Population Divergence: How are island lizards changing in the Skyros Archipelago?

Lesson Question

How does the concept of selective pressures explain population divergence in Skyros Wall Lizards?

Lesson Task

Students analyze anatomical and behavioral data from island and mainland populations to answer the lesson question. Then they write a report about the extent to which the selective pressure of predation promotes variability in the Skyros Wall Lizards.

Standards

- HS-LS2-2 Ecosystems: Interactions, Energy, and Dynamics
- HS-LS4-4 Biological Evolution: Unity and Diversity

NGSS Science and Engineering Practices

- Analyzing and Interpreting Data
- Constructing Explanations and Designing Solutions
- Engaging in Argument from Evidence
- Obtaining, Evaluating, and Communicating Information

NGSS Disciplinary Core Ideas

- LS3.B Variation of Traits
- LS4.C: Adaptation
- ETS1.B: Developing Possible Solutions

Crosscutting Concepts

- Stability and Change
- Cause and Effect

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OVERVIEW

Content Objectives

Students will understand

→ **Islands are special places** where evolution can progress afresh because events on islands are isolated from what happens elsewhere.

→ **Natural selection responds to selective pressures** by favoring the organisms that can cope with these challenges. This selection is diminished or not necessary when there is lack or decreased selective pressures.

→ **Evolution of form depends on ecological circumstances**, which are different in islands versus mainland. Lack or decreased selective pressures, mainly predation, allows for species to change and diverge.

Skill Objectives

Analytical Thinking

- Assessing evidence in relation to claims
- Generating claims based on data
- Integrating information across sources
- Reasoning with data

Data Communication

- Communicating ideas from data

Data Visualization/Interpretation

- Reading measurements from graphs or tables
- Identifying and describing data patterns

Math/Statistics

- Calculating statistics from a sample
- Evaluating and interpreting relationships between two variables

Instructional Sequence

Share this plan of action with students so they know what to expect from the lesson.

→ **HOOK** We will start by thinking about why lizards have diversified on the Skyros archipelago and how the island lizards have become different from lizards on the mainland.

→ **BACKGROUND** We will go over essential information that you need to know in order to understand the concepts in the lesson. We will learn about how natural selection responds to selective pressures, how traits diverge during evolution, and how to measure evolutionary changes. We will revise the concepts of mean and standard deviation and learn how can we use these measurements to understand evolutionary changes. We will use an example to explain variability of trait, and we will learn how predation, acting as a selective pressure, shapes the lizards' characteristics. We will meet the researchers who have produced the data and learn the methods they used to measure the lizards' traits.

→ **DATA ORIENTATION** We will become familiar with various CODAP tools used to analyze data. We will learn how to analyze the tables containing the data, how to make and modify graphs, and how to explore maps.

→ **INVESTIGATION** Then, as a member of one of three groups, you will investigate whether one of three lizard characteristics—body size, vigilance, or camouflage—differ between the island and mainland habitats, and you will determine the possible cause(s) for the divergence of these traits. During the investigations, you will propose a hypothesis, analyze data sets, construct graphs, make calculations, and summarize your results. At many points during the lesson, you will judge the outcome of your investigations by comparing results and discussing your findings and those of your peers. As a group, you will prepare a small presentation sharing the results with the rest of the class.

→ **WRITING** The final product of the lesson will be a written report consisting of the following: an introductory paragraph explaining the context of your investigation; a claim paragraph, where you will respond to the question, "How does predation release explain the differences in characteristics between island and mainland lizards?"; and a third paragraph where you will provide evidence for your claim using the results you obtained on the trait that you investigated. In the fourth paragraph, you will discuss a different trait using information from your notes and discussion with your peers. In the conclusion paragraph, you will consider a hypothetical situation and use data to back up your responses.

Lesson Background for Teachers

Teaching about the factors that influence diversification on islands is a good idea because it may lead students to ask more profound questions about how evolution works. For example, how exactly does an anatomical feature change with time? This question can lead to concepts such as mutation, selection, developmental trajectories, population variation, speciation, and so on.

This lesson is about how selective pressures shape evolutionary responses—and what happens when these pressures are reduced or disappear. For example, in a mostly green environment, when the selective pressure of predation is strong, few organisms that are not of a greenish hue will survive; a plot showing the population (y) and the trait variation (x) would display a very narrow curve. If the selective pressure of predation is relaxed or removed, the curve for the trait *color* would widen because individuals of more hues would survive and reproduce (see Background Slide 5).

The environment is of crucial importance for evolution, as the stage where evolutionary mechanisms play out. Organisms can reach islands in several ways—for instance, as drifting on floating material, being carried by birds, or when an island is formed by being cut away from the mainland by rising sea levels. On an island, the selection process is relaxed, and organisms can display characteristics that would not confer fitness on the mainland, where predators and other pressures would be present. For example, the Skyros Wall Lizards living on islands do not need to be as alert, they do not need to match their surroundings as closely, nor do they need to be small to hide from predators. In science, it is important to show repeatability. By studying this phenomenon in an archipelago, each island around the mainland can be considered an independent event. The Skyros archipelago was formed by an increase in sea level thousands of years ago, suggesting that all the islands were formed at the same time. The evolutionary process by which the lizards changed started at the same time in all locations. The similar time of divergence was confirmed by measuring the genetic distance between lizards from each island to lizards from the mainland. In the interest of simplicity, this level of investigation has not been considered in the lesson but it would be an interesting extension.

The investigators set out to investigate how lizards on the island have diverged from lizards on the mainland. The authors looked not only at how size changes in response to the absence of predators, but also how other characteristics, like alertness and camouflage, change with time. The main question under study in this lesson is whether the island lizards have diverged in all of these three characteristics and, if so, why.

Lesson Logistics

In this lesson, students will investigate how the selective pressure of predation contributes to diversification of three traits: body size, alertness, and coloration. After going through the Hook and Background material, students have to be divided into three groups. In the first part of the lesson, students in the first group will look at two measurements of lizard size: mass and length. The second group will investigate how alertness has evolved differently in island versus mainland lizards. The third group will investigate the effect that lack of predators has had on the evolution of camouflage. At this point in the lesson, each group should summarize their results and prepare a small presentation. Advise the rest of the class to pay attention and take notes, since they will be writing not only about their own results but also the results of a trait investigated by another group.

Woven throughout the lesson are elements of scientific investigation or practices that students should develop in a science class.

- Making hypotheses
- Data analysis: graph construction and calculations
- Reproducibility: lizard's characteristics are measured in more than one way
- Making a story with the results
- Research collaboration: group work
- Class discussion: peer review
- Writing a final essay: publication

Student Background Knowledge

Students should keep the folowing in mind throughout the investigation's lesson

- The way natural selection acts on organisms is fluid because it depends on the ever-changing environment. For example, a drought or a flood could alter the availability of food or shelter, a hurricane could wipe out or introduce new biota to an island, and so on. The result is that selective pressures often can, and do, change.
- Evolutionary changes take several generations, but can also happen quickly. For example, when the organism generation time is short, as with some bacteria that have a generation time of 20 minutes, evolving new traits can happen swiftly. There are other evolutionary mechanisms, such as hybridization, that promote rapid evolutionary changes.
- Research does not start with a hypothesis, but with an interesting observation or situation. Several hypotheses are constructed to investigate the topic or aspects of the area of interest. Then, individual experiments are designed to address each hypothesis or question. We make sense of and try to answer the big question by putting together the results of all the parts into a coherent story.

The Hook

(Estimated time: 10 minutes)

What happens when populations are separated?

Purpose

- To engage students in the question, "What happens when populations are separated?"
- To discuss how evolution works, and to identify misconceptions and prior knowledge

Big Ideas

- Islands are formed in different ways; the result is that the biota becomes separated.
- Organisms separated in this way evolve independently of each other and become different with time.
- Evolutionary mechanisms operate differently in islands versus other locations such as other islands and mainland.

Over thousands of years, rising sea levels have caused lizard populations in Skyros, Greece to become separated.

How – and why – might the island lizards have evolved differently than those on the mainland?

Facilitation Suggestions

- **Invite students** to observe the panel to the right, it depicts how in the Skyros Archipelago, these small animals find themselves separated from their counterparts in the mainland. Ask students to think about other ways in which this separation may happen.
- **Make sure students** understand that the lizards living on the islands and on the mainland have been separated for thousands of years, and that developing different or new characteristics takes several generations. Ask students to imagine how lizards may have changed after all those years.
- **Encourage student participation** by calling on a few of them to voice their ideas. Look for misunderstandings and prior knowledge in students' answers. This information should inform you as to what ideas to correct or support.
- This panel also informs students what are they going to do in the lesson: investigate how and why lizards on islands are different from their mainland counterparts.
- **Review new vocabulary and point out** the rollover feature for glossary terms. In discussions, encourage students to use the new words from the vocabulary.

