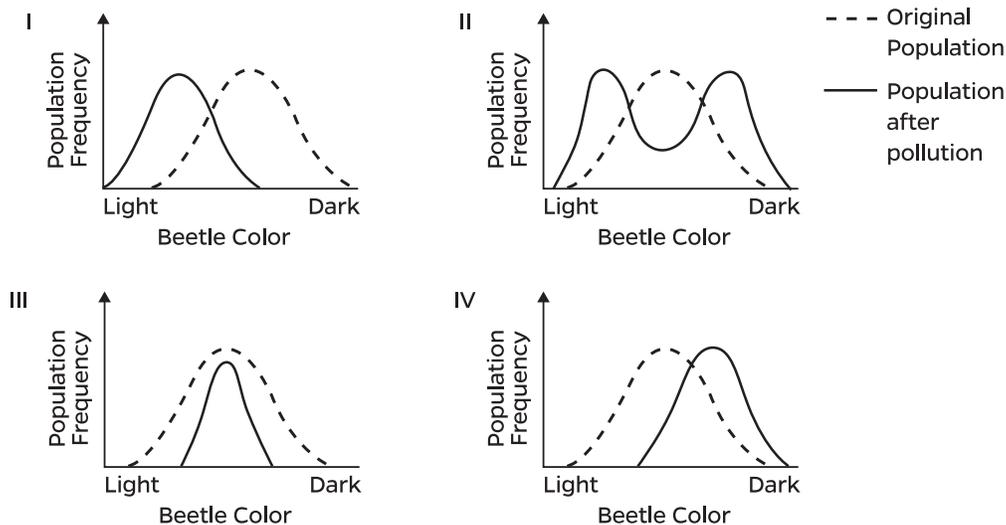
10. The shape and height of a tortoise's shell influence how high the tortoise can raise its head. A tortoise with a high shell that leaves a large gap can raise its head height than a tortoise with a lower shell and a smaller gap. In a population of herbivorous tortoises, a shift in the frequency of different shell heights is observed over time. A set of graphs representing the change in frequency of the different shell heights is shown below.



Which of the following selection pressures most likely produced the shift in frequency?

- a) lack of vegetation at ground level.
- b) dry, hot weather conditions for several years.
- c) habitat changes that forced nesting sites farther inland.
- d) intense competition with other species of tortoises with high shells.

11. Natural selection is based on all of the following except
- variation exists within populations.
 - the fittest individuals tend to leave the most offspring.
 - populations tend to produce more individuals than the environment can support.
 - individuals must adapt to their environment.
12. The rough skinned newt produces a toxin that can kill predators. Scientists have observed that some garter snakes can feed on the newts because they have a natural resistance to the toxin. In areas where populations of rough-skinned newts and garter snakes interact, which of the following predictions is best supported by evolutionary theory?
- The garter snakes with resistance to the toxin will successfully reproduce and pass the trait on to their offspring.
 - The garter snakes without resistance to the toxin will acquire resistance by increasing the rate at which they feed on the newts.
 - The rough-skinned newts that produce low levels of toxin will also develop camouflage adaptations that allow them to hide from the garter snakes.
 - The newts will stop making the toxin rather than continue to use energy to make a toxin that is ineffective against the garter snakes.
13. In recent years, certain strains of flies have been observed to be resistant to the effects of the insecticide DDT. Although the variation for resistance was probably present in the fly population prior to the use of DDT, the adaptive value of prior of the genetic trait did not become apparent until
- acquired traits were inherited.
 - the pesticide was introduced into the environment.
 - interbreeding between different fly species occurred.
 - the pesticide was chemically analyzed.
14. In a hypothetical population of beetles, there is a wide variety of color, matching the range of coloration of the tree trunks on which the beetles hide from predators. The graphs below illustrate four possible changes to the beetle population as a result of a change in the environment due to pollution that darkened the tree trunks.



Which of the following includes the most likely change in the coloration of the beetle population after pollution and a correct rationale for the change?

- a) The coloration range shifted toward more light-colored beetles, as in diagram I. The pollution helped the predators find the darkened tree trunks.
- b) The coloration in the population split into two extremes, as in diagram II. Both the lighter-colored and the darker-colored beetles were able to hide on the darker tree trunks.
- c) The coloration range became narrower, as in diagram III. The predators selected beetles at the color extremes.
- d) The coloration in the population shifted toward more darker-colored beetles, as in diagram IV. The lighter-colored beetles were found more easily by the predators than were the darker-colored beetles.

