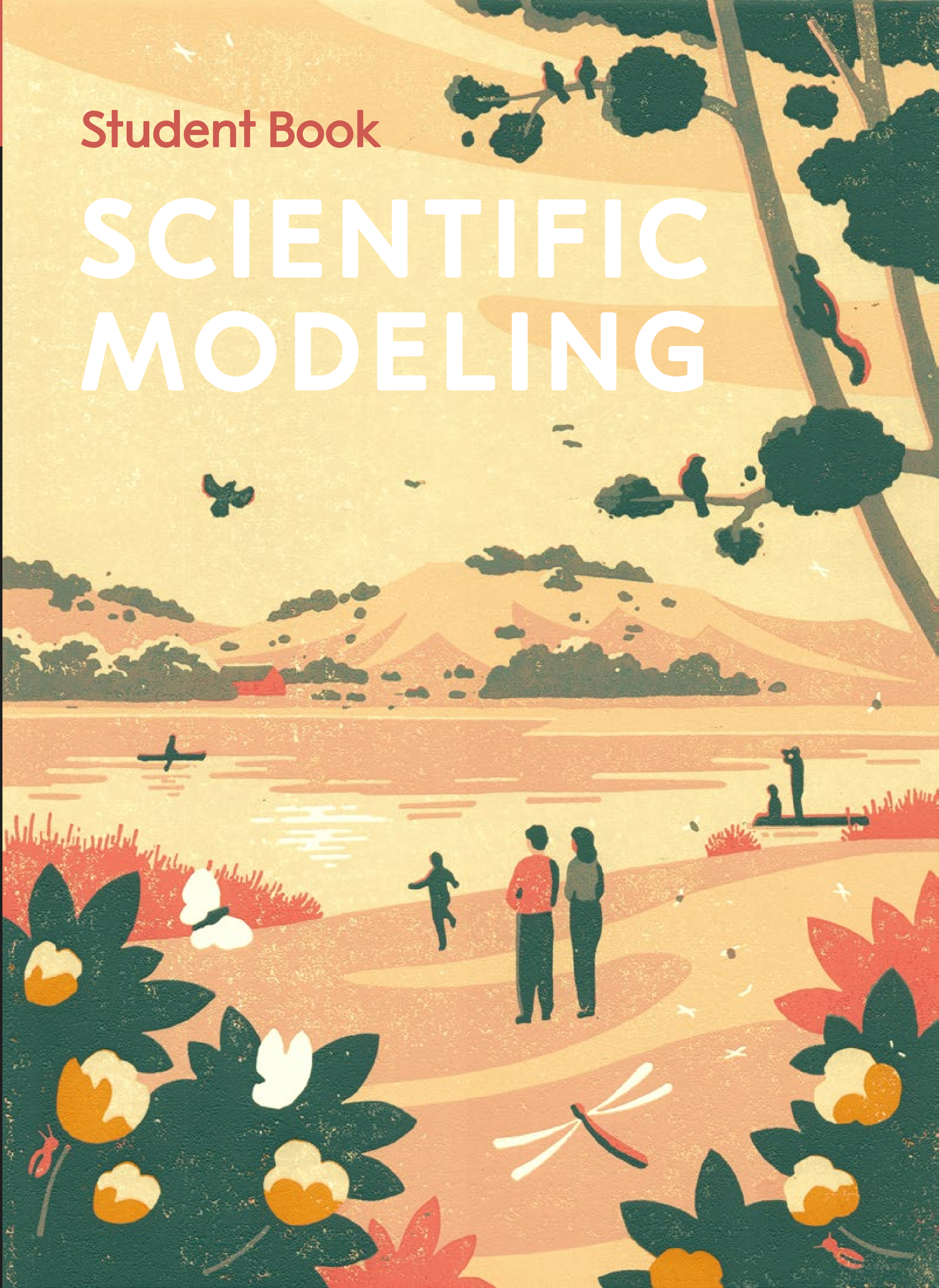
UNIT 2

v 1.0

Student Book

SCIENTIFIC MODELING



SCIENTIFIC THINKING FOR ALL : A TOOLKIT

This book is part of the *Scientific Thinking for All: A Toolkit* curriculum that is a high school adaptation of the University of California, Berkeley, "Big Ideas" course titled Sense and Sensibility and Science https://sensibility.berkeley.edu/. It was developed by professors Saul Perlmutter, John Campbell, and Robert MacCoun and represents a collaboration among physics, philosophy, and psychology. *Scientific Thinking for All: A Toolkit* was developed by curriculum developers and researchers at The Lawrence Hall of Science, University of California. The initiative is a cooperation between Nobel Prize Outreach (NPO) and Saul Perlmutter. This work is supported by a consortium of funders including Kenneth C. Griffin, the William and Flora Hewlett Foundation, the John D. and Catherine T. MacArthur Foundation, the Gordon and Betty Moore Foundation, and The Rockefeller Foundation.

