



Galápagos Penguin Lab:

Biodiversity at Risk

Student guide



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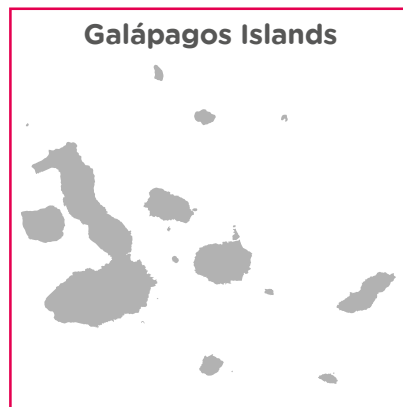


Background information

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

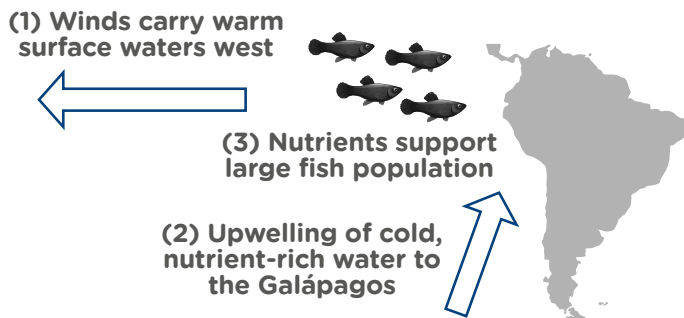
1

- 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.

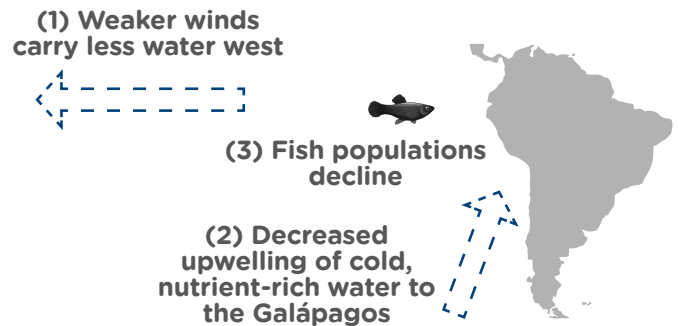
2

- 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:

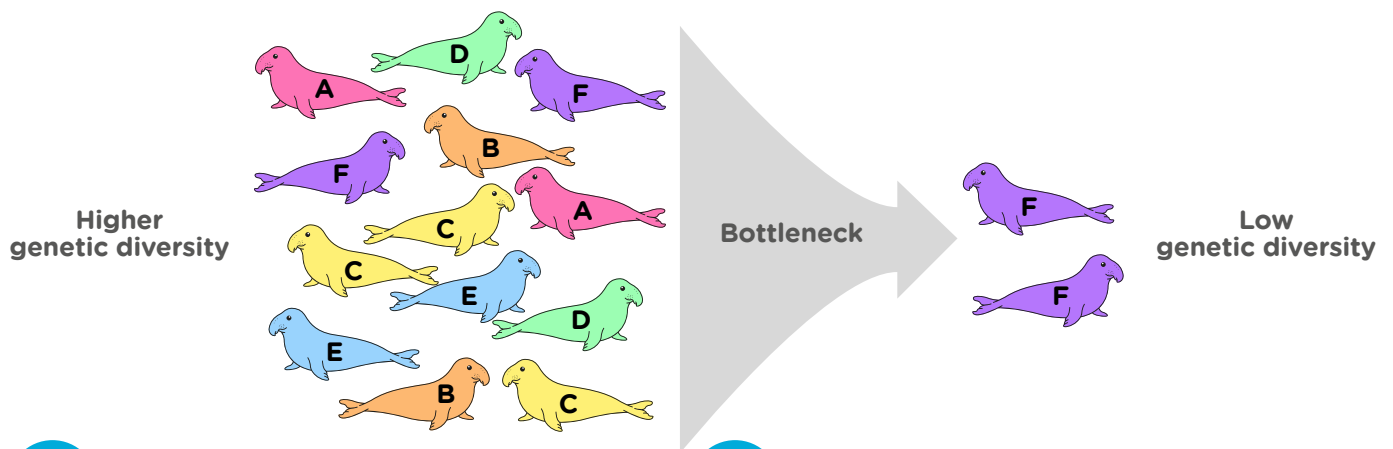
- Q1. ENSO is a **naturally occurring/human-caused** climate pattern.
- Q2. The observed increase in frequency and intensity of El Niño phases is **naturally occurring/human-caused**.
- Q3. El Niño **decreases/increases** the amount of cold, nutrient-rich water that reaches the Galápagos Islands.
- Q4 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.