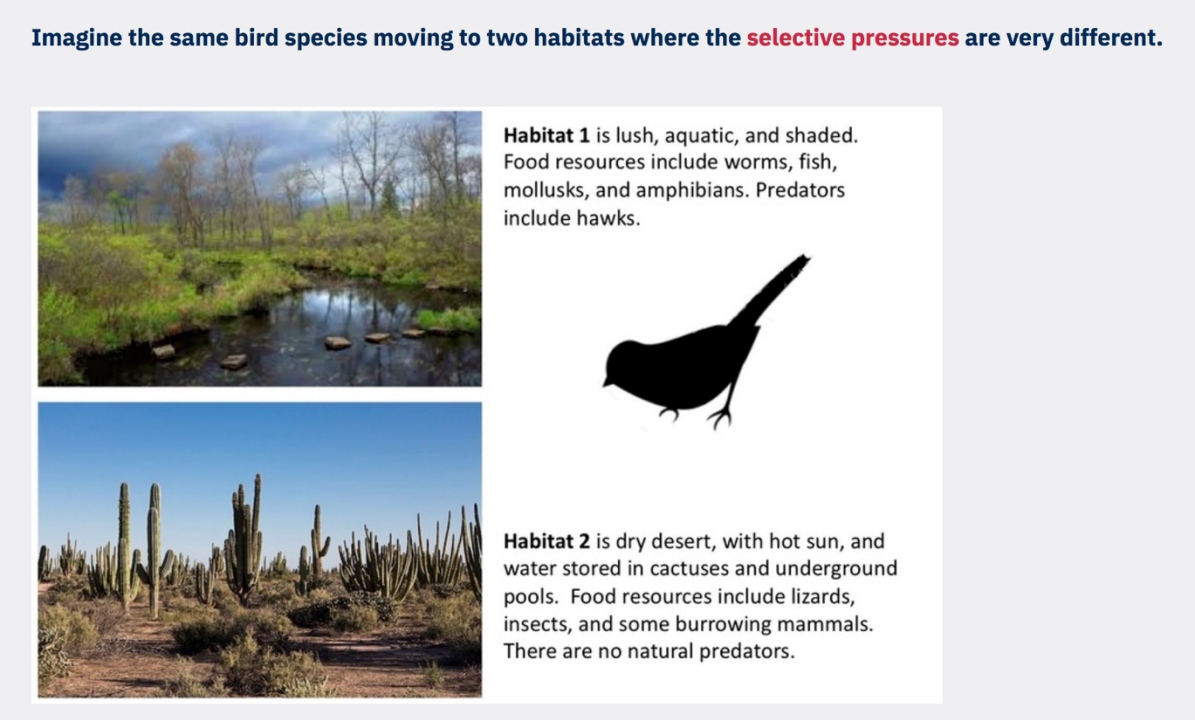
TRANSITION TO BACKGROUND

Tell students that all the ideas discussed during the Hook will be developed throughout the lesson. First, they need to learn some relevant background information to understand the lesson concepts. We will start by looking at how selective pressures and natural selection work.

Background

[Estimated time: 35 minutes]

Project the background slides to the class, and have students actively read and discuss the content and questions so that they develop background knowledge needed in the investigation. Make sure they understand the concepts before continuing to the "data orientation" and "investigations" sections.



Background 1: Natural Selection & Selective Pressures

Purpose

- To make the connection between natural selection and selective pressures.

Big Ideas

- Natural selection favors the organisms that can best deal with selective pressures.
- How organisms evolve depends on the challenges imposed by the environment and what favorable traits the organisms in a population possess.

Facilitation Suggestions

- **Introduce the ideas** of natural selection and selective pressures by reading the text on the left-hand side panel. Pause for comments and questions.
- **Direct students to look at the habitats** where the bird in the diagram may live. Using one selective pressure from the list, ask students to think about how the bird's characteristics will change with time (evolve) in each habitat. Give students a few minutes to think about the situations, and then call on them to participate in a class discussion.
- **Pay attention to how students apply the definition of selective pressure in this exercise.** Ask them to explain why their choice is a selective pressure, what happens to the bird in each habitat, and how the change in the bird's characteristics is advantageous in that environment.
- **Then direct students to write** in their own words the definition of "selective pressure." Make sure students learn the new words and their meanings.

TRANSITION POINT

Tell students, "Let us extend this concept further to see how evolution acted on an ancestor of a bird and gave rise to many populations, all showing differences in traits."

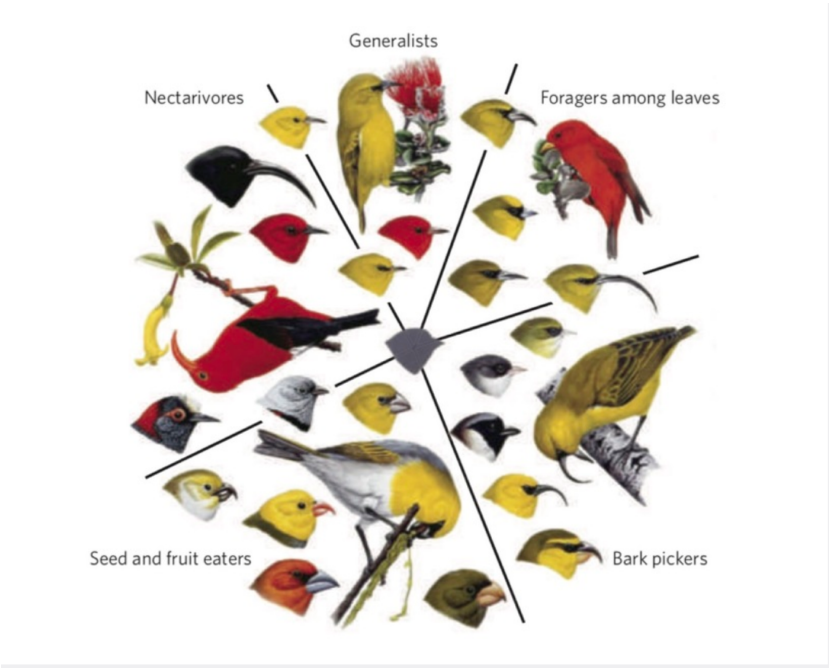
Background 2: Fitness and the Divergence of Traits

Purpose

- To understand how and why diversification occurs
- To learn how divergence of traits is restricted by selective pressures imposed by various habitats

Big Ideas

- Diversification happens when different habitats become available.
- Organisms occupying a habitat evolve a narrow range of traits that perfectly fit their environment.
- The type and range of traits are limited by constraints or pressures that are different because they depend on ecological context.



Facilitation Suggestions

- **Ask students to look at the diagram and describe what they see.** Focus on the bird shadow at the center (the ancestor) and ask students what each "slice of the pie" illustrates and what happened to the species over time. Encourage active participation by calling on a few students to voice their ideas.
- **Go through the diagram with students**, ask them to confer with a partner about the question, "How did the different foods available on the islands favor diverse traits among the birds?"
- **Direct students to look more closely at the beaks of the birds** in each section and explain their shape in terms of food resource, selective pressure, natural selection, and habitat. **Lead a small class discussion** and invite students to participate.

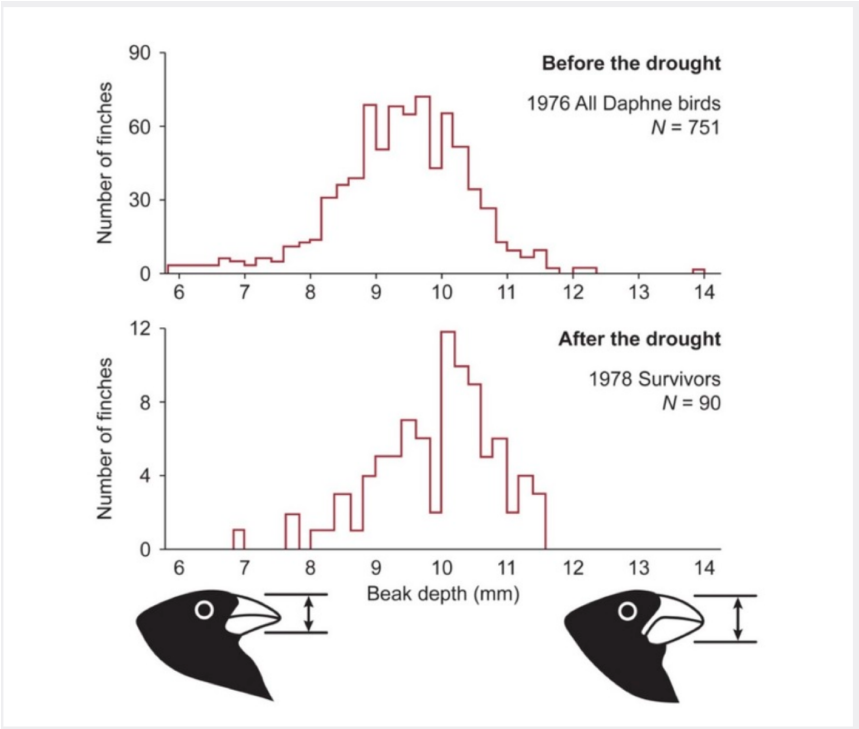
TRANSITION POINT

Tell students, "Qualitative descriptions of a phenomenon is important, but we also have to quantify changes. Next, we will look at an example of how to do this."

Background 3: Measuring Evolution at Work

Purpose

- To express the evolution (change over time) of characteristics by measuring the differences among birds' beaks at two time points
- To emphasize the close relationship between the ecology of a habitat and a trait, such as the bird's beak



Big Ideas

- Evolutionary changes can be followed if we can compare traits in the same species at different time points.

