



Galápagos Penguin Lab:

Biodiversity at Risk



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At a glance

Lab overview

Galápagos penguins are endangered and have undergone population bottlenecks. Join a research team to assess the genetic diversity of the Galápagos penguin population.

TECHNIQUES

Micropipetting
Gel electrophoresis

TOPICS

Genetics
Ecology
Environmental science
Conservation biology

GRADE LEVEL

General high school
Advanced high school
College

Planning your time

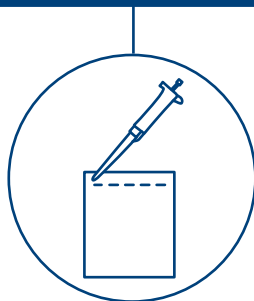
SINGLE CLASS: 45 MIN.

See the next page for detailed class time requirements

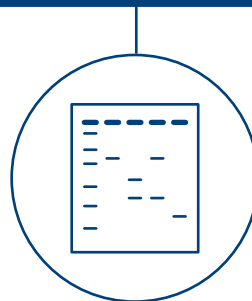
Teacher prep (30 min.)

See page 7 for details. We recommend that the teacher prepare the gels and dispense the DNA samples before class.

Gel electrophoresis



Interpret results



Technical support

If you have any questions about implementing this activity, contact support@minipcr.com.

Class time requirements

Steps	Time required
Prep: Make gels	We recommend the teacher prepare the gels outside of class (see page 9). Allot 30 minutes of class time if you opt to have students prepare the gels.
Load gel	10 minutes
Run gel	20-25 minutes The gel does not need to be actively monitored during this time.
Interpret results	5 minutes

Materials needed

Supplied in kit (KT-1509-01)

- Kit contains DNA samples for eight lab groups.
- If kept in the freezer, reagents can be stored for 12 months after receipt. If kept in the refrigerator, reagents can be stored for 6 months after receipt.
- Reagents for preparing gels, plastic tubes for distributing samples to individual groups, and pipette tips are sold separately. Refer to the section below for details.

Contents	Provided	Required per group	Storage
Simulated penguin DNA samples	150 µl each	15 µl each	Freezer
• Galápagos 1 • Galápagos 2 • Galápagos 3 • Galápagos 4 • Magellanic 1 • Magellanic 2 • Magellanic 3 • Magellanic 4			

Electrophoresis reagents and plastics sold separately

- This lab requires 2% agarose gels with a fluorescent DNA stain (e.g., SeeGreen™ or GelGreen®)
- The [Learning Lab Companion Kit](#) (KT-1510-01) provides sufficient reagents to prepare and run eight gels when using the blueGel or Bandit electrophoresis systems, as well as plastic tubes to distribute samples to student groups.
- Alternatively, [bulk electrophoresis reagents](#) and [plastics](#) (tubes, pipette tips) are available for purchase from miniPCR bio.
- Gel electrophoresis reagents and plastics can also be purchased from other suppliers.

Required equipment

- This lab is compatible with any horizontal gel electrophoresis system in combination with:
 - A fluorescent DNA stain (e.g., SeeGreen™ or GelGreen®).
 - A transilluminator that is compatible with the DNA stain used. Fluorescent DNA stains typically require blue light (~470 nm) or UV (~260 nm) illumination.
- The table below outlines gel electrophoresis equipment from miniPCR bio that meets these requirements.

Item	Recommended quantity
Gel electrophoresis and visualization system	
Option 1: electrophoresis systems with integrated blue light transilluminator	
• blueGel™	1 blueGel per group
• Bandit Duo™	1 Bandit Duo per group
• GELATO™	1 GELATO can be shared by two groups
Option 2: Bandit™ STEM Electrophoresis Kit paired with a BlueBox™ blue light transilluminator	1 Bandit per group + 1 blueBox for the class to share
Micropipettes and tips	
2-20 µl adjustable or 10 µl fixed volume	1 pipette per group
2-20 µl adjustable	1 pipette for teacher prep

Other materials supplied by user

- Distilled water
- Microwave or hot plate
- Heat-resistant flask or beaker
- Disposable laboratory gloves
- Protective eyewear
- Fine-tipped permanent marker

Teacher prep



Protective gloves and eyewear should be worn for the entirety of this experiment.

Overview

The table below provides an overview of the teacher prep, and the subsequent pages provide detailed instructions.

Prep	Time required	Timeline
Dispense reagents	10 minutes	Can be completed up to one week before use.
Prepare electrophoresis buffer and agarose gels	20 minutes	Varies - If using gel reagents from miniPCR, gels can be prepared up to five days before use.

Dispense reagents

- DNA samples can be dispensed up to one week in advance and stored in the refrigerator until use.
- This kit provides sufficient reagents for eight lab groups.

Materials needed

From the lab kit (stored in the freezer):

- 8 penguin DNA samples
 - Galápagos 1-4
 - Magellanic 1-4

Supplied by user:

- Plastic tubes for dispensing reagents (1.5 ml or 0.2 ml tubes can be used)
- 2-20 μ l micropipette and tips
- Fine-tipped permanent marker

1. Thaw reagents by placing tubes at room temperature.
2. Collect the liquid at the bottom of each tube. Either spin briefly in a microcentrifuge or shake the liquid down with a flick of the wrist.
3. When you open each tube, check for liquid stuck inside the cap. If necessary, put the cap back on and repeat step 2.
4. For each lab group, dispense reagents into labeled plastic tubes as shown in the table below. 1.5 ml or 0.2 ml plastic tubes can be used.

Reagent	Volume per group	Label tube as
Galápagos 1	15 μ l	G1
Galápagos 2	15 μ l	G2
Galápagos 3	15 μ l	G3
Galápagos 4	15 μ l	G4
Magellanic 1	15 μ l	M1
Magellanic 2	15 μ l	M2
Magellanic 3	15 μ l	M3
Magellanic 4	15 μ l	M4

5. Dispensed DNA samples can be stored at room temperature for 24 hours or in the refrigerator for up to one week before use.

Prepare gel electrophoresis reagents

1. Prepare electrophoresis buffer.
 - Follow the manufacturer's instructions to prepare buffer solution.
 - The volume of buffer needed varies depending on the gel electrophoresis system.
 - For the blueGel and Bandit electrophoresis systems, 600 ml of TBE buffer is sufficient for at least eight gel runs.
 - For other systems, refer to the manufacturer's instructions for:
 - (1) The buffer volume needed to prepare agarose gels.
 - (2) The buffer volume needed for use as a running buffer.
2. Prepare 2% agarose gels with fluorescent DNA stain.
 - You will need eight lanes per group.
 - This lab kit is compatible with any molecular grade agarose and fluorescent DNA stain (e.g., SeeGreen™ or GelGreen®).
 - The volume of gel needed varies based on the gel electrophoresis system you are using. Refer to the manufacturer's instructions.
 - If using gel electrophoresis reagents from miniPCR bio, gels can be prepared up to five days in advance. Store prepared gels at room temperature in an airtight container protected from light. Do NOT soak the gels in buffer or wrap them in paper towels.