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Scientific Thinking For All : A Toolkit

UNIT 2
Scientific Modeling
v1.0 JUN 2026

STUDENT BOOK

THE LAWRENCE HALL OF SCIENCE
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DEAR STUDENT,

Have you ever read a news article and wondered if the information it contained was true? Or had a friend make a claim and wondered if they were right? This curriculum will equip you with ideas and techniques from science that can be applied to everyday life. Your conceptual toolkit will include strategies to help you evaluate information, reflect on your thinking, and make more informed decisions. You will use these tools to ask questions, brainstorm ideas, interpret data, manage trade-offs, and develop solutions.

Scientific tools and techniques can lead to a better understanding of how the natural world works and provide approaches to solving the problems facing individuals, communities, and the environment. Each unit will provide you with additional conceptual tools for your toolkit, and you'll practice applying them to personal and societal issues such as human health, environmental pollution, and energy use. For example, you may consider questions such as: *How much sleep do I need? Is my community's drinking water safe?*

Science offers many useful strategies for learning about the world, including:

1. working together to share observations, questions, and ideas;
2. techniques for making sense of observations and data; and
3. the iteration of ideas by modifying them as new information becomes available.

Since it's difficult for anyone to catch their own mistakes, you'll collaborate with your classmates to share your thinking and learn from one another. It is our hope that this science toolkit will empower you to think more clearly about the things you care about, to provide you with strategies for addressing problems, and to help you achieve your personal goals.

Sincerely,

Scientific Thinking for All Program Team

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Scientific Modeling

UNIT 2

SCIENTIFIC MODELING

In this unit, you will use, compare, and develop scientific models to investigate scientific questions, such as where a species is likely to be found in the future. You will explore how data on ecological change is gathered and how scientists use different methods of population estimation, such as Fermi estimates, to simplify complex problems and guide research. You will apply your new skills to deciding on a scientific question, constructing a model, and determining the most important factors to include in your model (known as *orders of understanding*). Throughout the unit, you will apply these conceptual tools to local and global ecological issues.

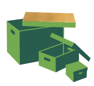
UNIT DRIVING QUESTION

How can scientific models be used to investigate changes in the distribution of species?

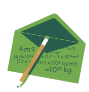
CONCEPTUAL TOOLS

In this course, conceptual tools refer to scientific ideas and approaches that can be applied to real-world situations. Each conceptual tool is further explained in the activity in which it is introduced. The conceptual tools found in this unit are shown here and in each activity in which they appear.

Scientific Modeling



Orders of Understanding



Fermi Estimations

ACTIVITY 1

Using Models

CARD-BASED INVESTIGATION

Ecological models are used to investigate populations of species such as frogs.

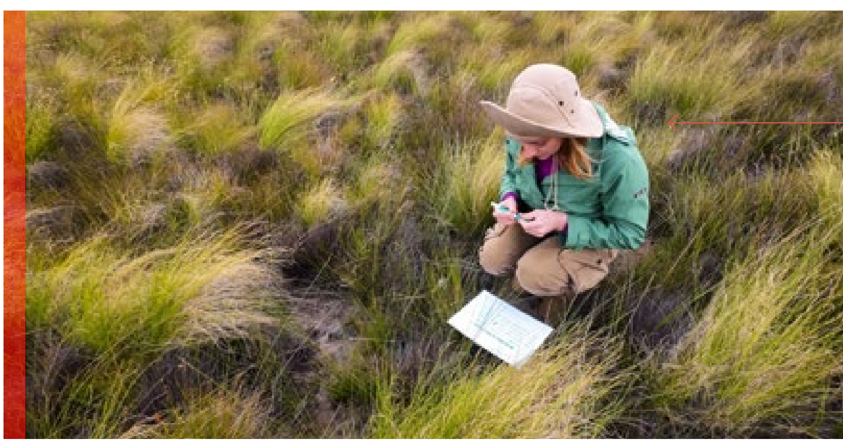
1 : USING MODELS

GUIDING QUESTION

How can models be used to inform a decision?