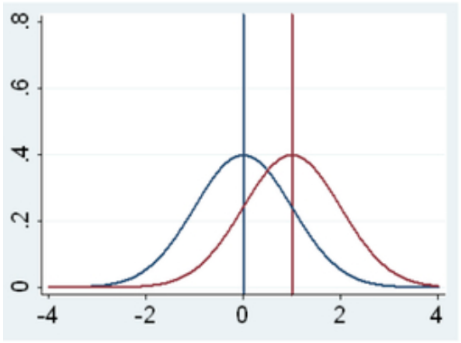
Facilitation Suggestions

- **Start by pointing out that this diagram shows a phenomenon in progress**. We are seeing what happens to the finches' beaks before and after a drought.
- **Read aloud the text on the left-hand pa**nel and allow time for the students to look at the diagram and describe the differences in the birds' beaks.
- **Ask students to think about how** the shapes of the birds' beaks explain the way evolution progressed. Keep in mind that one misconception about evolution is that it always happens on the scale of millions of years—this is not true. As noted in the students' background section, evolutionary processes happen in smaller time scales and can be observed.
- **Encourage students to answer the first and second questions by narrating the events in their own words.** For example, this graph shows how evolution works: There were birds with an average beak depth of about 9.5 mm; then an environmental event, the drought, changed the ecology of the habitat. The new selective pressures favored birds that can cope with the new situation; the birds that survived and reproduced have a deeper beak of about 10–10.5 mm. The deeper beaks allowed the birds to eat and survive, while the other birds died.
- **Make sure students identify the new** selective pressure after the drought: hard seeds as a food resource.

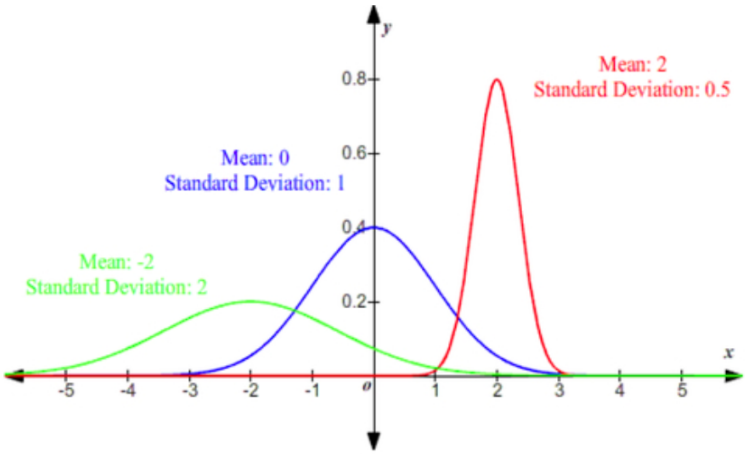
TRANSITION POINT

Tell students, "Let's think about two ways to measure changes in a population's traits. You will be using this during the investigations."

Background 4: Mean and Standard Deviation



The Mean
When comparing the same trait after a change in the environment, such as beak size, different means may indicate an overall change in that trait.



Standard deviation (SD)
When looking at the distribution of a trait such as body size in a population, standard deviation can be used to describe how much diversity there is for that trait.

Purpose

- To explain how the statistical measures of mean and standard deviation can be used to investigate overall change, as well as divergence, in a population's traits

Big Ideas

- A change in the *mean* or *average* indicates overall change in a characteristic.
- *Standard deviation* tells us about the diversity of the characteristic, or how many different types of the trait there are.

Facilitation Suggestions

- **Tell students that this is an important background slide,** since the concepts of mean and standard deviation will be used heavily in the investigations.
- **Start by explaining the definition of mean and relate this to the "measuring evolution at work" slide.** The change in beak mean from 9.5 to 10.5 mm is a good illustration of how change in mean indicates an evolutionary change in a trait. Inform the students that they may encounter this situation during the investigations.
- **Next, go over the text and diagram explaining standard deviation**. Tell students that standard deviation can be used to measure the *spread* of the data. Ask students to imagine that the three colored curves show a trait such as beak length in three species of birds. In which population does beak length show the greatest divergence, or diversity? (The green curve.) In which population does beak length have the least diversity?

TRANSITION POINT

Tell students, "Next, we will apply the concept of standard deviation to understand variability of a trait—coloration."

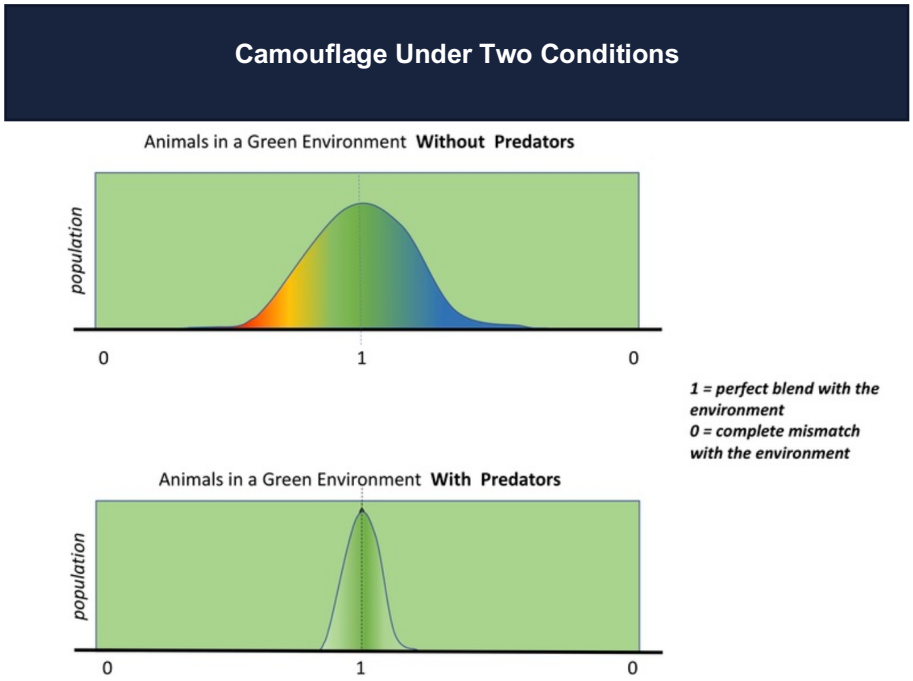
Background 5: Describing the Variability of a Trait—Camouflage

Purpose

- To explain how to use a curve, plotting population versus a trait measurement to investigate the change in variability

Big Ideas

- When organisms can diversify and be of different variety, the curve is wide.
- When there are many restrictions or selective pressures acting on organisms, the curve is narrow.



Facilitation Suggestions

- **Explain that there are two situations presented in this slide**; students working in pairs should examine each one alone and then put their answers together.
- **Go slowly, reading the text on the left-hand panel** and encouraging students' participation in answering the questions. The upper panel shows that colorful animals are alive because there are no predators to eat them; therefore, there are many types present, as represented by the wide curve. The lower panel shows the same environment but with predators; the curve is narrow because the colorful animals have been eaten, leaving those that can blend in with the environment.
- Once students understand the connection between wide versus narrow curves in terms of variety of trait, **ask them to perform a thought experiment** where the predators are removed from the environment. In their answers, students should describe the new situation, and this should be like the upper panel.
- **Note**: If students are narrating the events carefully, step by step (wide curve to narrow curve and back to wide curve), they may ask where the colorful animals came from in the third situation. Notice that in the second situation of the narrow curve there are no colorful animals. The answer is in the genetic variability of the population; the genes are there, just not expressed in great frequency, or, if there are a few animals that do not camouflage, they are quickly eaten.

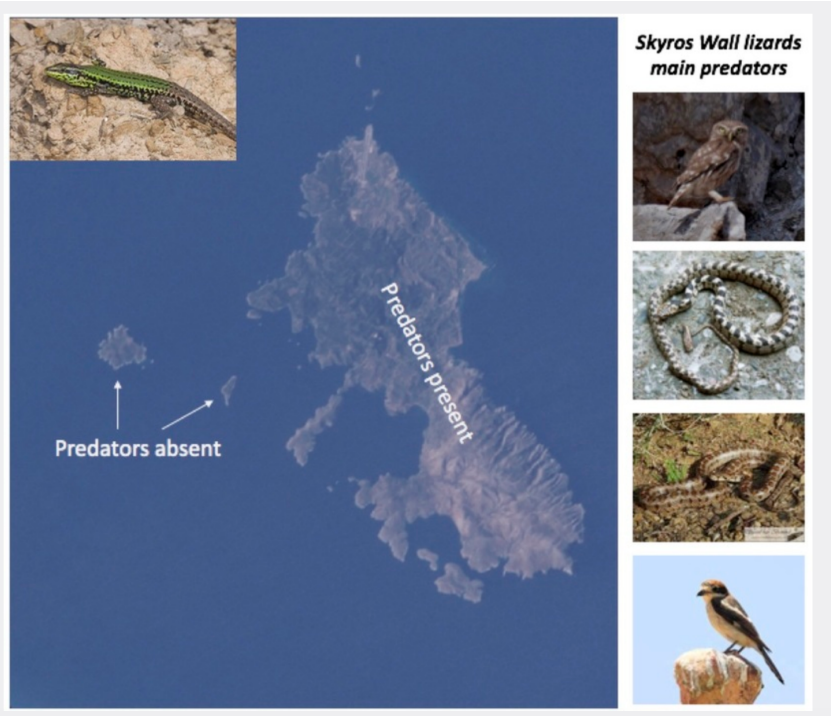
TRANSITION POINT

Tell students, "Let's get familiar with the location, the animal involved in the study, and the ecological situation of the phenomenon."