Detailed instructions for preparing buffer and gels for miniPCR electrophoresis systems



blueGel

<https://links.minipcr.com/gelpouring>



Bandit

<https://links.minipcr.com/BanditDNAgel>

Student workstation setup

At the start of this experiment, every lab group should have:

DNA samples: • Galápagos 1 (tube G1) • Galápagos 2 (tube G2) • Galápagos 3 (tube G3) • Galápagos 4 (tube G4) • Magellanic 1 (tube M1) • Magellanic 2 (tube M2) • Magellanic 3 (tube M3) • Magellanic 4 (tube M4)	15 µl each
2-20 µl micropipette or 10 µl fixed volume micropipette	1
Micropipette tips	At least 8
Electrophoresis buffer * Volume depends on your electrophoresis system	30 ml TBE if using a blueGel or Bandit
8 wells in a 2% agarose gel with fluorescent DNA stain	

Student guide



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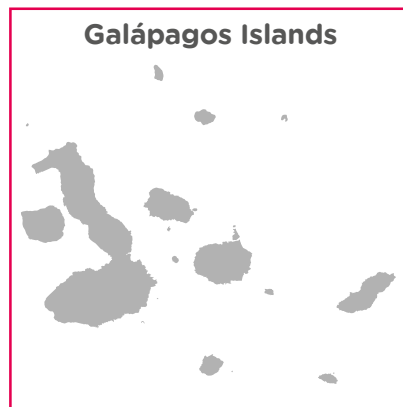


Background information

Meet the Galápagos penguin

1

- The Galápagos Islands are an archipelago situated approximately 600 miles off the coast of mainland Ecuador.
- Many species in the Galápagos Islands are **endemic**, meaning they are found nowhere else on Earth. This includes the **Galápagos penguin**.



2

- Galápagos penguins are small, standing around 50 cm (1.5 feet) tall. They feed primarily on small fish and nest in cool caves and crevices.
- They are currently listed as **Endangered** on the **IUCN Red List**.



El Niño Southern Oscillation impacts on Galápagos penguins

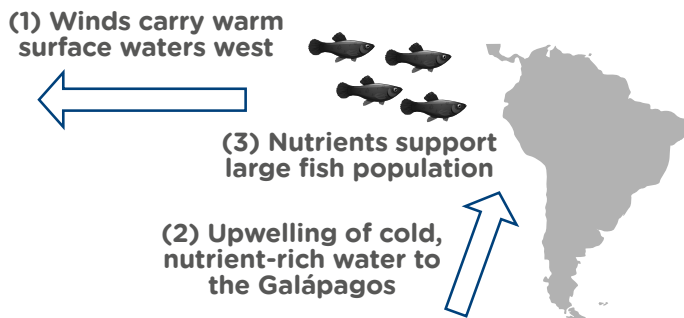
1

- The Galápagos **food web** depends on the **upwelling** of nutrient-rich cold water from the south.
- That upwelling is affected by a naturally occurring cycle of climate patterns known as **El Niño-Southern Oscillation (ENSO)** that involves changes in air circulation and ocean temperatures.

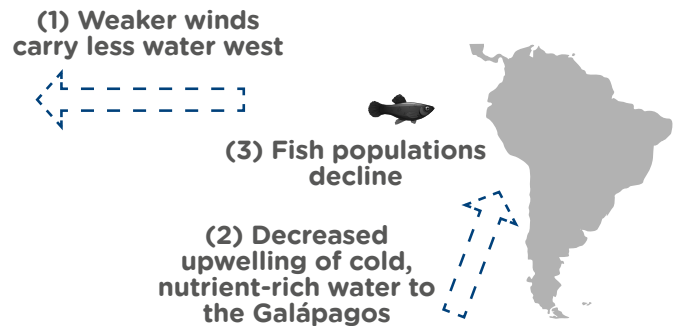
2

- One ENSO phase is **El Niño**. During El Niño, the east-to-west equatorial winds are weaker, and upwelling of cold, nutrient-rich water to the Galápagos is reduced.
- This reduces fish populations, which limits the survival and reproduction of Galápagos penguins.
- It is well established that Galápagos penguin populations decline during El Niño phases.

Normal pattern



El Niño pattern



3

- The frequency and intensity of El Niño phases are expected to increase during the 21st century due to **greenhouse gas** emissions and climate change.
- Although the Galápagos penguins have survived repeated El Niño phases for millennia, more frequent and intense El Niños increase their risk of population collapse.



Circle the words that accurately complete the statements:

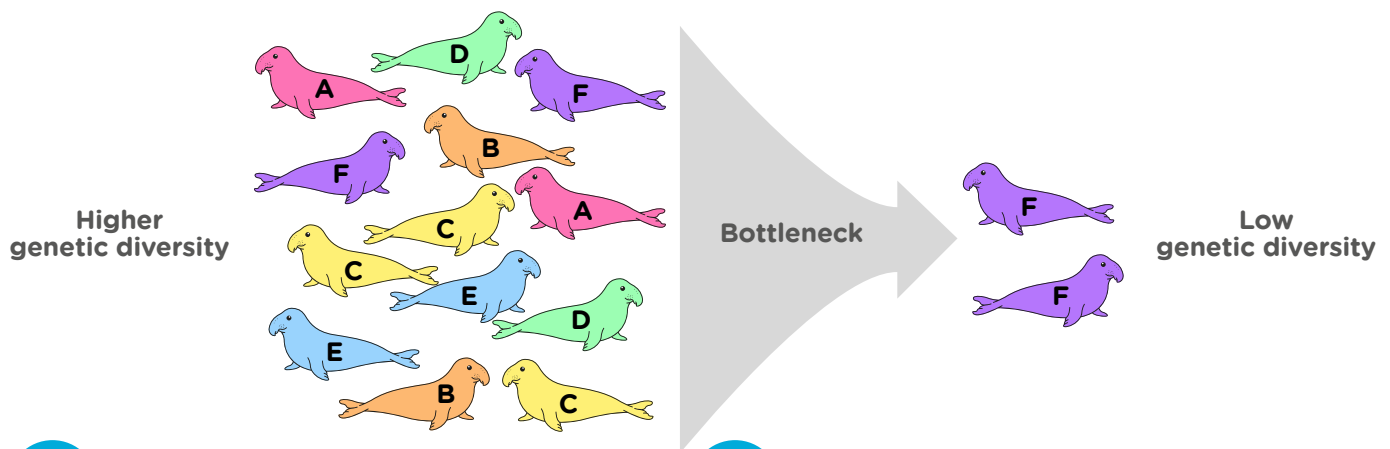
- Q1. ENSO is a **naturally occurring/human-caused** climate pattern.
- Q2. The observed increase in frequency and intensity of El Niño phases is **naturally occurring/human-caused**.
- Q3. El Niño **decreases/increases** the amount of cold, nutrient-rich water that reaches the Galápagos Islands.
- Q4. El Niño phases result in **fewer/more** fish along the Pacific coast of South America.
- Q5. El Niño phases result in **decreases/increases** in the population size of Galápagos penguins.