INTRODUCTION

Global environmental changes, such as invasive species, climate change, and habitat loss, are affecting organisms in new ways. Some species are expanding beyond their historic ranges, while others are contracting into smaller habitats. Understanding the effects of environmental change can help people make decisions about conservation, development, and resources. Scientists are creating models to predict the likely population size, distribution, and interactions of species in the future. A scientific model is a representation of an idea, object, process, or system. Scientific models can be used for different purposes, including to explain phenomena and make predictions. In this activity, you will use models to inform a decision about a frog population.



One way that scientists gather data to build models is by observation.

CONCEPTUAL TOOLS

If you need to review the concept of populations of organisms in ecosystems, you will find a Science Review at the end of this activity.

MATERIALS LIST

FOR EACH GROUP
OF FOUR STUDENTS

- SET OF 2 FROG MODEL CARDS
- SET OF 2 FROG DATA CARDS

FOR EACH STUDENT

- STUDENT SHEET 1.1 "Daylighting Decision"

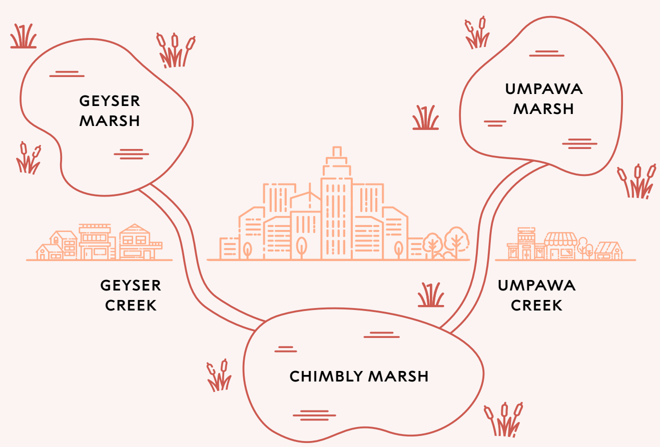
PROCEDURE

1 Read the following fictional scenario.

Anura menanda *is a species of frog found only within the county of Menanda. Changes in the regional climate over the past 50 years have resulted in a steady decline of its total population. Local residents have noticed an increase in the number of mosquitos over that same period. Because frogs eat mosquitoes, residents hope that increasing the frog populations will help address the mosquito problem.*

Historically, Anura menanda *frog populations have been found in 3 local marshes: Chimbly, Geyser, and Umpawa. As recently as 20 years ago, frogs were observed traveling along creeks between Chimbly Marsh and the other marshes. Since then, the creeks connecting the marshes have been paved over, and all 3 frog populations have declined.*

Uncovering a stream that was previously buried underground in drains and pipes and restoring its natural, above-ground flow is known as daylighting. *Local scientists agree that daylighting the creeks will allow the frogs to travel between marshes and likely increase the* Anura menanda *populations. But there is only funding to daylight one of the two creeks. While everyone agrees that it would be best to daylight a creek that connects to the better marsh habitat, they cannot agree on which creek to restore.*



2 As a group, your task is to decide which of the two creeks to daylight. To do this, you will look at models about two other fictional frog species. When there is limited data on a particular species, scientists sometimes use models based on data from similar species. Decide which half of your group will examine Frog Model 1 and which half will examine Frog Model 2.

3 Examine your model card, which shows the relationship between a frog population and factors affecting it. A factor is something that actively contributes to the production of a result. In scientific modeling, a factor is a variable that has an effect on another variable within the model. For example, one factor affecting the gold frog population is predators.

4 With your partner, use Student Sheet 1.1, "Daylighting Decision," to analyze your selected model. For now, complete only the first three rows of *either* Table 1 or Table 2.

5 Your table includes two rows of additional data about Geyser Marsh and Umpawa Marsh. Examine this data. Based on the model you examined, circle the value in each row that most likely indicates better conditions for the *Anura menanda* frogs.

6 Discuss the following questions with your partner and record your responses in your table:

- Based on the model you examined, which marsh do you predict will be a better habitat for the *Anura menanda* frogs: Geyser Marsh or Umpawa Marsh? Why?
- Which creek would you recommend for daylighting: Geyser Creek or Umpawa Creek?

7 Have each pair in your group explain their model to the group. Use this information to complete Tables 1 and 2 on Student Sheet 1.1.

8 As a group, discuss whether the two models resulted in the same recommendation about which creek to daylight and why or why not.

In 2005, the city of Seoul, Korea, daylighted an 11-kilometer (7-mile) stream by removing an elevated highway.

9 Over the last decade, scientists have collected data on *Anura menanda* populations. Your teacher will give 2 Frog Data cards to each group. With your group, examine the data and discuss how each of the following factors appears to be affecting the *Anura menanda* frog population:

- average temperature
- insect population
- pesticide
- Bd fungus

Record your ideas in Table 3 on Student Sheet 1.1.