Background 6: Predation and the Skyros Wall Lizards

Purpose

- To inform students that one crucial element of the lesson is that predators are absent in the islands, and this may have affected how the lizards evolved



Big Ideas

- Predation poses a very strong selective pressure in animals.
- Organisms evolve traits that help them deal with these challenges.

Facilitation Suggestions

- **Tell students that** the picture depicts the location under study—the Skyros Archipelago—and the animal in the study—the little Skyros Wall Lizard. To the right of the map there are pictures of the four main predators of the lizard.
- **Inform students that they must keep in mind** all through the lesson that the main difference between the islands and the mainland in the Skyros archipelago is that there are no predators in the islands.
- Students are asked to hypothesize how lizards' characteristics may differ between a habitat with predators, the mainland, versus a habitat without predators, the islands. Notice that this question is exactly what the investigations are going to explore.

TRANSITION POINT

Tell students that the data and research questions you will be exploring in the investigations are based on the research of people interested in learning how evolution works. Let us meet them.

Background 7: About the Researchers

Purpose

- To inform students about the source of the data used in this lesson.
- To connect with the investigators involved in the research and learn about their scientific interests.
- To learn about the data source and broader concepts used of the study.

Big Ideas

- Science is a collaborative endeavor among many people and institutions.
- The problem studied by these scientists has great implications for understanding how evolution works.

Facilitation Suggestions

- **Tell students that** research is a collaborative effort by many people and institutions, and is always based on past investigations. Inform students that they can find more information about the researchers by going to the link provided.
- With the purpose of making the NGSS practices more visible to students, throughout the lesson these ideas will be emphasized under the title **This is how science works.**

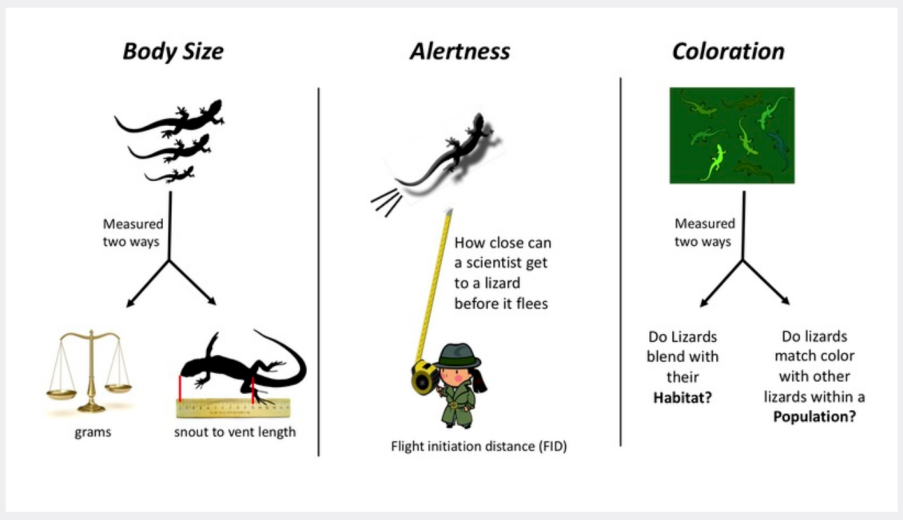
TRANSITION POINT

Tell students; one of the most important aspects of scientific research is to come up with experimental methods to study the phenomenon. Let us see how the researchers measure the lizards' traits.

Background 8: How the Lizards' Traits Were Measured

Purpose

- To learn about the methods used to measure the lizards' characteristics.



Big Ideas

- There should be more than one way to study a phenomenon.
- If the results point to the same conclusion, then the interpretation must be correct.

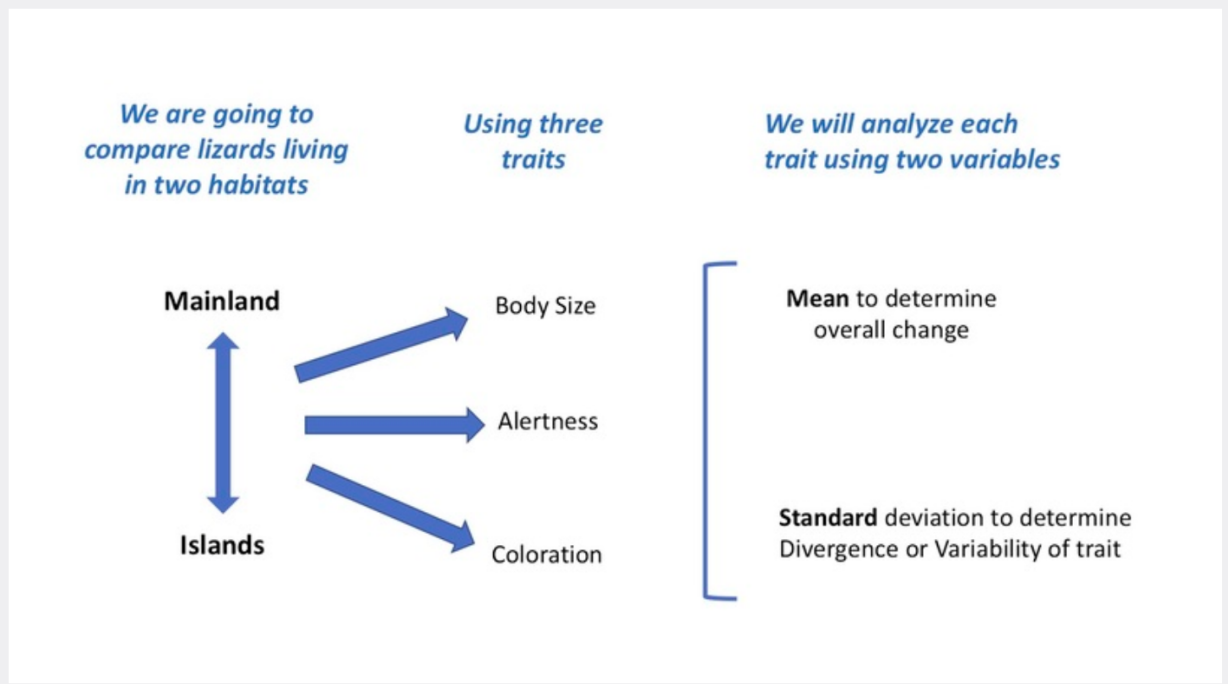
Facilitation Suggestions

- **Talk about** the big ideas behind the experimental methods, as these are central elements behind science research.
- **Go through each panel, discuss the methods** used to measure the three traits, and encourage students' participation. You may invite students to think about alternative ways to measure these traits.
- **Explain that size was measured** by how much the lizards weigh (mass in grams) and how long they are (in centimeters). Alertness, a behavioral trait, was measured by the distance, in meters, at which a lizard fled when a researcher approached. Coloration was measured in two ways: how well lizards camouflage against the environment, and whether they blend within their own population.
- **Make sure you discuss the importance of corroboration in science**. In order to build a solid piece of scientific information, more than one corroborating result must be used to make a valid claim.

TRANSITION POINT

Tell students, "Next we are going to look at the logistics of the rest of the lesson."

Background 9: Road Map to the Investigations



Purpose

- To inform students of the logistics of the lesson and their role in the lesson

Facilitation Suggestions

- **Inform students that the class will be divided** in three groups; the body size group, the alertness group, and the coloration group.
- **Explain that using their assigned trait,** each group will compare lizards living on the mainland to those living on the islands.
- **Let students know that after the investigations** each group will prepare and deliver a small presentation of the results to the rest of the class. During the presentation, the rest of the class must pay attention and take notes, since they will report on what they have heard.
- The final outcome of the lesson is that each student will write an essay reporting on the results. This includes the trait they investigated as well as a second trait, based on what they learn from their peers' presentations.

TRANSITION TO DATA ORIENTATION

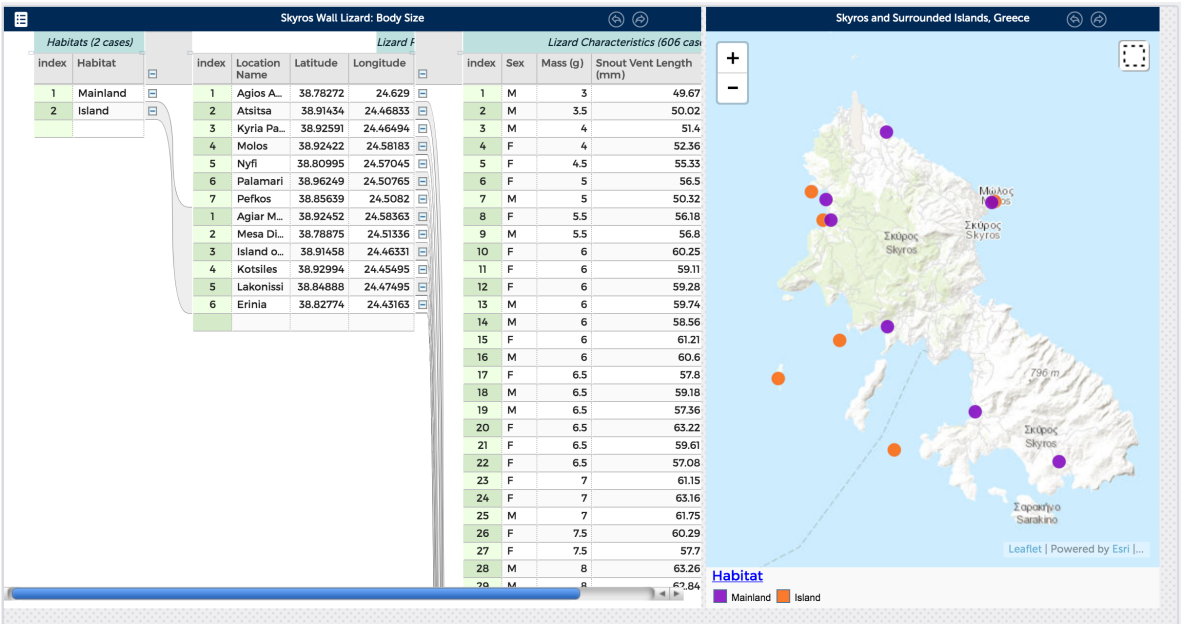
Remind students of the lesson task—to analyze anatomical and behavioral data from island and mainland populations to find out the extent to which the selective pressure of predation promotes variability in the Skyros Wall Lizards—and inform students that in the next section, the Data Orientation, they will be learning to use the necessary tools to analyze the data collected by the investigators.