15. In future generations, the frequency of the mutant allele may tend to increase. This would occur in a given environment if the new trait conferred by this mutation has

- a) the ability to form a fossil.
- b) a high survival value.
- c) a common ancestry.
- d) no advantage in competition.

16. A biologist spent many years researching the rate of evolutionary change in the finch populations of group of islands. It was determined that the average beak size of finches in a certain population increased dramatically during an intense drought between 1981 and 1987. During the drought, there was a reduction in the number of plants producing thin-walled seeds.

Which of the following best describes the mechanism behind the change in beak size in the finch population?

- a) The formation of two new finch species from a single parent species.
- b) A change in allele frequencies in the finch population due to selective pressure from the environmental change.
- c) A new allele appearing in the finch population due to mutation.
- d) The achievement of dynamic equilibrium in the finch population as a result of homeostasis.

17. In a population of ground-dwelling birds, the allele for short breaks is dominant to that of long beaks. During a particularly harsh summer, a drought kills off most of the vegetation the birds utilize as food and leaves behind insects which inhabit the cracks in the ground that result from the drought. Which of the following correctly describes both the mechanism of evolution and the effect it will have on allele frequencies for the beak trait.

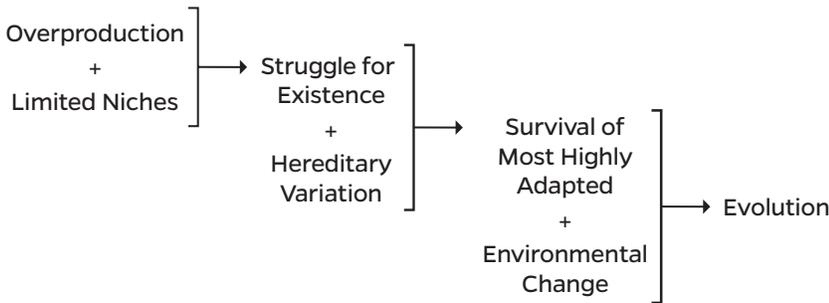
- a) Genetic drift; the frequency of the long beak allele increases
- b) Natural selection; the frequency of the long beak allele increases
- c) Gene flow; the frequency of the short beak allele decreases
- d) Genetic drift; the frequency of the short beak allele increases

18. A population of squirrels is preyed on by small hawks. The smaller squirrels can escape into burrows. The larger squirrels can fight off the hawks. After several generations, the squirrels in the area tend to be very small or very large. What process is responsible for this outcome, and what would you predict would be its effect on allele frequencies.

- a) Directional selection; the allele for small squirrel size is not favored over the allele for large squirrel size.
- b) Disruptive selection; the allele for large squirrel size is favored over the alleles for small squirrel size.
- c) Stabilizing selection; the alleles for large and small squirrel size are found in equal frequency in the population
- d) Disruptive selection; the alleles for large and small squirrel size are favored equally in the population.

19. Which theory is best illustrated by the flow chart shown?

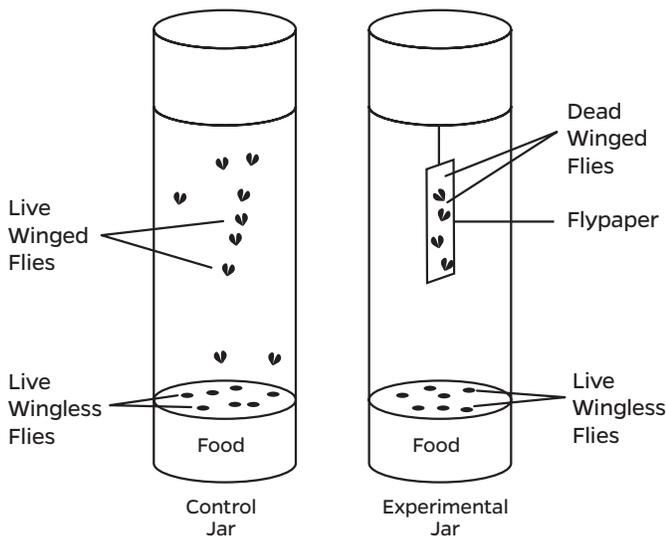
- a) cell theory
- b) theory of acquired characteristics
- c) use and disuse theory
- d) theory of natural selection