10 Work with your group to identify which one of the four factors appears to have the greatest effect on the *Anura menanda* frog population. Circle that factor in Table 3.

11 Based on the data, discuss with your group which marsh—Geyser Marsh or Umpawa Marsh—you predict will be a better habitat for *Anura menanda* and why. Record your prediction in the table.

12 Based on the data, discuss with your group which creek—Geyser Creek or Umpawa Creek—you would recommend for daylighting and why. Record your recommendation in the table.

13 Share your recommendation with your class.

BUILD UNDERSTANDING

1. In this activity, you used models to investigate an ecosystem.
   - **a** Which creek do you recommend for daylighting: Geyser or Umpawa?
   - **b** Explain which model—Model 1 or Model 2—was the most useful for deciding which creek to daylight and why.
   - **c** Provide at least two reasons why the model you chose supports your recommendation.
   - **d** Make a prediction for what will happen to the *Anura menanda* frog population if your recommendation is followed.

2. Simple diagrams modeled the interactions between frogs and the factors affecting its population. Identify at least two additional factors that could affect the size of a frog population.
   - **a** Using the following symbols, draw a model to show how these factors will likely affect a frog population.

     → a relationship between factors

     ⊕ a positive effect, such as an increase in population size

     ⊖ a negative effect, such as a decrease in population size
   - **b** What data could you collect to test the accuracy of your model?

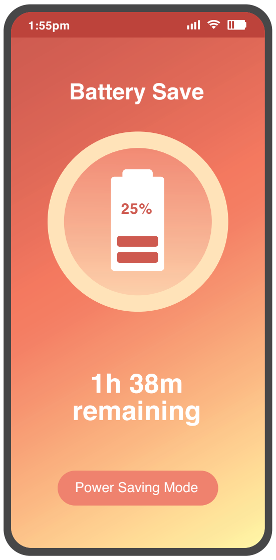
3. Time has passed. A group of residents has been working on habitat restoration of Menanda marshes. Their work has improved water quality and reduced pollution levels, including pesticides, to levels that cannot be measured. While some residents would like to daylight the other creek, it is currently buried under a pedestrian bridge. Other people do not want to daylight it because it would cost a significant amount to move the crossing.

   Would you recommend daylighting the other creek? Support your answer with evidence from Student Sheet 1.1 and identify the trade-offs of your decision. A trade-off is a desirable outcome given up to gain another desirable outcome.

The Build Understanding and Connections to Everyday Life items are intended to guide your understanding. Some of these items may be discussed with a partner, be part of a class discussion, or require an individual written response. Your teacher will guide you as to how these items will be used in your class.

CONNECTIONS TO EVERYDAY LIFE

4. Your smartphone uses a model to show you the estimated minutes or hours remaining on your phone's battery.
   - a What are some of the factors this model must incorporate to calculate an accurate time estimate?
   - b How could you test your ideas about the factors included in this model?



KEY SCIENTIFIC TERMS

factor
scientific model
trade-off

SCIENCE REVIEW: POPULATIONS OF ORGANISMS IN ECOSYSTEMS

Organisms

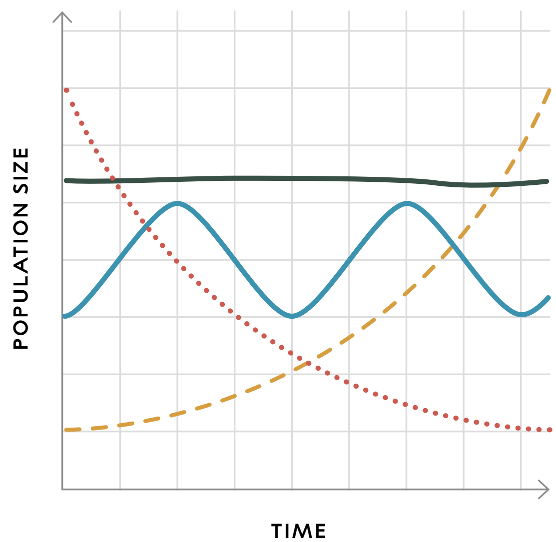
An individual animal, plant, or other living life-form is called an *organism*. Organisms live in an *ecosystem*—the living and nonliving parts of a physical environment that interact with each other in a specific area. An ecosystem can be as small as a puddle or as large as planet Earth. The particular ecosystem where a given organism lives and which provides it with necessary resources such as food and water is known as its *habitat*.