Population bottlenecks can reduce genetic diversity

1

- Due to El Niño phases, Galápagos penguins have undergone repeated **population bottlenecks**, sudden and dramatic reductions in population size.
- Let's examine how a population bottleneck can alter a population's genetic makeup. We will use the northern elephant seal as an example. In the 1800s, northern elephant seals were hunted to the brink of extinction, with as few as 20 individuals remaining.



2

- **Genetic diversity** is represented in the diagram using colors and letters.
- Initially, this population had higher genetic diversity, represented by six different colors and the letters A-F.

3

- In the 1800s, overhunting caused a sharp decline in the population.
- The surviving population had low genetic diversity, represented by a single color and letter.

4

- In general, a more genetically diverse population is a more adaptable population.
- Because genetic diversity increases variation in heritable traits, it increases the likelihood that some individuals will survive and that the population will persist during disturbances.

Indicate whether the following statements are true or false:

Q6. Galápagos penguins have never experienced a population bottleneck.

Q7. A population with variation in heritable traits is more likely to recover from environmental disturbance than a population with less variation.



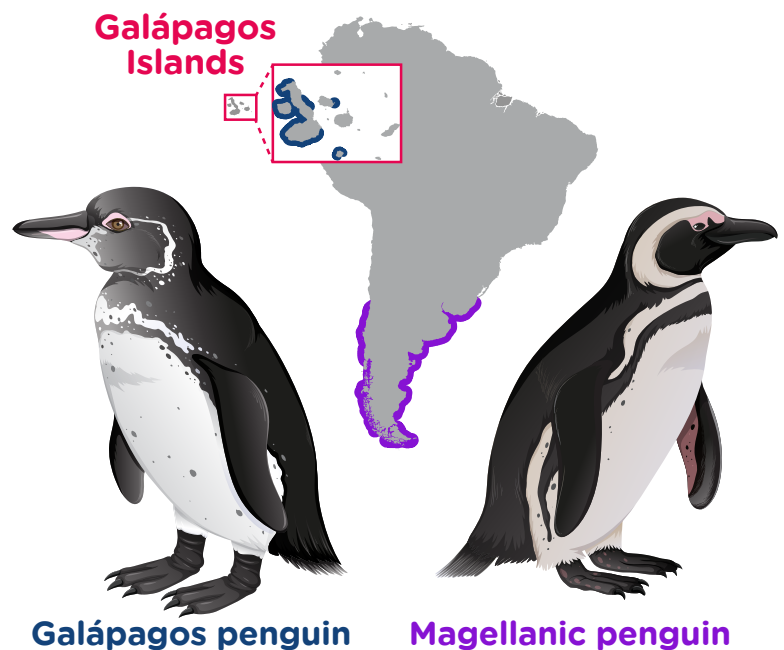
Today's lab

1

- You work on a research team that monitors Galápagos penguins.
- Because Galápagos penguins have experienced repeated population bottlenecks, there is concern that they may have low genetic diversity, increasing their risk of extinction.

2

- Your goal is to compare the genetic diversity of the Galápagos penguins to that of the closely related Magellanic penguins.
- Magellanic penguins** have a much broader range along the coasts of Argentina and Chile, where they are not severely affected by ENSO.
- The Magellanic penguin population has not experienced a bottleneck and has remained relatively stable, with more than a million breeding pairs.



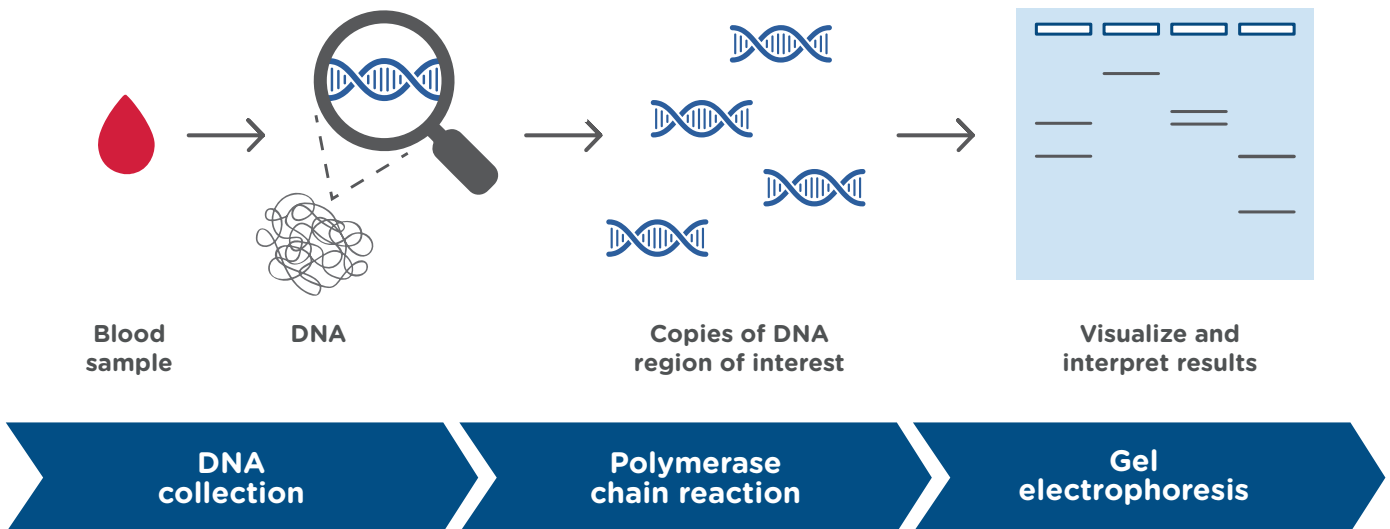
3

- To measure genetic diversity, scientists examine regions of DNA known to vary among individuals.
- Alleles** are different versions of the same place in the **genome**. A population that has many different alleles has greater genetic diversity.
- You will compare the number of alleles in the Galápagos penguin vs. the Magellanic penguin populations at a location in the genome commonly used to assess genetic diversity in penguins.



DNA testing workflow

Today's DNA testing workflow involves several steps. The following procedure will enable you to compare the genetic diversity of the Galápagos penguin and the Magellanic penguin populations.



1

First, DNA is collected from a tiny sample of penguin blood. Another scientist on your team already performed this step.

2

Next, **Polymerase Chain Reaction (PCR)** is used to make billions of copies of the location in the genome we are examining.

3

You will complete the last step to determine the number of alleles present in each sample and compare the Galápagos and Magellanic penguins.