20. The introduction of new genes into the gene pool of a population occurs through the process of

- a) survival of the fittest
- b) competition between organisms
- c) mutation
- d) overproduction

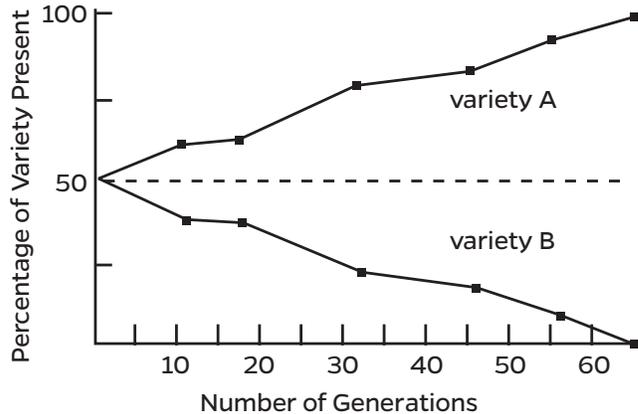
21. The diagram represents jars containing all the nutrients necessary for the growth and reproduction of fruit flies. A strip of sticky flypaper was suspended from the top of the experimental jar. Some fruit flies with wings and some fruit flies that lacked wings were placed in both jars. After a week, only the wingless flies were alive in the experimental jar, while in the control jar, both varieties of the flies were still alive, as indicated in the diagram.



What is the best conclusion to be drawn from this investigation?

- a) Wingless is an advantage in the experimental jar.
- b) Wingless is a disadvantage in the control jar.
- c) The winged trait is an advantage in the experimental jar.
- d) The winged trait is a disadvantage in the control jar.

22. The graph shown illustrates changes in the percentages of two varieties of a certain species.



Which is the most probable reason that the percentage of variety A is increasing in the population of this species?

- a) There is no chance for variety A to mate with variety B.
- b) There is no genetic difference between variety A and variety B.
- c) Variety A has some adaptive advantage that variety B does not.
- d) Variety A is somehow less fit to survive than variety B.

23. Which of the following are two factors that change allele frequencies in a population?

- a) no mutations and large populations
- b) no migration and no mutations
- c) large populations and random mating
- d) mutations and nonrandom mating

24. The allele frequency for a particular trait in a population was determined to be 80% A (the dominant allele) and 20% a (recessive allele). Fifty years later, the gene frequency was determined to be 60% A and 40% a. What does this change indicate about the gene pool?

- a) It has remained stable.
- b) It is evolving.
- c) It has become predominantly recessive.
- d) It lacks mutations.

25. For many generations, a particular species of snail has lived in an isolated pond. Some members of the species have light-colored shells and some have dark-colored shells. During this time the species has been producing large members of offspring through random mating and no migration has occurred.

A change in the environment of the pond caused the light-colored shells to become an important survival trait and the number of light colored snails increased. This situation will most likely cause

- a) geographic isolation within the population.
- b) a change in the frequency of the alleles for shells color.
- c) no change in the frequency of the alleles for shells color.
- d) the extinction of the species of snail.

PART II INSTRUCTIONS

For each of the following statements, mark one box indicating Strongly Agree (SA), Agree (A), Undecided (U), Disagree (D), or Strongly Disagree (SD).

	SA	A	U	D	SD
1. Most living things have some very basic similarities.	<input type="checkbox"/>				
2. Everyone should understand evolution.	<input type="checkbox"/>				
3. It is important to let people know about how strong the evidence that supports evolution is.	<input type="checkbox"/>				
4. Some parts of evolution theory could be true.	<input type="checkbox"/>				
5. Evolutionary theory applies to all plants and animals, including humans.	<input type="checkbox"/>				
6. People who plan to become biologists need to understand evolution.	<input type="checkbox"/>				
7. I would be willing to argue in favor of evolutionary theory in a public forum such as a school club, church group, or meeting of public school parents.	<input type="checkbox"/>				
8. Simple organisms such as bacteria change over time.	<input type="checkbox"/>				
9. Nothing in biology makes sense without evolution	<input type="checkbox"/>				
10. Understanding evolution helps me understand other parts of biology.	<input type="checkbox"/>				
11. I would be willing to argue in favor of evolution in small group of friends.	<input type="checkbox"/>				
12. Evolution is a good explanation of how humans first emerged on the earth	<input type="checkbox"/>				
13. Evolution is a scientific fact.	<input type="checkbox"/>				
14. Evolution is a good explanation of how new species arise.	<input type="checkbox"/>				

ANSWER KEY FOR PART I OF PRE/POST ASSESSMENT (MULTIPLE CHOICE OBJECTIVE QUESTIONS)

1. D
2. A
3. D
4. D
5. B
6. A
7. B
8. B
9. B
10. A
11. D
12. A
13. B
14. D
15. B
16. B
17. B
18. D
19. D
20. C
21. A
22. C
23. D
24. D
25. B

Summative Written Assessment (Free Response Questions)

The following question and rubric, which have been modeled after AP Biology style FRQ assessments, can also be used to determine student learning outcomes.