Population

There may be many populations of various species in an ecosystem. A *population* is a group of individuals of the same species that live in the same general area and are able to reproduce with one another. For example, in a pond ecosystem, there can be populations of frogs, dragonflies, and aquatic plants. A group of individuals that can interbreed in nature is a *species*. The common green darner and the clubtail are both species of dragonflies that can be found in pond ecosystems, but they cannot interbreed to produce offspring.

The following graph shows different ways in which the size of a population might change over time. Think about which line is likely to represent a species heading toward extinction and which line is likely to represent a species that has been successfully introduced into a new ecosystem.

FIGURE 1.1
Four Populations Over Time



Range

Some species are found across large regions, such as the brown rat, which was originally native to Asia but is now found on every continent except Antarctica. Other species are located in a much smaller area, such as Devils Hole pupfish. The species is found in a single location: the upper 24 meters (80 feet) of Devil's Hole Pool, a limestone cave in California's Death Valley National Park. In ecology, a *range* is the total geographic area where a species lives and is found during its lifetime—including where it migrates or hibernates.

ACTIVITY 2

Scientific Models and Scientific Questions

DATA ANALYSIS

As environmental conditions change, scientific models are used to predict what may happen to species such as polar bears.

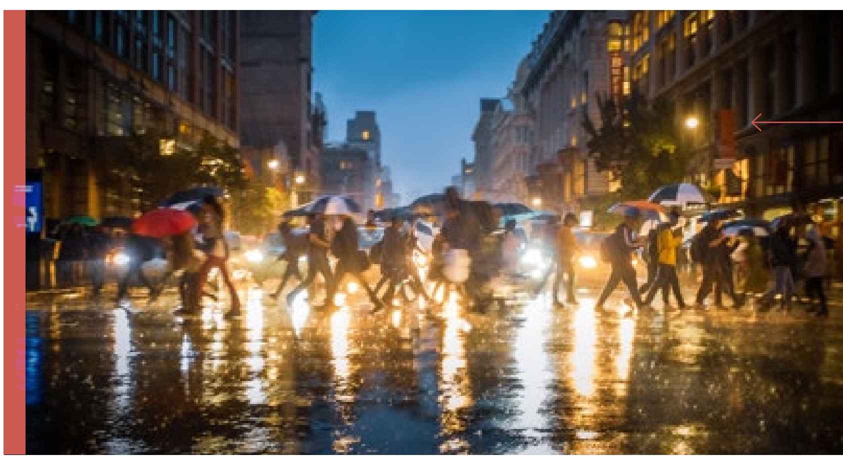
2 : SCIENTIFIC MODELS AND SCIENTIFIC QUESTIONS

GUIDING QUESTION

How are scientific models used to answer scientific questions?

INTRODUCTION

Imagine if New York City was moved over 800 kilometers (500 miles) south of where it is now. That is essentially what happened in terms of climate when, in 2020, the U.S. government reclassified it from a coastal temperate zone to a subtropical zone. Such changes are happening globally, and they are affecting many species.



The average annual precipitation in New York City has increased over the past 50 years, sometimes resulting in flooding.

CONCEPTUAL TOOLS

MATERIALS LIST

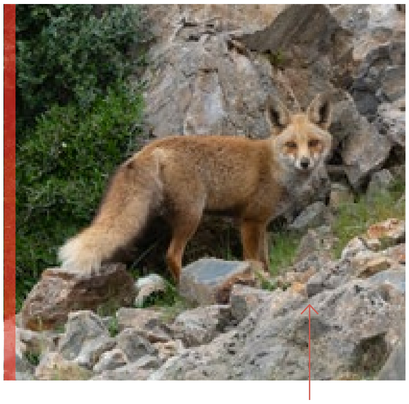
FOR EACH GROUP
OF FOUR STUDENTS

- SET OF 4 SCIENTIFIC QUESTION CARDS
- SET OF 4 SCIENTIFIC MODEL CARDS

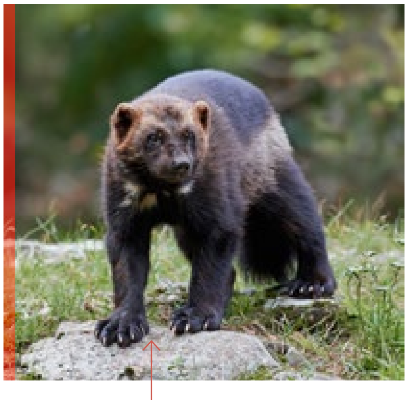
FOR EACH STUDENT

- STUDENT SHEET 2.1 "Investigating Scientific Models"

Some species are unable to adapt, resulting in population declines. For other species, environmental shifts are driving changes—in diet, location of breeding grounds, and even timing of egg laying. For example, the range of the red fox has expanded as new regions become suitable habitat. The range of other species such as the wolverine has decreased with population declines.. Many scientists are studying species distribution, the pattern of occurrence of a species within a geographic range. They are using scientific models to predict what the future might look like.