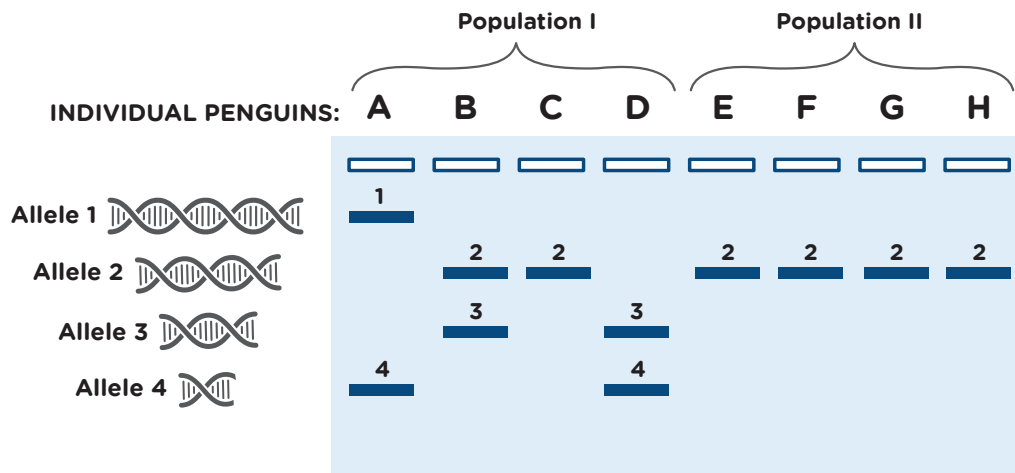
Interpreting gel electrophoresis results

1

- The penguin alleles we are studying differ in length, a characteristic that allows us to separate and distinguish them using **gel electrophoresis**.
- During gel electrophoresis, DNA fragments of the same size migrate together through the gel, forming a discrete band.
- Larger DNA fragments travel more slowly through the gel, while smaller DNA fragments travel faster.

2

- Let's walk through an example comparing the number of unique alleles from two penguin populations. Four penguins were tested from each population.
- Like humans, penguins primarily have two copies of each allele, one inherited from each parent. The two copies may be identical or different.
- The bands on the gels have been numbered to facilitate counting the number of unique alleles in each population. The numbers were assigned based on the length of the alleles, with "Allele 1" being the longest.



3

The penguins tested from Population I share a total of four unique alleles for the location being examined.

4

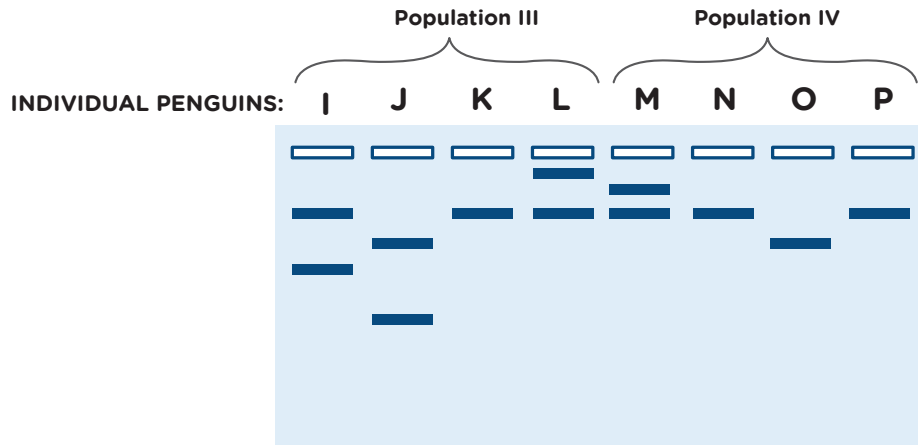
All the penguins tested from Population II share a single allele, suggesting low genetic diversity.

Q8. Why is gel electrophoresis a good tool for assessing genetic diversity in this experiment?

- Because it allows you to make copies of the penguin alleles you want to study.
- Because penguins have two alleles for each gene.
- Because it allows you to isolate penguin DNA from blood samples.
- Because the penguin alleles being studied differ in length.



The diagram below shows the gel electrophoresis results for eight additional penguins, four from each of two populations: III and IV. Use the diagram to answer questions 9-11.



Q9. Which of the following penguin(s) inherited two copies of the same allele from both its parents?

- A. Penguin K
- B. Penguin L
- C. Penguin M
- D. Penguin N

Explain how you can tell:

Q10. How many unique alleles are represented in this small sample of penguins in Population III?

- A. 1
- B. 2
- C. 3
- D. 4
- E. 5

Q11. How many unique alleles are represented in this small sample of penguins in Population IV?

- A. 1
- B. 2
- C. 3
- D. 4
- E. 5



Glossary

Allele: Alternative versions of the DNA sequence at the same location in the genome.

Consumer: An organism that feeds on other organisms.

El Niño: The warm phase of ENSO. During El Niño phases, the equatorial winds that normally blow from east to west weaken, and ocean surface temperatures increase. During El Niño phases, reduced upwelling of cold, nutrient-rich water around the Galápagos Islands negatively affects the marine food web.

El Niño Southern Oscillation (ENSO): A naturally occurring climate pattern that involves changes in air circulation and ocean temperatures. ENSO has three phases: the opposing El Niño and La Niña phases, and a neutral phase.

Endangered: A species that has a high risk of extinction in the wild. The International Union for Conservation of Nature (IUCN) sets criteria defining endangered species. Galápagos penguins are listed as Endangered by the IUCN.

Endemic: Found only in a specific geographic area. Galápagos penguins are endemic to the Galápagos Islands.

Food chain: A linear sequence that depicts the transfer of energy through an ecosystem as one organism eats another.

Food web: A complex network of feeding relationships within an ecological community.

Galápagos penguin (*Spheniscus mendiculus*): A penguin species found only in the Galápagos Islands. Galápagos penguins are endangered, with a population estimated at fewer than 2,000 birds as of 2020.

Gel electrophoresis: A method that separates pieces of DNA by length. For more detailed information on electrophoresis, refer to <https://www.minipcr.com/gel-electrophoresis/>.

Genetic diversity: The variety of inherited traits in a species or population. One measure of genetic diversity is the number of different alleles present in a population. High genetic diversity is associated with the ability of a population to survive environmental change.

Genome: All of the genetic information present in an organism.



Greenhouse gas: Gases including carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O) that warm the atmosphere by trapping heat.

IUCN Red List: A database that assesses the extinction risk of animal, fungus, and plant species, managed by the International Union for Conservation of Nature (IUCN).

La Niña: The cool phase of ENSO. During La Niña phases, the equatorial winds that blow from east to west are stronger, and ocean surface temperatures decrease. During La Niña phases, increased upwelling of cold, nutrient-rich water around the Galápagos Islands benefits the marine food web.

Magellanic penguins (*Spheniscus magellanicus*): A penguin species that inhabits coastal Argentina, Chile, and the Falkland Islands. The global population is stable with more than one million breeding pairs. Magellanic penguins are closely related to Galápagos penguins.

Polymerase Chain Reaction: A technique used to make multiple copies of a specific DNA segment for further study. For more detailed information on PCR, refer to <https://www.minipcr.com/polymerase-chain-reaction/>.

Population bottleneck: A dramatic reduction in population size. A population bottleneck may lead to a loss of genetic diversity. Historically, Galápagos penguins have experienced several population bottlenecks after El Niño phases due to food shortages.

Producer: An organism that harvests energy from abiotic sources, most commonly through photosynthesis. Producers are at the base of food chains and webs.

Trophic level: Hierarchical levels in a food chain based on where an organism obtains energy.

Upwelling: A process in which winds push surface water away from the coastline, pulling deep, cold, nutrient-rich ocean water toward the surface along the shore. Upwelling supports the Galápagos Islands' marine food web.