DROWSY DROSOPHILA SUMMATIVE ASSESSMENT QUESTIONS



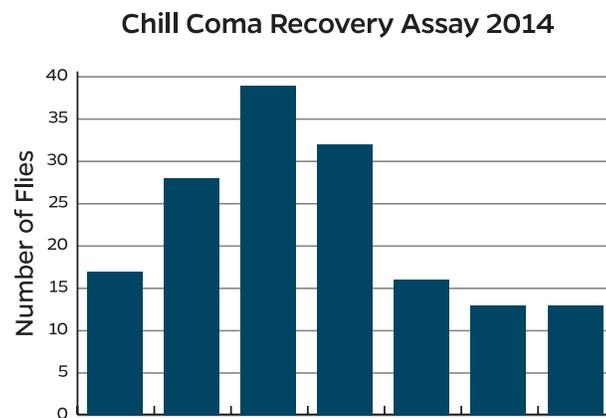
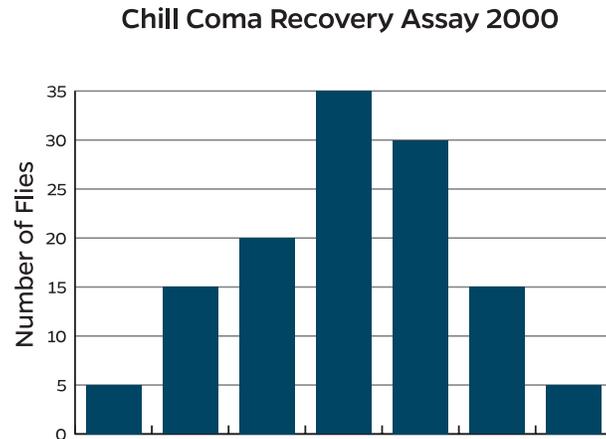
1. The Greater Yellowleg is a tall, long-legged shorebird that lives in freshwater ponds and tidal marshes/ the Greater. The Audubon Society reports seeing the Greater Yellowlegs in high numbers on its Christmas Bird Counts, especially inland in the southern U.S. This increase in number is thought to be a result of climate change.



The Spectacled Eider is a large sea duck that lives at northern latitudes and breeds on the coasts of Alaska and northeastern Siberia. Populations of spectacled eiders are declining especially in Western Alaska due to climate change.

- a) **PROPOSE** TWO reasons why the Greater Yellowleg is a climate change winner (the population is increasing as a result of climate change), while the Spectacled Eider is a climate change loser (the population is decreasing as a result of climate change)

2. A scientist has collected the following data on chill coma recovery time from a population *Drosophila melanogaster* from a farmer's market. Graphs not drawn to scale.



- The scientist hypothesizes that the population is undergoing directional selection in response to climate change. **Justify** her hypothesis using the information from the graphs and information that you learned about chill coma recovery from this unit.
- The exact mechanism is currently unknown. If a mutation in the gene *FST* (*Frost*) results in faster chill coma recovery time **predict** what would happen to the allele frequency of the mutant allele. **Justify** your answer.
- Describe** how genetic variation in a population of fruit flies contributes to the process of evolution of the population.

Summative Written Assessment (Free Response Questions)

The following question and rubric, which have been modeled after AP Biology style FRQ assessments, can also be used to determine student learning outcomes.

DROWSY DROSOPHILA SUMMATIVE ASSESSMENT QUESTIONS



1. The Greater Yellowleg is a tall, long-legged shorebird that lives in freshwater ponds and tidal marshes/ the Greater. The Audubon Society reports seeing the Greater Yellowlegs in high numbers on its Christmas Bird Counts, especially inland in the southern U.S. This increase in number is thought to be a result of climate change.