The red fox has a widespread range that includes parts of North America, Europe, Africa, Asia, and Australia (where it was introduced in the mid-1800s). With a warming climate, its range is expanding into new regions that were previously too cold.



The range of the wolverine is primarily in the subarctic areas of the northern hemisphere, and it can be found in northern regions of Canada, United States, Europe, Russia, and China. A decrease in spring snowpack is one factor contributing to its population decline.

PROCEDURE

PART A: UNDERSTANDING SCIENTIFIC MODELS

1 Each person in your group will read about one of the following four scientific models and describe it to the rest of the group. Each model is based on factual information.

2 Read and analyze your model and record your ideas in Table 1 on Student Sheet 2.1, "Investigating Scientific Models." (Do not complete the final row of the table, "Scientific question," at this time. In Step 4, your group will think of a scientific question for each model.)

SCIENTIFIC MODEL 1

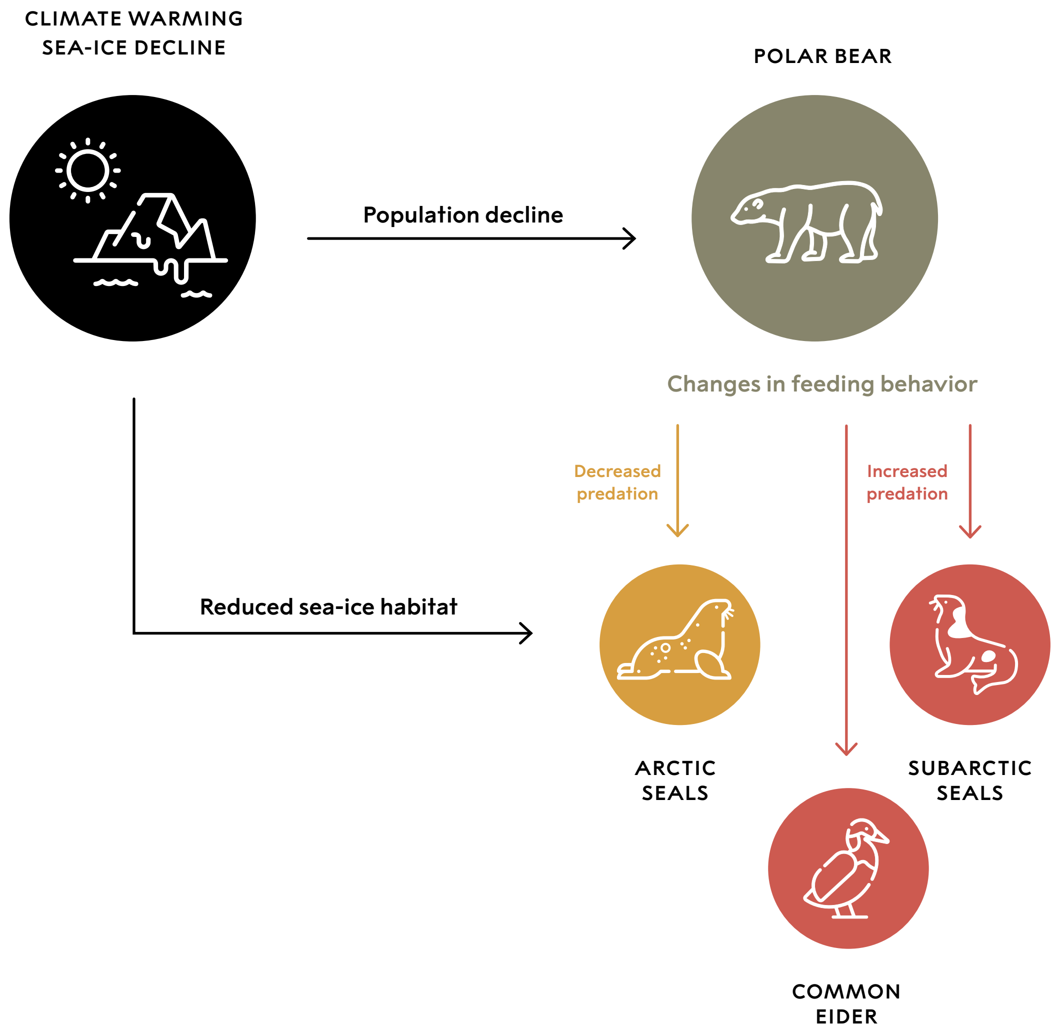
POLAR BEARS

Scientists constructed a model to predict the most likely ways that climate change will affect predation by polar bears (*Ursus maritimus*) in the Arctic, as shown in Figure 2.1. Long-term observational data and environmental data on atmospheric and oceanographic conditions were used to build the model. This model predicts both positive and negative impacts on other species. The positive predicted impact is less polar bear predation on Arctic seals. The negative predicted impact is more polar bear predation on subarctic seals and common eider ducks.