Student lab protocol



Protective gloves and eyewear should be worn for the entirety of this experiment.

1. Place the prepared gel into the electrophoresis chamber.
2. Add enough electrophoresis buffer to fill the chamber and just cover the gel.
 - You will need 30 ml of TBE buffer for a blueGel™ or Bandit™ electrophoresis system. Do not overfill the chamber.
 - If using another electrophoresis system, refer to the manufacturer's instructions for the recommended buffer type and volume.
3. Use a micropipette to load samples in the following order. To prevent contamination, use a new tip for each sample.
 - Lane 1: 10 µl Galápagos 1 (tube G1)
 - Lane 2: 10 µl Galápagos 2 (tube G2)
 - Lane 3: 10 µl Galápagos 3 (tube G3)
 - Lane 4: 10 µl Galápagos 4 (tube G4)
 - Lane 5: 10 µl Magellanic 1 (tube M1)
 - Lane 6: 10 µl Magellanic 2 (tube M2)
 - Lane 7: 10 µl Magellanic 3 (tube M3)
 - Lane 8: 10 µl Magellanic 4 (tube M4)
4. Run the gel for 20-25 minutes.
 - The blueGel™ and Bandit™ electrophoresis systems run at a fixed voltage.
 - If using another gel electrophoresis system, set the voltage in the 70-90 V range.
5. To visualize the DNA samples, turn on the blue light in your electrophoresis system, or move the gel to a transilluminator.
6. If needed, continue to run the gel until there is sufficient separation between the bands to interpret the results..
7. If desired, take a photo to document the results.

Detailed operating instructions for miniPCR electrophoresis systems



blueGel

<https://links.minipcr.com/blueGelRun>



Bandit

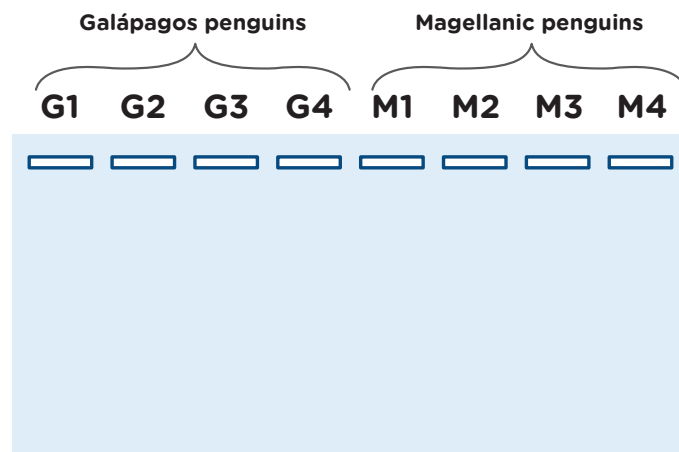
<https://links.minipcr.com/BanditViewit>



Post-lab questions

Interpreting results

1. Use the image on the right to draw what your gel looks like. For each sample, draw the bands observed on your actual gel.



2. Use your gel electrophoresis results to complete the table below.

	Sampled Galápagos penguins	Sampled Magellanic penguins
Number of unique alleles		
Relative genetic diversity (lower or higher)		

3. Do your results suggest that the Galápagos penguin population has low genetic diversity? Explain your reasoning.

Critical thinking

4. Isolated islands, such as the Galápagos, have historically been colonized by species arriving from elsewhere. These new arrivals are referred to as the founding population.
 - A. If the founding population is very small, what effect might that have on the genetic diversity of the resulting population? Explain your reasoning.
 - B. What information would you need to conclusively determine that the low genetic diversity of Galápagos penguins today is not due to a small founding population?



APES connection: Environmental solutions

Breeding success is an important factor in stabilizing Galápagos penguin populations. Galápagos penguins are opportunistic breeders and lay eggs when resources are plentiful. Scientists have identified a lack of suitable nesting sites for Galápagos penguins due to flooding, competition from marine iguanas, and degradation of previous nesting sites over time. To ensure that Galápagos penguins had high-quality nests, a team built more than 100 shaded nests by creating protected depressions and stacking lava rocks.

5. Describe the following aspects of the proposed solution to build nesting sites for Galápagos penguins.

- A. Advantages:

- B. Disadvantages:

- C. Unintended consequences:

6. Research other threats faced by Galápagos penguins. One source of information is the [IUCN Redlist](#).

- A. Propose an additional solution to help the Galápagos penguin population.

- B. What are the advantages of your proposed solution?



CER table

Fill in the table based on your results from the lab. Refer to the rubric on the next page.

Question:

Does the Galápagos penguin population exhibit low genetic diversity?

Claim

Make a clear statement that answers the above question.

Evidence

Provide data from the lab that supports your claim.

Reasoning

Explain clearly why the data you presented supports your claim. Include the underlying scientific principles that link your evidence to your claim.



Score	4	3	2	1
CLAIM A statement that answers the original question/problem.	Makes a clear, accurate, and complete claim.	Makes an accurate and complete claim.	Makes an accurate but incomplete or vague claim.	Makes a claim that is inaccurate.
EVIDENCE Data from the experiment that supports the claim. Data must be relevant and sufficient to support the claim.	All of the evidence presented is relevant and sufficient to support the claim.	Provides evidence that is relevant and sufficient to support the claim. May include some non-relevant evidence.	Provides relevant but insufficient evidence to support the claim. May include some non-relevant evidence.	Only provides evidence that does not support claim.
REASONING Explain why your evidence supports your claim. This must include scientific principles/knowledge that you have about the topic to show why the data counts as evidence.	Provides reasoning that clearly links the evidence to the claim. Relevant scientific principles are well integrated in the reasoning.	Provides reasoning that links the evidence to the claim. Relevant scientific principles are discussed.	Provides reasoning that links the evidence to the claim, but does not include relevant scientific principles or uses them incorrectly.	Provides reasoning that does not link the evidence to the claim. Does not include relevant scientific principles or uses them incorrectly.

We recommend that teachers use the following scale when assessing this assignment using the rubric. Teachers should feel free to adjust this scale to their expectations.

Rubric score	3	4	5	6	7	8	9	10	11	12
Equivalent Grade	55	60	65	70	75	80	85	90	95	100



Extension: The Galápagos food web and the effects of El Niño-Southern Oscillation

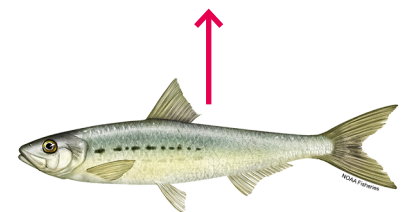
- In the main lab, we learned about the consequences of El Niño on the genetic diversity of the endemic Galápagos penguins.
- In this extension, we will explore how Galápagos penguins fit into the broader marine food web of the Galápagos ecosystem and the effects of El Niño and the opposite phenomenon, called La Niña.