DATA ORIENTATION

Estimated Time: 15 minutes

We recommend that the teacher continue to project the slides to the class, and guide students as they practice working with the data. As students complete the exercises, allow them to explore each data visualization, show them how to use CODAP to construct a graph, and use the attributes to highlight data on the map.

Data Orientation 1: The Table and the Map



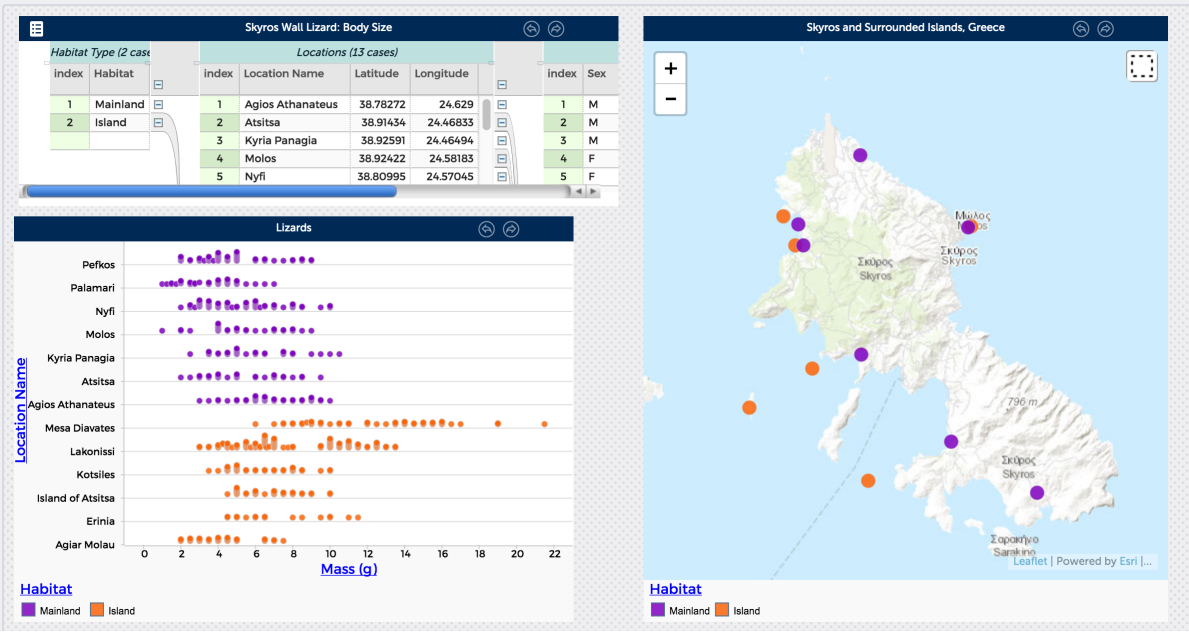
Purpose

- To familiarize the students with the data in the table and how the data is related to the map
- To have students do simple manipulations with the data in preparation for later
- To learn how to use CODAP features and tools

Facilitation Suggestions

- **Start by reading the text in the left-hand panel.** Go slowly through the actions and questions suggested in the left-hand panel.
- **Inform students** that in step two they will learn how to color code data points. **Offer students a lot of support, and encourage** them to explore the connections between table entries and map locations.

Data Orientation 2 : The Graph



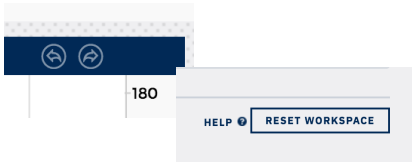
Purpose

- To have students do simple manipulations with the data in preparation for later work
- To learn how to use CODAP features and tools

Facilitation Suggestions

- **Inform students that in this section** they will learn (1) how to construct a graph by dragging attributes to the y-axis and x-axis and (2) how to color code data points by dragging attributes to the center of the graph or map.
- Tell students that for help with the construction of the graphs, they should make full use of the "Show How" videos.
- **Offer students a lot of support,** and encourage them to explore the connections between table entries, map location, and graph dots to prepare for the lesson where they will construct more involved graphs.
- **Project the slide and perform the moves** slowly so students can compare their graphs and make sure they performed the tasks correctly.
- **Encourage students to explore the connections between** the data points represented in the graph, the table, and the map. Click on points on the graph to see corresponding data in the table; click on rows in the table to see corresponding data points on the graph. Point out the connections between the table and graph. Ask students what each point on the graph means.
- **Show students how they can go back** to any of the previous sections (background, orientation) by clicking on the top green panel. Inform students that they can always undo or re-set their work by going to the icons.

UNDO:



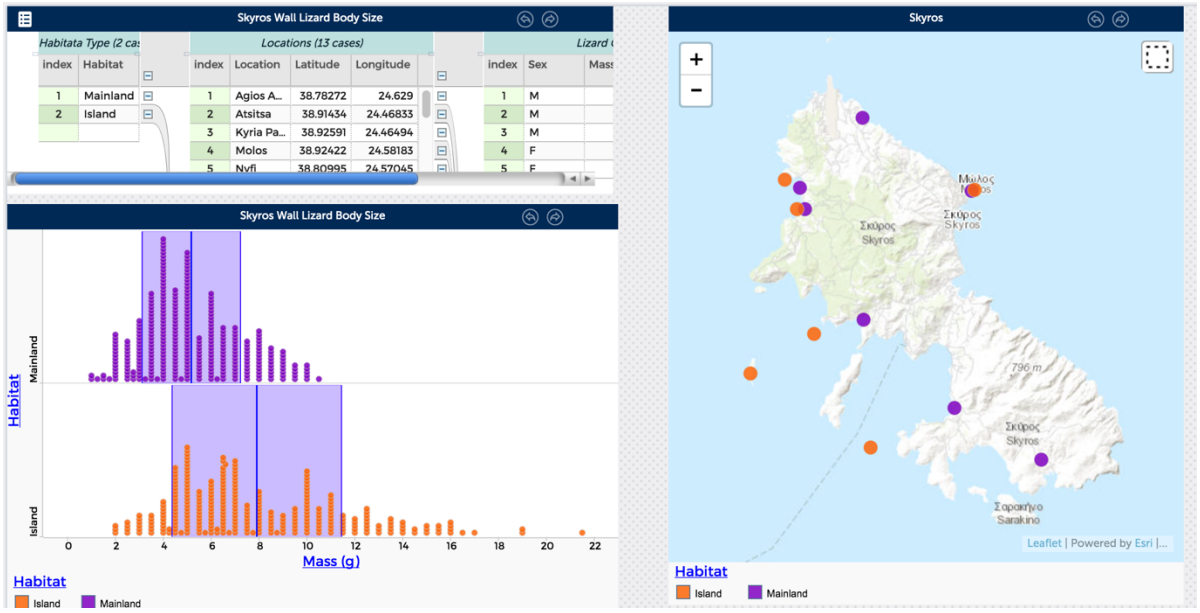
Start Over:

TRANSITION TO INVESTIGATION

Tell students that now that they know how to work with CODAP, they will continue to use these tools to work with the data on their own to answer the question, "*How does the selective pressure of predation explain population divergence in Skyros Wall Lizards?"* Now we are moving to investigate a possible cause for differences in traits between island and mainland lizards. Each of the three groups will investigate one trait: size, alertness, or camouflage.

INVESTIGATE Body Size: Is There a Difference Between Mainland and Island Lizards?

Estimated Time: 20 minutes



Purpose

- To Investigate two measures of body size and determine whether there are differences in mean and variability of trait
- To introduce the concept of corroboration of results as an essential scientific feature

Big Ideas

- Lizards from the islands have more variability of body mass and length than do mainland lizards, showing a wider curve graph.
- Overall, island lizards show increased body size compared to the mainland lizards.

Facilitation Suggestions

- **Start by reminding students how the researchers measure body size** and that the ecosystems in the island and mainland have one main difference, the presence or absence of predators.
- Based on this information, **ask students to make a hypothesis,** and respond to the questions posted: Do you expect that lizard size would vary in these two habitats? How? How would the presence or absence of predators affect whether or not there is a difference in size between island and mainland? (Remember to ask whether their hypothesis was correct or not at the end of the section.)
- This is the first time the students are asked to construct a graph using data from the table. **Introduce the "Show How" movie to illustrate graph construction.**
- **Tell students to make sure to save the graph** with the mean and standard deviation in their notebook by taking a snapshot.