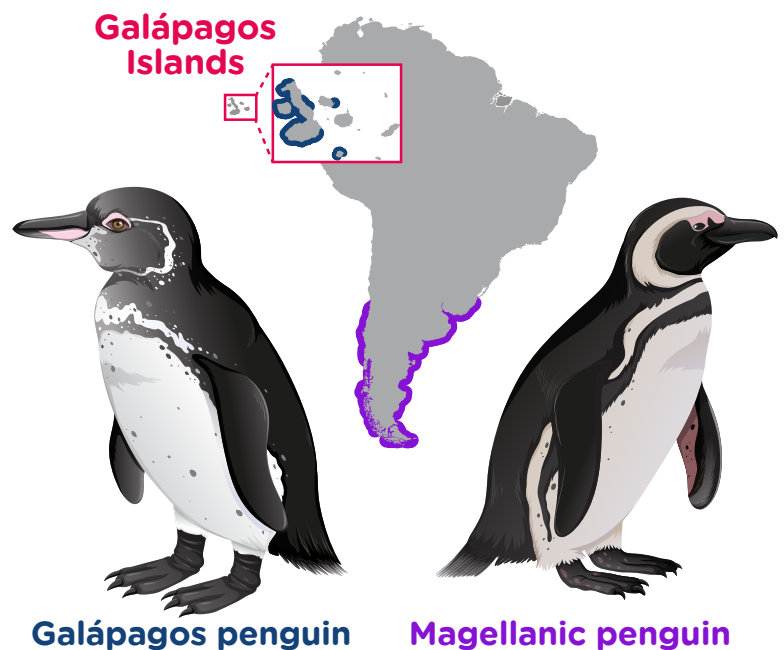
Today's lab

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.



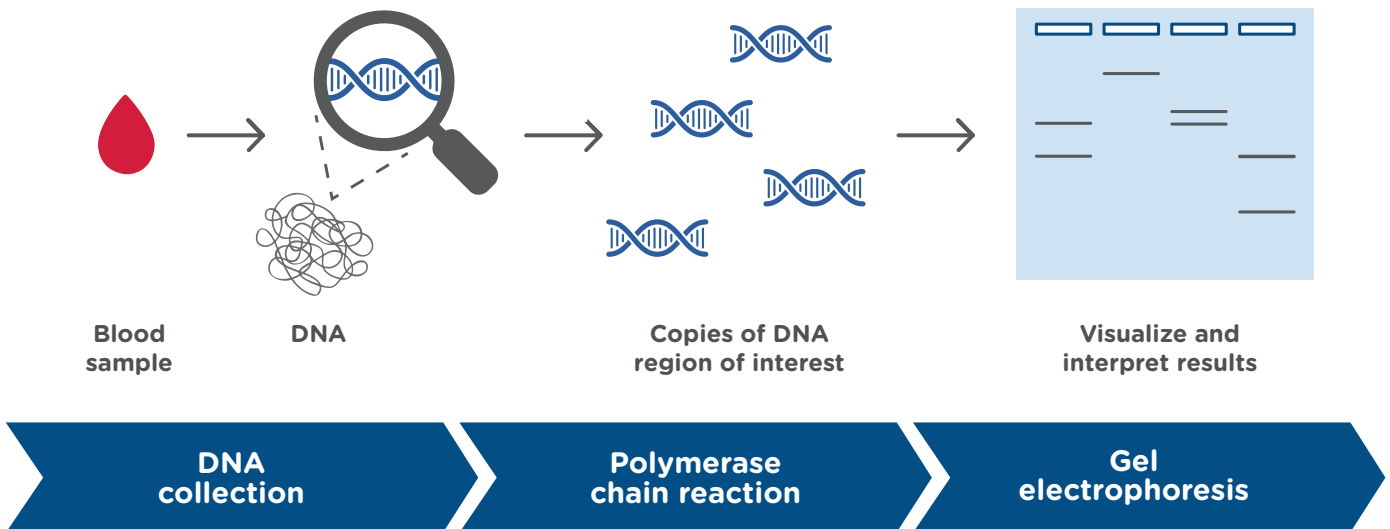
3

- 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.