The marine food web in the Galápagos

- **Food webs** depict “what is eating what” in an ecological community and allow us to visualize the interconnectedness of organisms in an environment, from microscopic plants to large mammals. Food webs contain many **food chains** that depict the linear relationships in energy transfer when one organism eats another.
- A food chain from the Galápagos marine ecosystem is shown to the right. In this food chain, sardines eat phytoplankton and penguins eat sardines. The arrows show the flow of energy from the bottom to the top of the food chain.
- **Trophic levels** refer to an organism’s place in the food chain. **Producers** are at the lowest trophic level and harvest energy from the sun. Consumers occupy the other trophic levels and eat other organisms, such as plants and/or animals. **Consumers** are sometimes also called predators. The organisms eaten by predators are called prey.



Galápagos penguin



Pacific sardine

Image credit: [NOAA Fisheries](#)



Phytoplankton

Image credit: [URI/Stephanie Anderson](#)

Answer the following questions based on the food chain:

1. Which organism in the example food chain is a producer?
 - A. Phytoplankton
 - B. Sardines
 - C. Galápagos penguins
2. Which term describes the level of Galápagos penguins in the example food chain?
 - A. Predator
 - B. Consumer
 - C. Both



3. Complete the partial Galápagos marine food web below by drawing arrows to connect organisms based on the information provided. The arrows connecting the food chain from the previous page have already been filled in as an example.

- Penguins eat mullet and sardines
- Orcas eat sharks and sea lions
- Sea lions eat grouper and creolefish
- Creolefish eat zooplankton
- Mullet and sardines eat zooplankton and phytoplankton
- Mullet also eat algae
- Zooplankton eat phytoplankton
- Lobsters eat sea urchins
- Grouper eat lobster and creolefish
- Sharks eat sea lions and grouper
- Sea urchins eat algae



Sailfin grouper

Image credit: [Adam Cherson](#)



Galápagos Shark

Image credit: [NOAA](#)



Orca

Image credit: [NOAA Fisheries](#)



Galápagos sea lion

Image credit: [Casey Klebba](#)



Thoburn's mullet

Image credit: [James s. Ryan](#)



Galápagos penguin



Spiny lobster

Image credit: [MNHN](#)



Pacific creolefish

Image credit: [Derek Keats](#)



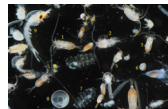
Pacific sardine

Image credit: [NOAA Fisheries](#)



Slate pencil sea urchin

Image credit: [Mountainmoeba](#)



Zooplankton

Image credit: [Lole Di Capua](#)



Algae

Image credit: [Holger Krisp](#)



Phytoplankton

Image credit: [URI/Stephanie Anderson](#)



Use the completed food web to answer the following questions:

4. Which predator(s) consume grouper fish?

5. Which organism(s) in the food web are producers?

6. What would be the effect of an increased number of Pacific creolefish in the Galápagos ecosystem?
 - A. What would you expect to happen to predators of Pacific creolefish? Explain your reasoning.

 - B. What would you expect to happen to the prey of Pacific creolefish? Explain your reasoning.

 - C. Would the number of Galápagos penguins increase, decrease, or be unaffected? Explain your reasoning

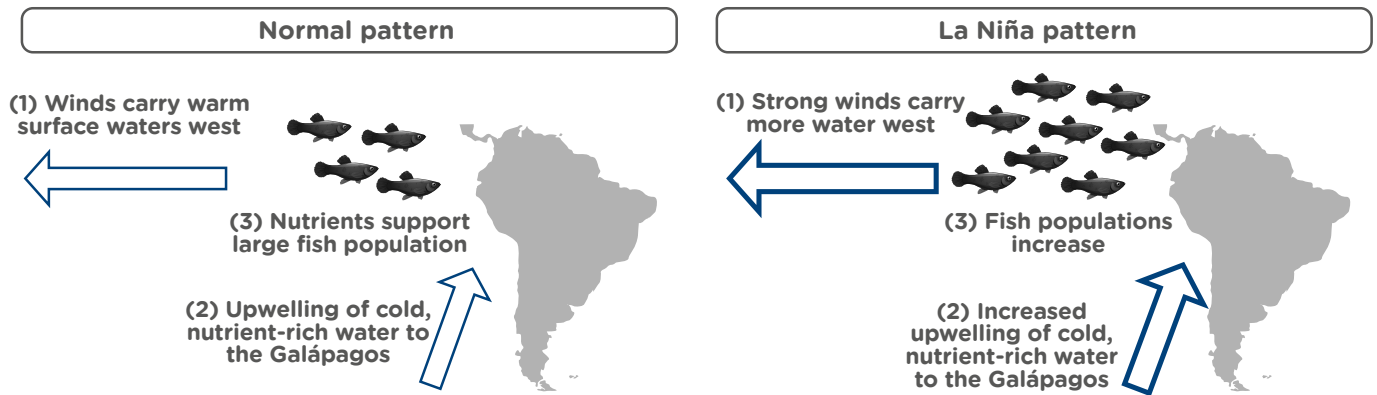
7. During El Niño, decreased nutrient upwelling negatively affects phytoplankton and algae, which require nutrients like phosphorus and nitrogen to grow. If phytoplankton and algae decrease during El Niño, what would be the consequences to your food web?
 - A. Which species in your food web would decrease in population size? Give specific examples and explain your reasoning.

 - B. Which species in your food web would increase in population size? Give specific examples and explain your reasoning.



The marine food web in the Galápagos

- **El Niño** can clearly have enormous and devastating impacts on many species in the Galápagos and on the entire marine food web.
- But, there is an opposite phenomenon called **La Niña**, which is the cold phase of the ENSO climate cycle.
- During La Niña, strong trade winds churn the ocean and increase upwelling of cold, nutrient-rich waters off the Galápagos. La Niña years provide an opportunity for the marine food web to recover.
- Oceans naturally oscillate between El Niño and La Niña phases every few years. This produces good years and bad years for the Galápagos marine ecosystem.



Circle the words that accurately complete the statements:

- La Niña **increases/decreases** the amount of cold, nutrient-rich water that reaches the Galápagos Islands.
- La Niña phases result in **fewer/more** fish along the Pacific coast of South America.



10. The figure to the right shows the concentration of chlorophyll, a compound found in phytoplankton and algae, in the waters off the Galápagos during the El Niño of 1997-1998 and the following La Niña of 1998-1999.

A. How do La Niña phases affect phytoplankton and algae in the Galápagos ecosystem?

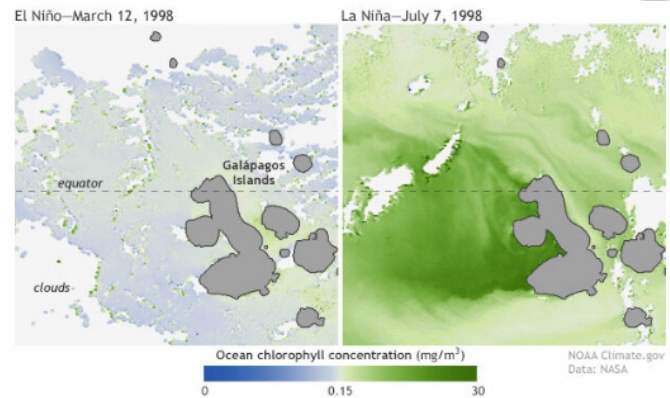


Image credit: [NOAA](https://www.noaa.gov)

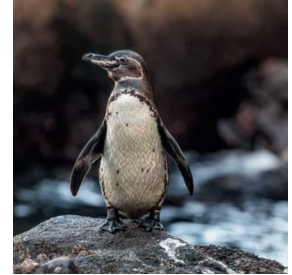
B. What do you think happens to the Galápagos marine food web you completed in question 3 during La Niña phases? Which species would increase or decrease in population size? Give specific examples and explain your reasoning.