FIGURE 2.1

Model of Predicted Climate Change Effects on Polar Bear Predation

Arrows show relationships.

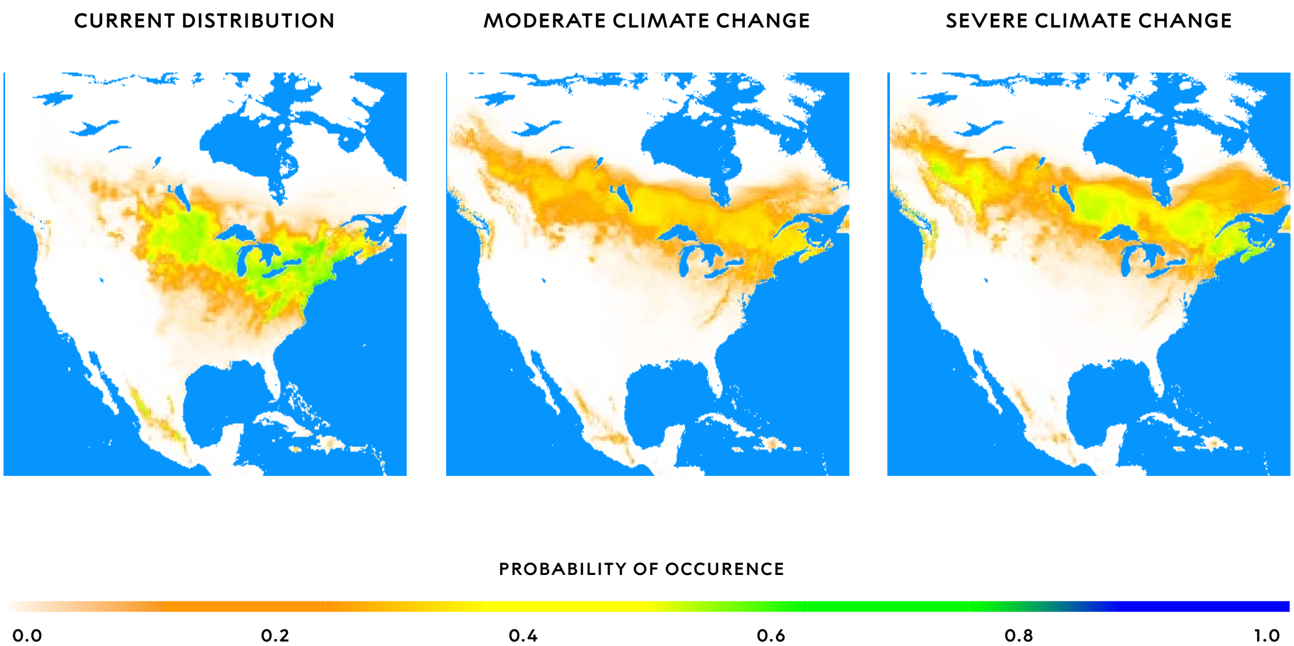


SCIENTIFIC MODEL 2

MONARCH BUTTERFLIES

Scientists are using computer software models called Species Distribution Modeling (SDM) to predict where a species might live in the future. Monarch butterflies (*Danaus plexippus*) migrate between Mexico and the United States, heading north in the summer and south in the winter. In one study, SDM was used to predict the future distribution of monarch butterflies under three different climate scenarios. The model combined data on historical butterfly distribution with food availability for butterfly larvae. These inputs were used to predict future habitat suitability in June. As shown in Figure 2.2, the geographic range is projected to move northward.