The Spectacled Eider is a large sea duck that lives at northern latitudes and breeds on the coasts of Alaska and northeastern Siberia. Populations of spectacled eiders are declining especially in Western Alaska due to climate change.

- a) **PROPOSE** TWO reasons why the Greater Yellowleg is a climate change winner (the population is increasing as a result of climate change), while the Spectacled Eider is a climate change loser (the population is decreasing as a result of climate change) **(4 points)**

Greater Yellowleg Proposal (2 points maximum)

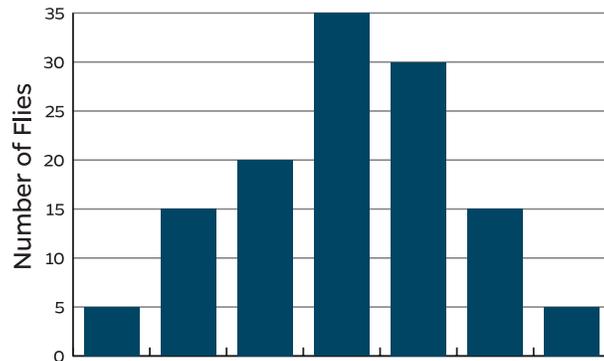
- The Greater Yellowlegs population is large and this increases the chance that at least some members of the population will have the genetic diversity present to adapt to climate change.
- The Greater Yellowleg population has likely been able to extend its range to the north where the climate is similar to the original climate the Greater Yellowlegs are adapted to.
- The Geater Yellowleg population has strong dispersal ability due to their large population size and ability to fly.

Spectacled Eider Proposal (2 points maximum)

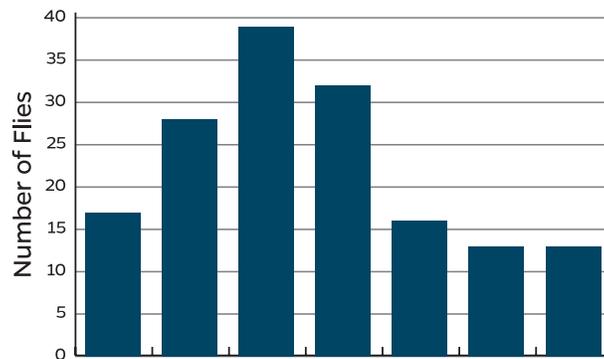
- The Spectacled Eider is adapted to cold environments. Since they already live at northern latitudes and Spectacled Eiders are not able to move farther north or expand their range.
- The Spectacled Eider may be classified as having poor dispersal ability because there is likely no suitable habitat left for the species.
- Spectacled Eiders may not have genetic diversity present in the species gene pool to be able to evolve to survive in changing climates.

2. A scientist has collected the following data on chill coma recovery time from a population *Drosophila melanogaster* from a farmer's market. Graphs not drawn to scale.

Chill Coma Recovery Assay 2000



Chill Coma Recovery Assay 2014



a) The scientists hypothesizes that the population is undergoing directional selection in response to climate change. **Justify** her hypothesis using the information from the graphs and information that you learned about chill coma recovery from this unit.

Definition (1 point)

Directional selection is a type of natural selection in which an extreme phenotype is favored over other phenotypes, causing the allele frequency to shift over time in the direction of that phenotype.

Justification (1 point)

In this example the average time to recovery has shifted from 20 minutes to 15 minutes. The number of flies recovering at 5 and 10 minutes increased from 2000 to 2014.

b) The exact mechanism is currently unknown. If a mutation in the gene *FST* (*Frost*) results in faster chill coma recovery time **predict** what would happen to the allele frequency of the mutant allele. **Justify** your answer.

Prediction (1 point)

· The mutant allele frequency of FST would be expected to increase.

Justification (1 point)

· Flies that are able to recover more rapidly from a chill coma will be less likely to be eaten by predators and/or have more time to attract mates and reproduce. I would expect the flies with the mutant alleles to produce more offspring that also have the mutant alleles than the flies in the population that do not have the mutant FST alleles. Since the flies with the mutant alleles produce more offspring than other flies in the population the mutant FST allele would increase in frequency.

c) **Describe** how genetic variation in a population of fruit flies contributes to the process of evolution of the population.