11. As climate change warms the ocean waters off the Galápagos, it will lead to more frequent and stronger El Niño and La Niña phases. Which do you think poses a bigger danger to the marine food web? Explain your reasoning.



Data analysis of Galápagos sea temperatures and penguin populations between 1993-2000

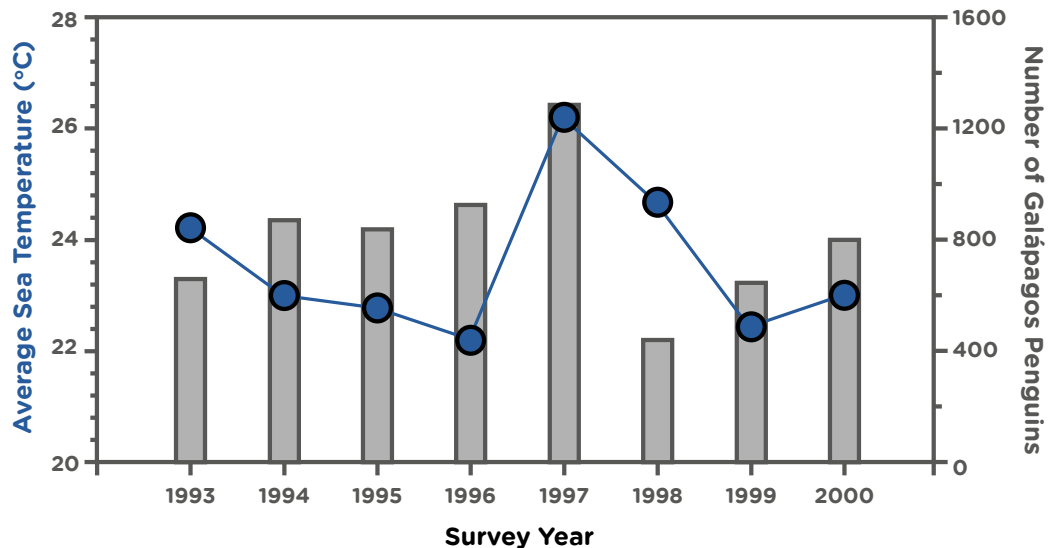
- Let's go back to the Galápagos penguin and look at some real data during El Niño and La Niña phases.
- Scientists working in the Galápagos collect information about yearly sea temperature.
- They also conduct annual surveys to count the penguin population.
- We can combine these data to better understand how penguin populations change during El Niño and La Niña phases.



Galápagos penguin

12. The graph below shows the average temperatures of the Galápagos sea from 1993 to 2000 on the left y-axis (in blue circles) and the Galápagos penguin survey data collected during the same time period on the right y-axis (in grey bars). Use this graph to answer the following questions.

- Sea surface temperature data from the [Charles Darwin Foundation Climatology Database](#)
- Penguin population data from Boersma *et al.*, 2013a.



A. Recall that El Niño phases are associated with increased sea temperature in the Galápagos. Which year in the graph above marked an especially strong El Niño? Cite specific evidence in your answer.

B. The Galápagos penguin population went from 1,284 animals in 1997 to 444 animals in 1998. What percentage of the population was lost during this time?



- C. The years from 1998 to 2000 saw strong La Niña phases, which cooled the temperature of the Galápagos sea and increased phytoplankton and fish populations. What happened to the population of Galápagos penguins during this period of time? Cite specific evidence in your answer.
- D. In 1995 and 2000, there was a similar number of ~800 Galápagos penguins in the population. Do you think genetic diversity in the Galápagos penguin population was greater in 1995 or in 2000? Explain your reasoning.
- E. This graph shows a spike in both average sea temperatures and the number of Galápagos penguins in 1997. Explain why this does NOT mean that warm seas increase penguin numbers.



Instructor guide

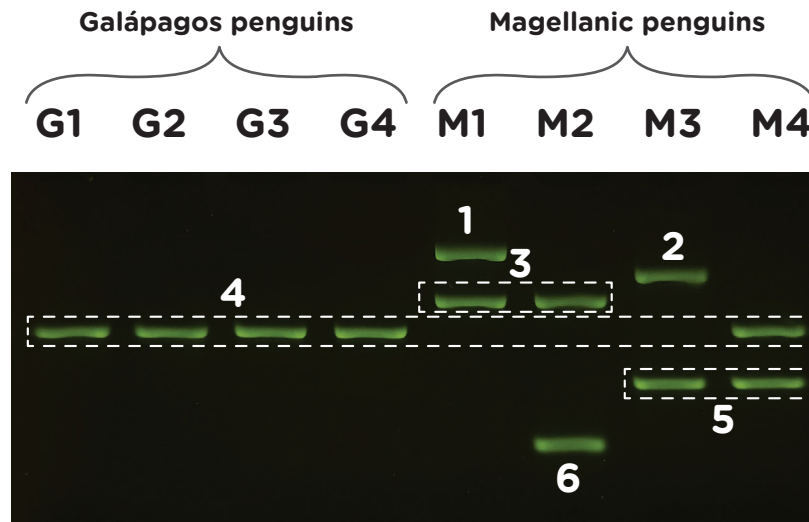


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Expected results

- Gel electrophoresis results are expected to resemble the photo below.
- The bands on the gel have been arbitrarily numbered from largest to smallest.



- There are six unique alleles in the sampled Magellanic penguins.
- On the other hand, only one allele was observed among the sampled Galápagos penguins, suggesting low genetic diversity.

For technical support, contact support@minipcr.com

For answers to the student questions, email answers@minipcr.com

Please include in the body of the email:

- The name of the lab
- Your name, school, and job title



Unexpected results and troubleshooting

If fluorescent DNA bands are not visible on the gel, the following may have occurred:

- Failure to use a fluorescent DNA stain: This lab requires agarose gels made with a fluorescent DNA stain (e.g., SeeGreen™ or GelGreen®). DNA stains that reveal DNA with a visible blue compound are less sensitive and are not compatible with this lab kit.
- Incorrect visualization conditions: Fluorescent DNA stains (e.g., SeeGreen™ or GelGreen®) must be viewed using a blue light or UV transilluminator. The blueGel electrophoresis system has an integrated blue light transilluminator. For DNA visualization, ensure that you have turned on the blueGel's blue light by pressing the light bulb button.
- Samples were run off the gel: If you run the gel too long, DNA samples may migrate off the gel. Monitor progress by occasionally checking the DNA samples under a transilluminator or tracking the loading dye, which is visible to the eye. Stop the run before the colored loading dye reaches the end of the gel.
- Reagents were stored improperly and/or are expired: DNA samples can be stored in the freezer for up to twelve months after receipt or in a refrigerator for six months. Storage under different conditions or in excess of this guidance may impair performance.