- **Make sure students understand what the terms mean and standard deviation mean.** Ask students to explain what the graphs show using these variables. For example: the mean mass of the mainland lizards tells me that … .
- Before answering the questions on variability in size, it may be a good idea to revisit the background information on "Describing the Variability of a Trait—Camouflage." **You may want to have a brief conversation in class about** variability of traits and why would this difference be observed. This may help you check if the students are on the right track.
- **Go through the same process for the second trait**, snout-to-vent length. Make sure students save both plots in their notebook.
- **Ask students what corroboration means and answer the question**, "Why is corroboration important in science?" A brief class conversation could get students thinking about this science practice.
- **Challenge**: Some students may need support calculating percentage difference. Scaffolding may be necessary to understand and use the concept of standard deviation in relation to variability and divergence.

INVESTIGATE Body Size: Summarize the Difference Between Mainland and Island Lizards.

Estimated Time: 20 minutes

Mass	**Mean**	**% difference from mainland lizards**	**Standard deviation**
Mainland	5.17 g	----------	2.05
Island	7.91 g	35%. The island lizards are bigger than the ones in the mainland, may be smaller lizards can run faster or can hide in small places.	3.54
SNV Length	**Mean**	**% difference from mainland lizards**	**Standard Deviation**
Mainland	56.6	----------	6.6
Island	65.1	15% no because if the lizards are bigger in mass then other things will also be bigger like length.	9

Purpose

- Summary tables help students bring their results together, weigh all the evidence, and decide what factors are important to include in their conclusions.

Big Idea

- Both pieces of data, mass and SNV length, corroborate that there is increased variability in island lizard body size compared to mainland lizards.

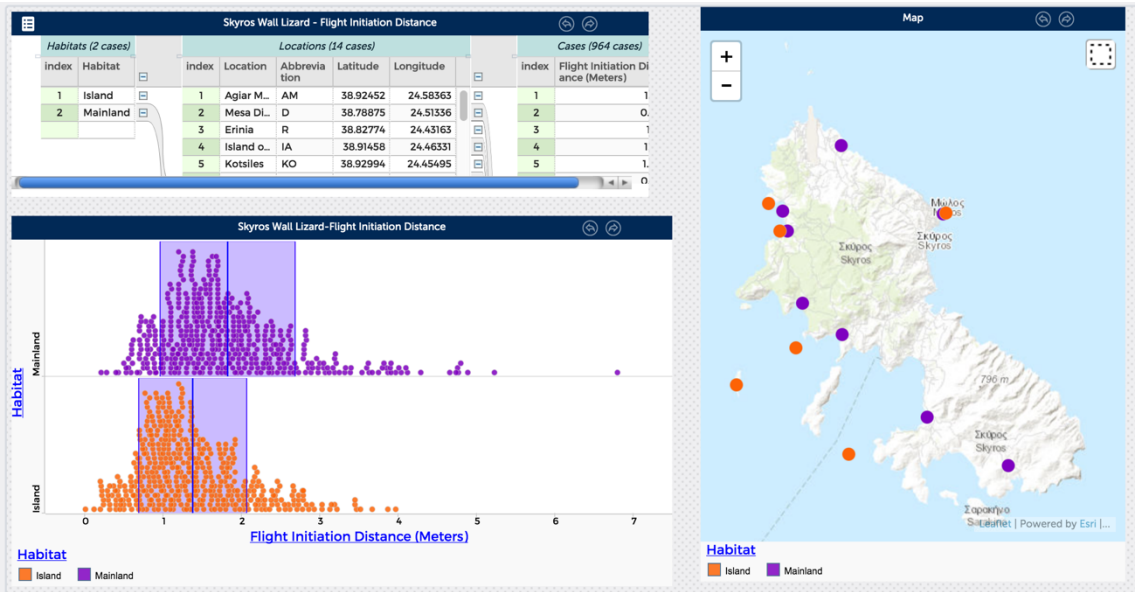
Facilitation Suggestions

- **Go through the summary table with students and encourage active participation** by calling on a few students. Call their attention to the fact that they have produced two different results, on mass and on SNV length. Do the results corroborate each other?

- Students have established that there is an overall change in size and that there is variability in size between the island and mainland lizards. **Ask students to consult with a peer and to think about the possible cause for this difference—predation.** Encourage students to verbalize their ideas during the "compare" part of the exercise.
- **Ask these questions to get the students thinking** more deeply on the concepts of divergence and predation release: (1) What are the selective pressures in these ecosystems (island and mainland) that affect size variability? (2) Reduced pressure from predators will relax evolutionary constraints and so we expect increased variability in different traits. How does divergence happen? (Hint: through natural selection.)
- **Inform students** that, as a group, they have to prepare a small presentation for the rest of the class. **Walk around the groups** making yourself available for students' questions and comments.

INVESTIGATE Alertness: Do Island Lizards Run From Danger Faster or Slower than Mainland Lizards?

Estimated Time: 20 minutes



Purpose

- To investigate whether predation release is a possible cause for increased variability in island lizards
- To use alertness as an indication of whether predation is a selective pressure on the Skyros mainland

Big Idea

- Lizards need to be more vigilant in the presence of predators.
- There are no predators on the island, so the release from this pressure allows lizards to become less alert.

Facilitation Suggestions

- **Start by reminding students how the researchers measured alertness,** and that the ecosystems on the island and mainland have one main difference—the presence or absence of predators.
- Suggest that students work in pairs before voicing their ideas. **Ask students to think of the best way lizards can avoid death by predation** before they make their hypothesis. You may ask the following questions: "Do you think that alertness is an important trait for a lizard to have? Why? What differences in alertness (if any) would you expect to see between island and mainland lizards?"
- **Direct students to construct the graph and, if they need more assistance**, to look at the "Show How" movie. After the graph is made, encourage students to verbalize and describe the graph in their own words. Give them time to think and to write down their ideas.
- **Tell students to make sure to save the graph** with the mean and standard deviation in their notebook by taking a snapshot.
- The fourth step asks students to find the mean and interpret the result. **Ask students: Which lizards would be more afraid of predators? Where do these nervous lizards live?**
- **Challenge:** The investigation into variability of alertness in step five needs special attention. Standard deviation is defined as a measure of dispersion; a large value of standard deviation indicates a greater variability and thus the values are more spread out. **Ask students: What does standard deviation tell us about the data on alertness?**
- Notice that there are outliers in the mainland portion of the graph with longer flight initiation distance (FID), and that the graph suggests higher variability for the mainland lizards. This is contrary to the idea that pressure release promotes variability on the island lizard populations. **Discuss the answer to the questions to make sure students understand the graph and its meaning.** Ask the students what the outlier data points suggest about alertness, predation, and living on the mainland.
- **Talk to students about how science works**. When scientists analyze data and the results are contrary to expectations, investigators have to reevaluate the idea, come up with questions, provide alternative explanations, and propose further experiments.
- Animals are under many selective pressures; some are stronger than others. In this case, predation is very strong since the result is life or death. When one selective pressure is removed, then other pressures will come into play. Running away is favorable when the predator is present, but when the predator is no longer there, running away is no longer favorable. Running away requires energy and this precious resource can be used for other purposes such as mating, foraging, and so on.

INVESTIGATE Alertness: Summarize the Data on Flight Initiation Distance

Estimated Time: 20 minutes

Habitat type	Mean Flight Initiation Distance	Standard deviation
Mainland	1.82	0.86
Island	1.38	0.69

Purpose

- Summary tables help students bring their results together, weigh all the evidence, and decide what factors are important to include in their conclusions.

Big Idea

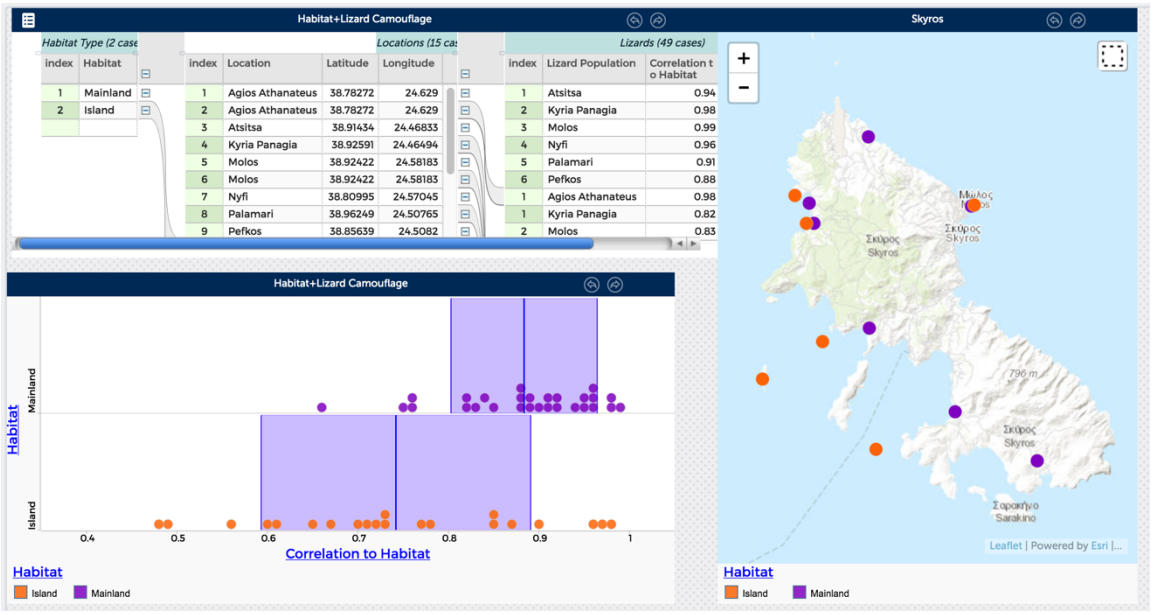
- Animals flee from predators to avoid death.
- Organisms are shaped by many selective pressures; predation is a very strong selective pressure.