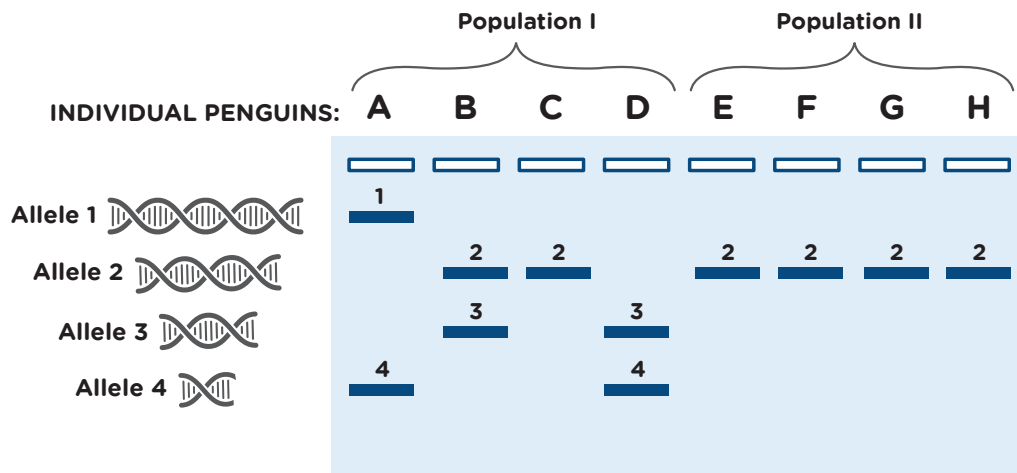
Interpreting gel electrophoresis results

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

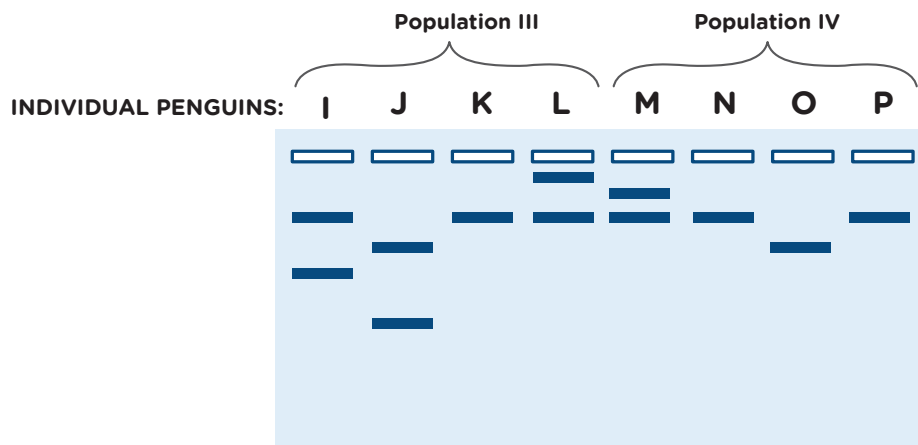
All the penguins tested from Population II share a single allele, suggesting low genetic diversity.

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

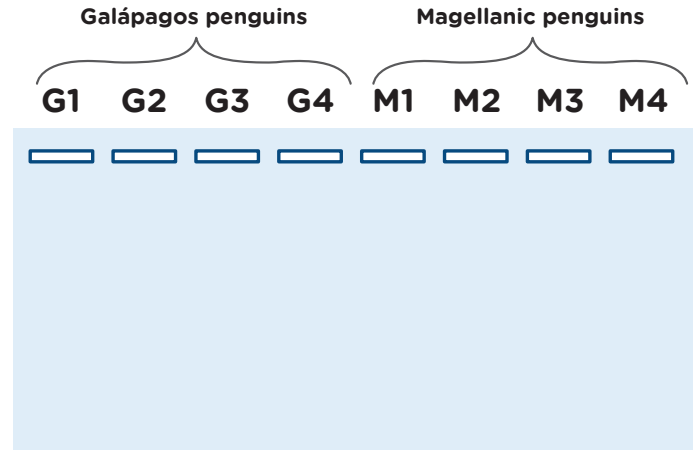
<https://links.minipcr.com/BanditViewit>



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

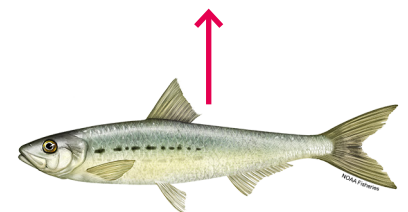
- In the main lab, we learned about the consequences of El Niño on the genetic diversity of the endemic Galápagos penguins.
- In this extension, we will explore how Galápagos penguins fit into the broader marine food web of the Galápagos ecosystem and the effects of El Niño and the opposite phenomenon,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