If some or all of the bands appear faint, the following may have occurred:

- Failure to load the DNA samples: Loading DNA samples for gel electrophoresis takes a little practice. The bands will appear faint if students do not successfully deposit the full sample volume into the well. Refer to <https://www.minipcr.com/how-to-load-a-gel-electrophoresis/> for gel loading tips.
- Non-optimal visualization conditions: Dimming the lights in the room can make the fluorescent DNA stain easier to see in the transilluminator. If using the blueGel, viewing the gel using the Fold-a-View documentation hood and a smartphone camera will provide the best results.
- Old or improperly stored gels: Agarose gels can generally be prepared in advance, but the storage time and conditions depend on the fluorescent DNA stain being used. If using SeeGreen™ or GelGreen® DNA stain, gels can be prepared up to five days in advance. Store gels at room temperature in an airtight container protected from light. Do not soak the gels in buffer or wrap them in paper towels.
- Old or incorrectly prepared buffer: Gel visualization defects not directly ascribable to other causes may be remedied by using freshly prepared buffer compatible with your gel electrophoresis system. If using the blueGel, TBE buffer is recommended.

For tips on picture-perfect gels, see <https://www.minipcr.com/gel-electrophoresis-troubleshooting/>.

For additional technical support, contact support@minipcr.com.



Notes on lab design

This lab serves as an introduction to genetic diversity in populations. We believe this approach provides the right balance between intellectual engagement, inquiry, and accessibility. The design of this lab has simplified certain elements to achieve these goals. Some of these elements include:

- This lab uses prepared DNA to simulate PCR products from penguin genomic DNA.
- While the research papers that inspired this activity analyzed six penguin microsatellite loci to assess genetic diversity (Akst, Boersma, and Fleischer, 2002; Arauco-Shapiro, Schumacher, Boersma, and Bouzat, 2020), this lab examines only one to allow for a clear interpretation of the results.
- To allow for clear resolution of the penguin microsatellite alleles by gel electrophoresis, the range of DNA fragments used is greater than what is observed for a given penguin microsatellite locus.
- For simplicity, the Student guide omits a description of microsatellites. Microsatellites are regions of the genome where a short DNA sequence is repeated multiple times. The number of repeated segments varies among individuals in a population, making microsatellites well-suited for assessing genetic diversity, as there are many possible alleles. Microsatellites tend to occur in non-coding regions of the genome, but remain useful indicators of genome-wide genetic diversity. Alternatively, scientists can study genetic variation in protein-coding genes known to increase a population's adaptability, such as those encoding immune proteins.

Citations

Akst, E.P., Boersma, P.D., and Fleischer, R.C. (2002). A comparison of genetic diversity between the Galápagos Penguin and the Magellanic Penguin. *Conservation Genetics* 3, 375–383. <https://doi.org/10.1023/A:1020555303124>.

Alava, J.J. (2009). Carbon productivity and flux in the marine ecosystems of the Galapagos Marine Reserve based on cetacean abundances and trophic indices. *Revista de Biología Marina y Oceanografía* 44: 109–122. <https://doi.org/10.4067/S0718-19572009000100010>

Arauco-Shapiro, G., Schumacher, K.I., Boersma, D., and Bouzat, J.L. (2020). The role of demographic history and selection in shaping genetic diversity of the Galápagos penguin (*Spheniscus mendiculus*). *PLoS ONE* 15, e0226439. <https://doi.org/10.1371/journal.pone.0226439>.

Boersma, P.D., et al. (2013a). Galápagos penguin (*Spheniscus mendiculus*). In Borboroglu, P.G. and Boersma, P.D. (Eds.), *Penguins: Natural History and Conservation* (pp. 687–732). University of Washington Press.

Boersma, P.D., et al. (2013b). Magellanic penguin (*Spheniscus magellanicus*). In Borboroglu, P.G. and Boersma, P.D. (Eds.), *Penguins: Natural History and Conservation* (pp. 567–640). University of Washington Press.

Ebersole, R. (2025). The world's rarest penguins don't avoid heat—they embrace it. National Geographic. <https://www.nationalgeographic.com/animals/article/rare-penguins-galapagos-islands-heat>.

Vargas, F.H., Harrison, S., Rea, S., and Macdonald, D.W. (2006). Biological effects of El Niño on the Galápagos penguin. *Biological Conservation* 127, 107–114. <https://doi.org/10.1016/j.biocon.2005.08.001>.



Additional student supports

E-worksheets: Student questions accompanying this lab are available for download [here](#) as editable text documents you can customize and upload to your LMS. E-worksheets can also be accessed from the Curriculum Downloads tab at <https://www.minipcr.com/product/galapagos-penguin-lab>.

miniPCR tutorials: Access an extensive set of free resources to help your students succeed in molecular biology techniques. Visit <https://www.minipcr.com/tutorials/>. The resources most relevant to this lab are listed below.

- **Micropipetting:** Video, worksheet, and hands-on activity resources to train students in the basic use of a micropipette.
- **Gel electrophoresis:** Video and worksheet activity instructing students on the fundamentals and practice of agarose gel electrophoresis.
- **PCR:** While students do not perform PCR in this lab, the samples they analyze represent PCR products. If you want to discuss PCR in more detail with your students, we have a video and worksheet activity instructing students on the fundamentals and practice of PCR.

miniPCR Digital: Interactive tools for experiment-based learning with or without hands-on lab kits. Visit <https://digital.minipcr.com>.

Extension activities

The following optional extension activities are provided for students to explore topics more deeply.

The Galápagos food web and the effects of El Niño-Southern Oscillation (page 27): Explore how the Galápagos penguin fits into the broader marine food web of the Galápagos ecosystem, and the effects of El Niño phases and the opposite phenomenon, called La Niña, on the community.



Learning goals and skills developed

Student learning goals:

- Analyze genetic diversity in a population
- Explore the effects of population bottleneck
- Describe the effects of El Niño Southern Oscillation on an ecological community

Scientific inquiry skills:

- Identify or pose a testable question
- Formulate hypotheses
- Identify dependent and independent variables and appropriate experimental controls
- Follow detailed experimental protocols
- Create tables or graphs to present results
- Interpret data presented in a chart or table
- Use data to evaluate a hypothesis
- Make a claim based on scientific evidence
- Use reasoning to justify a scientific claim

Molecular biology skills:

- Micropipetting
- Principles of PCR
- Agarose gel electrophoresis

Standards alignment

The standards alignment document for this activity is available for download [here](#). This document can also be accessed from the Curriculum Downloads tab at <https://www.minipcr.com/product/galapagos-penguin-lab>.

This activity is aligned to the following standards:

- Next Generation Science Standards: High School Life Science
- Advanced Placement Biology
- Advanced Placement Environmental Science
- Texas Essential Knowledge and Skills: Biology
- Texas Essential Knowledge and Skills: Biotechnology
- Common Core ELA/Literacy Standards (9-10)

For additional information on alignment to state standards, please contact support@minipcr.com.