Facilitation Suggestions

- **Go through the summary table with students and invite participation** before they answer the prompts.
- **Focus on the mean differences between mainland and island lizards,** and have students discuss and reach a consensus that they can present to the rest of the class.
- **Then discuss the variability results**, and elicit opinions and answers from students. Ask them: Are they surprised by the results? What would be the possible explanations for higher variability in mainland lizards? You may suggest ideas to consider, such as activities that require energy expenditure, and ways to explain the outliers in the graph.
- **Inform students** that, as a group, they have to prepare a small presentation for the rest of the class. **Walk around the groups** making yourself available for students' questions and comments.

INVESTIGATE Coloration:
Is There a Difference Between Mainland and Island Lizards?

Estimated Time: 20 minutes



Purpose

- To investigate lizard coloration as an evolutionary response to predation and whether relaxing predation results in divergence of color

Big Idea

- Blending with the environment and with each other provided lizards with protection against predators.
- Corroboration indicates the results are consistent and therefore adds validation to the idea being investigated.

Facilitation Suggestions

- **Start by reminding students how the researchers measured coloration** and that the ecosystems in the island and mainland have one main difference, the presence or absence of predators.
- **Tell students that before making their hypothesis, they should consider both of the questions in step 2**: Why would the color of an animal be important in order to avoid predators? What differences in coloration do you predict there will be between island and mainland lizards?
- **Inform students that, similar to the investigation on body size,** the authors looked for corroboration of results by using two different approaches to study camouflage.
- In the first approach, students ask which lizards blend better with their environment by comparing the correlation to habitat between mainland and island lizards. Make sure students understand that this data looks at the ability of the lizards to blend with their environment.

- **Tell students to make sure to save the graph** with the mean and standard deviation in their notebook by taking a snapshot.
- **Encourage students to describe the graph, and ask them** to explain what the outliers represent. Then ask students to find the mean and use this data to answer the questions in the Step 4 panel.
- **Direct students to query divergence** by finding the standard deviation and judging which lizard populations have more variability of color—and why. Ask the students to keep in mind when answering the questions that there are no predators on the island.
- **The second part** of the exercise asks students to determine whether the lizards are more homogeneous in color on the mainland or island, and why.
- **Direct students to modify the graph** to show habitat versus correlation to population. **Make sure to save the graph** to their notebook by taking a snapshot.
- In interpreting the results, **encourage students to think of the process of natural selection**. The predator would eat the lizards that do not match their habitat, so only a narrow range of colors is allowed, and thus most of the lizards look like each other. If there are no predators, there is no need to look similar.
- **Color measurements.** Investigators measured reflectance of 200 lizards' dorsal body surfaces using a spectrometer. A matrix correlation was constructed in which two identical populations would have a matrix correlation of one, whereas two populations with no overlapping color would have a correlation of zero. The same type of matrix correlation was used for the phenotype-environment matching.

INVESTIGATE Coloration: Summarize the Data on Coloration

Estimated Time: 20 minutes

Habitat Type	Mean Coloration - Correlation to Habitat	Standard Deviation -Correlation to Habitat	Percentage (%) Correlation to Population
Mainland	0.884	0.081	86%
Island	0.742	0.149	33%

Purpose

- Summary tables help students bring their results together, weigh all the evidence, and decide what factors are important to include in their conclusions.

Big Idea

- Animals use camouflage in order to hide from predators and avoid death.
- Blending with the environment and with other members of the population (conspecifics) are two ways to measure the same idea: camouflage as a defense mechanism.

Facilitation Suggestions

- **Go through the results on correlation to habitat first,** making sure that students use the idea of predation release in the discussions and that they reach a conclusion as a group.

- **Then discuss the results on correlation to population** and ask students to compare the results. Do the results from correlation to habitat corroborate the results from correlation to population? Is there more or different information obtained from the investigation of correlation to population?
- **Inform students** that, as a group, they have to prepare a small presentation for the rest of the class. **Walk around the groups** making yourself available for students' questions and comments.

Summarize Your Findings for All Skyros Lizard Characteristics

Estimated Time: 20 minutes

Characteristic	Mainland	Island
Size	bigger	smaller
Alertness	more	less
Camouflage	better	worse
Predators	present	absent

Purpose

- Students will use the table to summarize results and to answer questions.
- Use the table as reference when students present their work to the rest of the class.

Big Idea

- Animals evolving in different habitats show differences in many traits.
- Habitats such as islands and mainland may have different selective pressures imposed by the environment.

Facilitation Suggestions

- **Go through the table row by row and ask students** to think of the entries using the concepts of predation and predation release.
- **Call groups in turn** to present their results. When each presentation is finished, promote students' participation by asking them to voice their ideas, comments, and questions.
- **Keep in mind** that some students will not voice their ideas; you may recommend that they write questions or make comments on sticky notes.
- Alternatively, **direct each group** to write their results on a big piece of paper and hang it on the wall. Then have students visit the stations and atach their comments and question on sticky notes. You may choose which questions or comments to discuss in class.
- **Direct students to write a brief paragraph addressing the following**: Describe how lizards have diverged in the Skyros archipelago. How has the trait you studied changed over time? How does relaxed predation (the absence of predators) in the islands versus the mainland explain divergence in lizard size, alertness, and coloration?

TRANSITION TO WRITING

Inform students that they will write an essay answering the lesson question, "*How does the selective pressure of predation explain population divergence in Skyros Wall Lizards?*" Ask students to keep in mind that their statements should be backed up by evidence drawn from their notes.

WRITING TASK: Why do lizards diverge from each other and acquire different characteristics on islands?

Estimated Time: 35 minutes

Purpose

- To produce a piece of writing using evidence from the investigations to answer the question, "How does the selective pressure of predation explain population divergence in Skyros Wall Lizards?"
- To show that students have learned the concepts by synthesizing their findings and representing them by words

Big Idea

- Learning how to effectively communicate scientific findings is as important as the investigations.
- Presenting data, explaining what the data mean, and making a concise story of the results in writing is the concluding piece of an investigation.

Facilitation Suggestions

- **Re-engage students** with main idea and support students in putting together their ideas, pointing them to the right part of the lesson to obtain additional support.
- **Encourage students to review their notes and to revisit the background section** if they need to remember information. Remind students that they should weigh the evidence, select the appropriate evidence from their notes and, if helpful, include pictures to support their ideas.
- **Preview the "Writing" page and the outline that students will follow.**

    1. *Intro Paragraph*—Help your readers understand the context for your investigation by explaining how lizards on the islands became separated from their mainland cousins, what selective pressures are, and how predation is a selective pressure.
    2. *Claim Paragraph*—Briefly describe the trait you will be investigating —body size, alertness, or coloration—and summarize how predation as a selective pressure has influenced the evolution of your trait in island versus mainland lizards.
    3. *Evidence and Reasoning Paragraphs*—Write two short paragraphs presenting data that support your claim about the trait you selected, and on one trait studied by your peers.
       Each evidence paragraph should explain how the evidence supports the claim, and should include
        - a summary sentence;
        - sentences citing data and including graphs as evidence for your statements;
        - A comparison of island and mainland lizards' traits using average and variability, and a description of how predation release leads to these changes in traits.
    4. *Conclusion Paragraph*— Consider a hypothetical situation in which lizard predators populate the islands. Use the concepts of predation, predation release, and trait divergence to explain how the lizard population would likely change, and why.

Sample Writing Product

Why do island lizards acquire different characteristics than mainland lizards in Skyros, Greece?

The lizards in this study were once one big population living together in Skyros, Greece. Then 18,000 years ago the sea levels in the Mediterranean rose, and islands formed around the Skyros mainland. Because of this, Skyros Wall Lizards became isolated from lizards living on the mainland and on the other islands. We investigated whether the island lizards have evolved differently from the lizards on the mainland. Our investigation focused on comparing three traits in island and mainland lizards — size, alertness, and coloration.

In this essay I will use the concept of predation to explain the differences we found between lizard populations. Predation is a selective pressure because over time animals evolve traits that allow them to avoid predators — things like small size, speed, and camouflage. In Skyros Greece birds and snakes are the lizards' predators. But these predators do not live on the islands, something scientists call predation release. Because predators are not present, more types of lizards can survive and reproduce on the islands. Their traits are more variable. I will present data on two traits, body size and alertness.