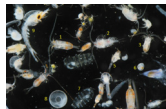
Pacific sardine

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

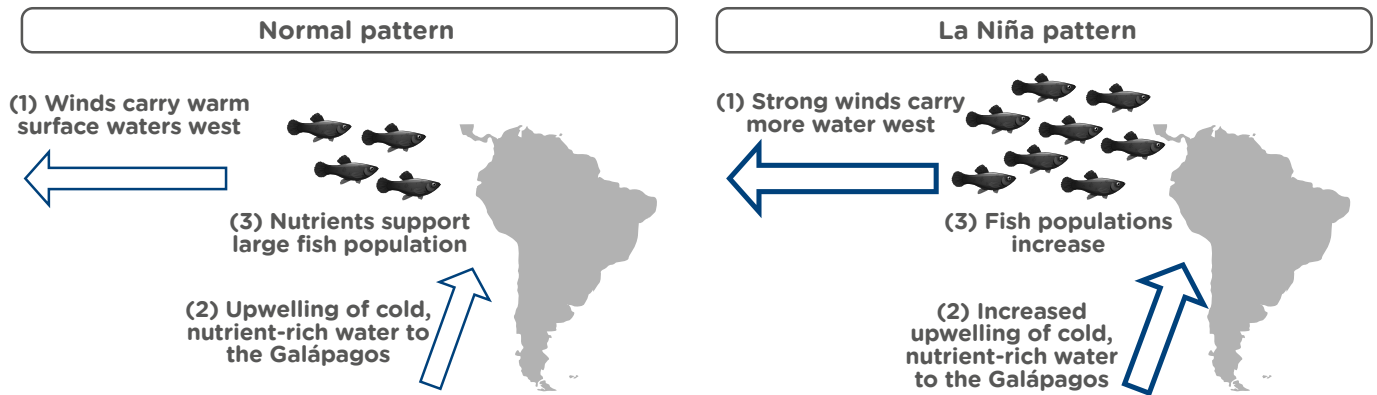
7. During El Niño, decreased nutrient upwelling negatively affects phytoplankton and algae, which require nutrients like phosphorus and nitrogen to grow. If phytoplankton and algae decrease during El Niño, what would be the consequences to your food web?
 - A. Which species in your food web would decrease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

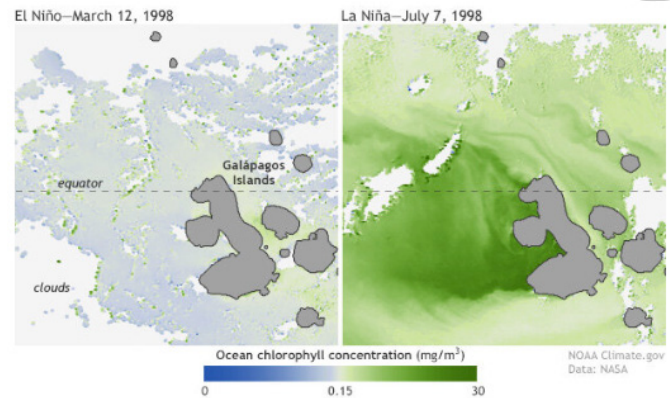


Image credit: [NOAA](https://www.noaa.gov)

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

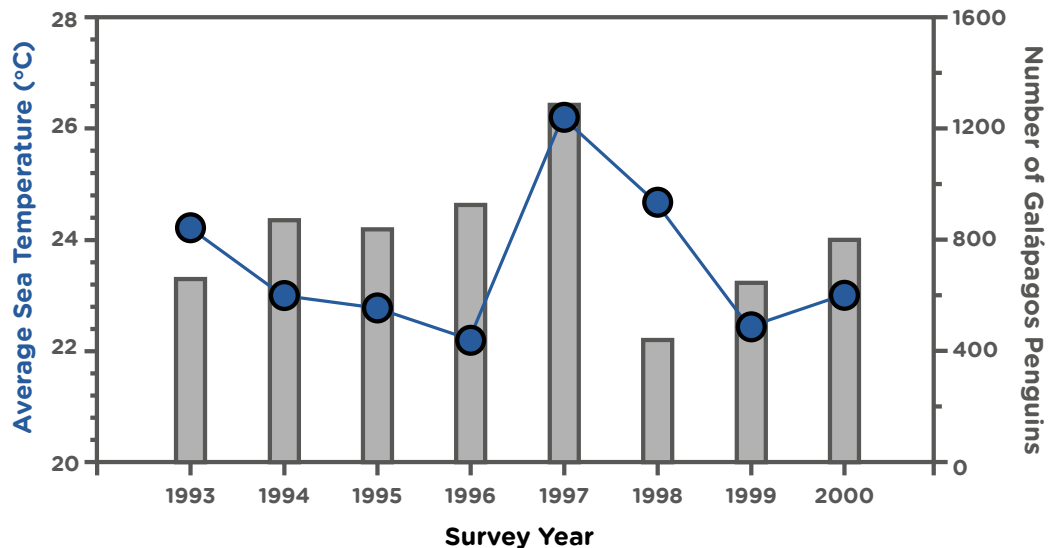
- Let's go back to the Galápagos penguin and look at some real data during El Niño and La Niña phases.
- Scientists working in the Galápagos collect information about yearly sea temperature.
- They also conduct annual surveys to count the penguin population.
- We can combine these data to better understand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