Description (1 point)

- Genetic variation is the basis of phenotypic variation that can be acted upon by natural selection*
- Without genetic variation, there is no phenotypic variation on which natural selection can act*

STUDENT FEEDBACK FORM: DROWSY DROSOPHILA

Student code: _____ Date: _____ Student grade level: _____ Circle one: Male Female
 School: _____ Teacher Name: _____ Subject: _____

PART I: EVALUATION OF INDIVIDUAL ACTIVITIES

SECTION A: For each question below, please indicate your response for each **specific activity** by marking High, Moderate, Low, or Not Applicable (NA).

	Activity 1				Activity 2				Activity 3			
	High	Mod	Low	N/A	High	Mod	Low	N/A	High	Mod	Low	N/A
1. Is the amount of background information sufficient?	<input type="checkbox"/>											
2. Were you provided enough time to perform the activity?	<input type="checkbox"/>											
3. Is the procedure clearly written?	<input type="checkbox"/>											
4. Does the data collection/analysis section assist documentation of your observations?	<input type="checkbox"/>											
5. Do the review questions help clarify thinking?	<input type="checkbox"/>											
6. Are the assessment instructions clearly stated?	<input type="checkbox"/>											
7. Are the illustrations/charts/tables helpful?	<input type="checkbox"/>											

SECTION B: Please provide additional comments pertaining to each specific experiment.

	ACTIVITY 1	ACTIVITY 2	ACTIVITY 3
1. Are there any topics/ sections that should be added or deleted? If so, please explain.			
2. Additional comments?			

PART II. PLEASE EVALUATE THE DROWSY DROSOPHILA CURRICULUM OVERALL.

For each item below, indicate your personal response by marking Strongly Agree (SA), Agree (A), Undecided (U), Disagree (D), or Strongly Disagree (SD).

	SA	A	U	D	SD
1. Do you think evolution is an interesting topic?	<input type="checkbox"/>				
2. Do you think evolution is relevant to your own life?	<input type="checkbox"/>				
3. Did you enjoy the activities?	<input type="checkbox"/>				
4. Did performing the activities increase your knowledge of evolution?	<input type="checkbox"/>				
5. Do you feel the activities reflect actual research practice?	<input type="checkbox"/>				

PART III.

Do you have any questions or is there anything you do not understand related to the activities you performed?

PART IV.

Do you have any additional comments related to the activities you performed that you would like to share?

STUDENT DEMOGRAPHIC FORM

School: _____ Teacher Name: _____ Subject: _____

For our reporting purposes, we need to identify the following information. Please help us provide complete and accurate data! This form is to be used for collecting data about class(es) that participate in the field testing of the Drowsy Drosophila curriculum. If you implemented the curriculum with different subjects and/or levels, please complete a form for each (for example, one form for AP Biology and another form for Biology I Standard Level).

1. Number (not percentage) of students in your class only by RACE and GENDER in the current school year. Please fill these categories out to the best of your ability and please do not create new categories.

TABLE 1	Number of Students		
Ethnicity	Male	Female	Total
Asian			
Black			
Hispanic			
Native Alaskan			
Native American			
Native Pacific Islander			
White, not Hispanic			
Table 1 Totals			

Please fill out all Total columns and rows.

2. Number of students in your class by GRADE LEVEL in the current school year.

Grade	Number
6	
7	
8	
9	
10	
11	
12	
TOTAL	

(Must equal total from Table 1)

3. How many of your students indicated above are considered special education?

4. How many of your students indicated above are eligible for free or reduced lunch?

TEACHER IMPLEMENTATION FEEDBACK FORM: DROWSY DROSOPHILA

Thank you for implementing the Drowsy Drosophila curriculum in your classroom! We are very interested in how you actually used the lessons with your students to better understand different strategies and outcomes in diverse school settings. Please answer the items below, if possible reflecting on each lesson as you move through implementation to capture as many nuances as possible.

School: _____ Teacher Name: _____ Subject: _____

Email: _____

ACTIVITY ONE

1. Briefly describe your implementation of Activity One, noting any modifications you made.
2. Did you or your students have any particular challenges with this activity?
3. Were there particular successes or “ah-ha” moments with this activity for you or your students?
4. What modifications would you made to this activity prior to using it again?

ACTIVITY TWO

1. Briefly describe your implementation of Activity Two, noting any modifications you made.
2. Did you or your students have any particular challenges with this activity?
3. Were there particular successes or “ah-ha” moments with this activity for you or your students?