Body Size. *There are clear size differences in size between island and mainland lizards: The island lizards are 35% heavier and 15% longer compared to the mainland lizards. The mean weight for the mainland lizards is 5.17 g and the mean length is 56.6 cm long. The mean weight for the island lizards is 7.91 g and the mean length is 65.1 cm. These data suggest that, without predators, the island lizards have evolved into bigger and longer animals. This might be because being bigger helps lizards compete for mates and food.*

The island lizards are also more variable in weight (st.d.3.54) and length (st.d.9) compared to variability in the mainland lizards' weight (st.d.2.05) and length (st.d.6.5). Predation release explains this, because when there are no predators, lizards don't just have a narrow range of sizes. When predators are present, like in the mainland, there is a narrow size range. Why? Perhaps lizards have to be of the right size to hide, to be agile, and to run away, or it is hard for a very small ectothermal animal to keep warm, and so on.

Supporting data: Snapshots of size and snout-to-vent graphs

Alertness*. On the mainland there are predators, and the lizards seem to be more alert and vigilant compared to island lizards, who live where there are no predators. Researchers can get closer by ½ meter on average to the island lizards compared to mainland lizards. On the mainland there are some lizards that are very fearful, they run away when researchers get as close as 6.8 meters. The average flight initiation distance (FID) for mainland lizards is 1.82 meters, versus 1.38 meters for island lizards.*

Based on the background information, I was expecting that alertness variability would be higher on the islands, where predation release is in play. This is not what the results show: There is more variability in the mainland lizards (st.d.0.86) versus the island lizards (st.d.0.69). One reason could be that there are very fearful individuals on the mainland: These are the outliers shown to the left of the graph. These data points will increase the mainland FID standard deviation. Another issue is that there are fewer types of alertness on the islands because other selective pressures may come into play. Running away costs energy, and it is better to use this energy for other purposes.

Supporting data: Snapshot of graph

***Coloration**. Camouflage was measured in two ways: camouflage against the environment, and how well lizards blend within their own population. Lizards on the mainland are better camouflaged against their environment, with a correlation of 0.884 compared to 0.742 for island lizards. They can also hide among their own kind: 86% of mainland lizards are highly color-correlated to each other (0.8-1), while only 33% of island lizards have a correlation to population of 0.8-1. The results show a very clear difference between island and mainland lizards' need for camouflage. Predation release in the islands allows more colorful lizards to live, they are not eaten and so they survive and reproduce; as a result, we see a lot more variability in the island lizard populations (st.d.0.149) versus the mainland lizards (0.081).*

Supporting data: Snapshots of graphs

Conclusion

If predators were reintroduced to the islands, most of the colorful lizards would be eaten, leaving the ones that can camouflage against their environment and the ones that can blend with the lizards around them. Only these lizards would be favored by natural selection and, with time, they would be similar to the mainland lizards in color. With respect to alertness, the more vigilant lizards would survive because they hide and run away faster. The selective pressure on size would also be in effect, and smaller lizards that can hide and run faster would survive and reproduce. However, there might be other environmental elements that are still different between island and mainland lizards, and reinstating predators might not make all the island lizards' characteristics the same as mainland lizards'.

One important fact learned in this lesson is that many selective pressures act on organisms, some more powerful than others. Predation is very powerful because the result is life or death; however, under predation release other pressures may come into play. For example, the need to save energy does not allow lizards on the island to diversify in the direction of higher alertness.

One interesting question is whether the lizards on each island differ to the same extend from the mainland lizards.

ASSESSMENT

Writing Product Assessment

Look for the following when evaluating students' writing tasks.

INTRO PARAGRAPH

- ❑ Begins by stating how island lizards got separated from their mainland conspecifics
- ❑ Defines predation, selective pressures
- ❑ Explains how predation explains divergence of trait

CLAIM PARAGRAPH

- ❑ Identifies the lizard trait that will be discussed
- ❑ Explains the difference in predation between islands and mainland
- ❑ Describes how predation release explains divergence of trait

EVIDENCE AND REASONING PARAGRAPHS

- ❑ There should be two paragraphs—one on the trait examined and one on a trait studied by other students.
- ❑ Each paragraph should present evidence *and* explain how it supports the claim. For example, by including
    - A summary sentence on how the trait has diverged in island versus mainland lizards
    - A description of the results on mean and variability, citing data and including pictures from the notes
    - An explanation of how predation release has led to divergence of trait, and how the evidence backs up the ideas presented

CONCLUSION PARAGRAPH

- ❑ Analyzes the hypothetical situation using the concepts of predation release, evolution, and divergence of trait
- ❑ Advances questions, doubts, comments on the study, and/or proposes further experiments to answer the questions

Key Question Notes

We suggest that teachers use these Key Question Notes to find out whether students understand the concepts and if students are keeping pace with the rest of the class. This is important since there are three different groups doing their own investigations before the whole class comes together for small group presentations.

ALL GROUPS

Key Question 1. If predators are removed from the habitat—something biologists call "predation release"—the population of animals will start diversifying. What will happen to the variability curve for camouflage, and why?

Where. Background 5.2: Describing the Variability of a Trait—Camouflage

Key Understanding. Students should recognize that without the selective pressure of predators, the curve will widen and that a wider curve represents higher variability (greater divergence) in a trait such as camouflage.

Sample Answer. The narrow curve would become a wide curve again. Without predators around, the animals that don't match their environment (those located in areas of the curve towards zero) will still be able to survive.

BODY SIZE GROUP

Key Question 2. How much heavier are the island lizards compared to those on the mainland? Express your answer as a percentage difference. How might predation release explain the difference you found?

Where. Investigation 1.4: Body Size

Key Understanding. Students should note that island lizards are about 35% larger, and should use reasoning to explain how the lack of predators could be responsible for this.

Sample Answer. The island lizards are 35% bigger than the ones on the mainland. Without predators around, the island lizards evolved to be bigger and slower. Maybe when predators are around the pressure is to be smaller, so you can run faster and hide in small places. Or if there are no predators, maybe being big helps you compete for food and mates.

Key Question 3. Which population of lizards has more variability in SNV length? Why might this be?

Where. Investigation 1.6: Body Size

Key Understanding. Look for evidence that students are using the idea of predation release in their answers and that they address how the values of standard deviation explain variability.

Sample Answer. The island lizards are more varied in length. This is probably because if there are no predators to eat the short lizards—or the long ones—lizards of all sizes will survive and be able to reproduce.

ALERTNESS GROUP

Key Question 4. Which lizards are more alert, or vigilant? Use data in your answer and explain what the data show. Discuss the population means, and also the outliers.

Where. Investigation 2.4: Alertness

Key Understanding. Students should use the data collected (numbers) in their answers and should explain that the data reflect how close researchers were able to get before the lizards ran away.

Sample Answer. The mainland lizards are more alert. Those lizards ran away when the researchers were an average of 1.82 meters away. On the islands, researchers could get closer, an average of 1.38m away (about 1/2 meter closer), before the lizards ran. It seems like lizards on the mainland are very nervous. One lizard ran away when the researchers were more than 6.8 meters away!

Key Question 5. What is the difference in variability between the island and mainland lizards? Why do you think this is?

Where. Investigation 2.5: Alertness

Key Understanding. Students should discuss this question since it is contrary to expectations. Make sure that they keep in mind that there are multiple challenges acting on one trait and that when one challenge is lifted, others came into play. Make sure that when students offer an idea or take a position, they give a reason for it.

Sample Answer. The mainland lizards are more variable (st.d. 0.86) compared to island lizards (0.69). This is contrary to expectations. We can speculate that lizards on the islands are not more diverse than mainland lizards because running away requires energy. If there are no predators, then escaping is not favorable, it is better to use that energy for other purposes.

COLORATION GROUP

Key question 6. Comparing both populations, island and mainland lizards, which one has more variability in color? What is the evidence?

Where. Investigate Coloration and Camouflage: Is there a difference between mainland and island lizards? (Step 5)

Key Understanding. Students should understand why lizard coloration or lizards matching their habitat is important. Predation should be mentioned in the answer.

Sample Answer. The island lizard coloration varies more (std 0.149) than the mainland lizard coloration (std 0.081). The mainland lizards should have a much narrower fitness peak compared to the island fitness peak because on the mainland the selective pressure, predators, keeps the range of coloration narrow.

Key question 7. Explain the difference (as a percentage) in correlation to population between island and mainland lizards. *Use the words "predator" and "predation release."*

Where. Investigate Coloration and Camouflage: Is there a difference between mainland and island lizards? (Step 7)

Key Understanding. Students should understand the difference between camouflage by blending with the environment versus camouflage among their conspecifics.

Sample Answer. The difference in how well lizards blend within their own population on the mainland (86%) versus the island populations (33%) is very clear. These numbers suggest that, in the absence of predators, lizards do not need to hide among the other lizards. After predation release, the lizards diversify and now, after thousands of years, there are different types of lizards on the islands

ALL GROUPS

Key question 8. How does relaxed predation (the absence of predators) on the islands explain divergence in the lizards' size, alertness, and coloration from lizards on the mainland?

Where. Summarize your findings for all Skyros lizard characteristics. (Step 2)

Understanding. Make sure students use their notes from the presentations and their own results to answer this question. Look for understanding that not all traits have diverged to the same extent and direction—for example, alertness (variability) is different from body size and coloration.

Answer. Relaxed predation on the islands allowed bigger, less alert, and more colorful lizards to survive. On the mainland these lizards would die by predation. The island lizards have diverged from the ones on the mainland because of predation release.