4. What modifications would you made to this activity prior to using it again?

ACTIVITY THREE

1. Briefly describe your implementation of Activity Three, noting any modifications you made.

2. Did you or your students have any particular challenges with this activity?

3. Were there particular successes or “ah-ha” moments with this activity for you or your students?

4. What modifications would you made to this activity prior to using it again?

OVERALL

1. Where did you situate the Drowsy Drosophila curriculum within your course sequence? What unit/lessons did you teach immediately before and after the Drowsy Drosophila curriculum?

2. Are there any topics/sections that should be added to/deleted from the curriculum? If so, please explain.

3. Would you use this curriculum again? Why or why not?

TEACHER FEEDBACK FORM: DROWSY DROSOPHILA

Teacher name: _____

Subjects taught: _____ Grade levels taught: _____

School: _____ Email: _____

Thank you for reviewing the Drowsy Drosophila curriculum. Please review the entire curriculum and then complete the questions below. You are welcome to insert comments directly in the manual as well as in the section provided below. Comments and suggestions are greatly appreciated!

PART I: EVALUATION OF THE ENTIRE CURRICULUM

SECTION A: For each item below, please indicate your response to each question as it relates to the curriculum overall by marking Strongly Agree (SA), Agree (A), Undecided (U), Disagree (D), or Strongly Disagree (SD).

	SA	A	U	D	SD
1. Are the experimental procedures appropriate for your students?	<input type="checkbox"/>				
2. Are the topics addressed important for your course objectives?	<input type="checkbox"/>				
3. Are the topics addressed relevant to your students' lives?	<input type="checkbox"/>				
4. Are the topics addressed interesting to your students?	<input type="checkbox"/>				
5. Is the depth of coverage of topics appropriate?	<input type="checkbox"/>				
6. Is the overall quality of the curriculum satisfactory?	<input type="checkbox"/>				
7. Is the content in the manual properly sequenced?	<input type="checkbox"/>				
8. Is the content in the manual adaptable for a range of student ability levels?	<input type="checkbox"/>				

SECTION B: Please provide additional comments pertaining to the curriculum overall.

1. Are there any topics/sections that should be added to/deleted from the curriculum? If so, please explain.

2. Additional comments

PART II: EVALUATION OF INDIVIDUAL EXPERIMENTS

SECTION A: For each question below, please indicate your response for each specific experiment by marking High, Moderate (Mod), Low, or Not Applicable (N/A).

	Activity 1				Activity 2				Activity 3			
	High	Mod	Low	N/A	High	Mod	Low	N/A	High	Mod	Low	N/A
1. Is the amount of teacher background information sufficient?	<input type="checkbox"/>											
2. Do the time estimates seem reasonable?	<input type="checkbox"/>											
3. Is the advance preparation reasonable?	<input type="checkbox"/>											
4. Is the student procedure clearly stated?	<input type="checkbox"/>											
5. Do the review questions help students clarify their thinking?	<input type="checkbox"/>											
6. Does the data collection/analysis section help students organize their thoughts?	<input type="checkbox"/>											
7. Is the suggested assessment of sufficient quality?	<input type="checkbox"/>											
8. Are the illustrations/charts/tables helpful?	<input type="checkbox"/>											

SECTION B: Please provide additional comments pertaining to each specific activity.

	Activity 1	Activity 2	Activity 3
1. Are there any topics/ sections that should be added or deleted? If so, please explain.			
2. Additional comments?			

CONTENT AREA EXPERT EVALUATION: DROWSY DROSOPHILA CURRICULUM

Please review the entire manual and then complete the questions below. Comments may be inserted directly in the manual as well as in the section provided below. Comments and suggestions are greatly appreciated!

Reviewer name: _____ Date reviewed: _____

Email: _____ Employer: _____

Department/Division: _____ Job title: _____

PART I: For each item below, please indicate your response to each question as it relates to the curriculum overall by checking Yes (Y), No (N), or Undecided (U).

	Y	N	U
1. Is the science content in the curriculum accurate?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
2. Is the science content in the curriculum current?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
3. Is the science content in the curriculum important for science literacy?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
4. Is the content in the manual related to major biological concepts? (e.g., evolution)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
5. Is the content coverage in the curriculum thorough and complete?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
6. Are potential misconceptions adequately addressed?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
7. Is the content in the lesson properly sequenced for a novice?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
8. Do the experiments model authentic research?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
9. Are there additional concepts that should be included? (If yes, please elaborate below.)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

PART II: Please include below any comments or suggestions about the curriculum.

1. General comments about the overall curriculum

2. Comments regarding individual experiments

Activity 1	
Activity 2	
Activity 3	