FIGURE 2.2
Predicted June Monarch Butterfly Distribution from SDM Model

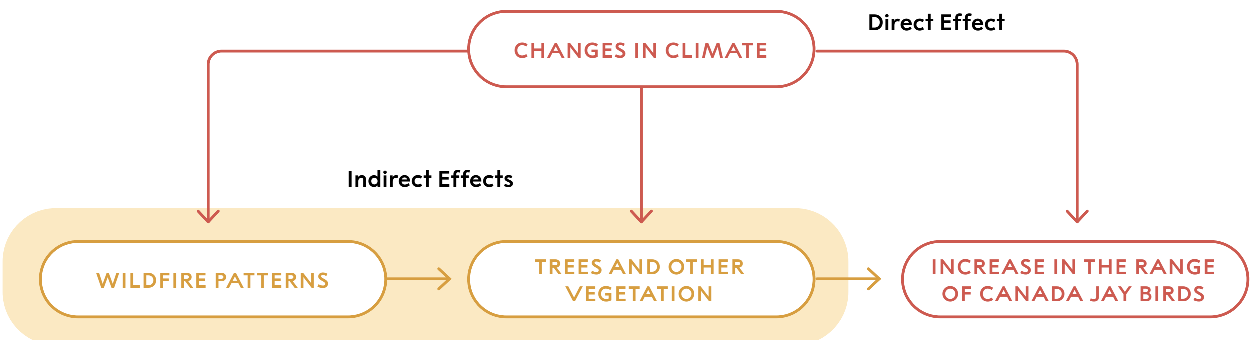


SCIENTIFIC MODEL 3

CANADA JAYS

Scientists constructed a model to predict the most likely ways that climate change will affect the distribution of Canada jay birds (*Perisoreus canadensis*) in northern Canadian forests, as shown in Figure 2.3. This model compares both direct and indirect impacts of long-term changes in temperature and precipitation. Directly, climate change affects bird populations by impacting their physical health and their ability to reproduce. Indirectly, climate change alters the environment by changing wildfire patterns and the vegetation on which the birds rely.

FIGURE 2.3
Model of Predicted Climate Change Effects on Canada Jay Distribution in Northern Canada

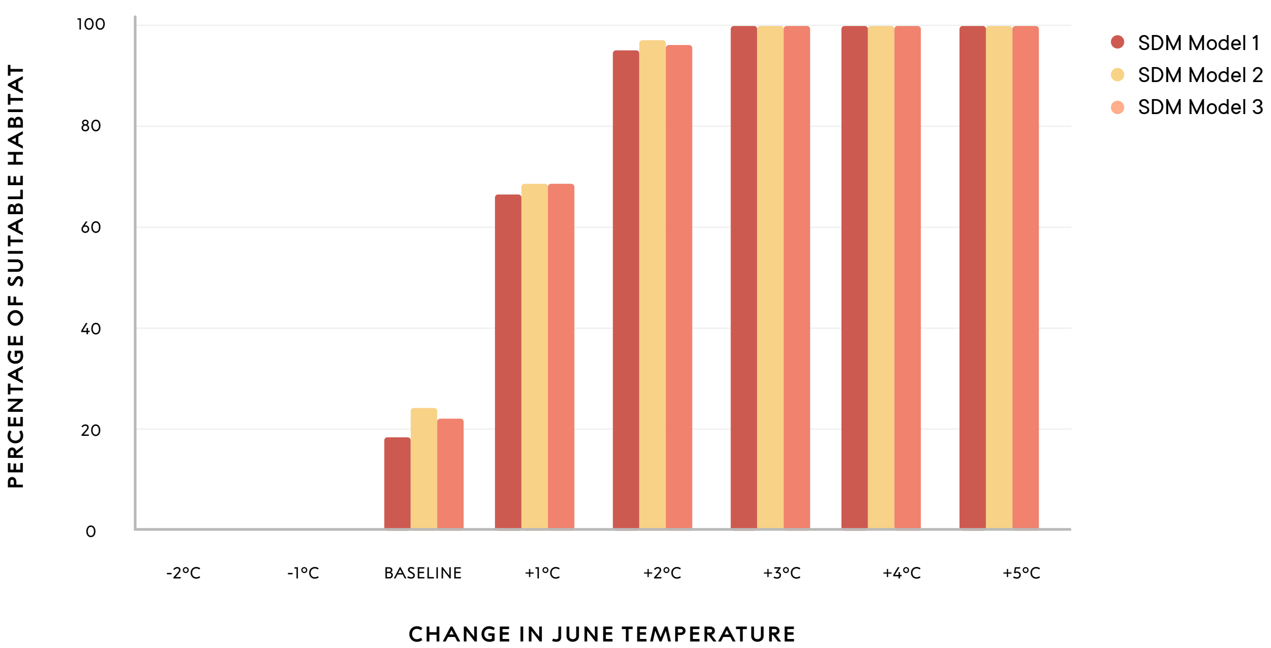


SCIENTIFIC MODEL 4

EUROPEAN COMMON FROGS

Scientists are using computer software models called Species Distribution Modeling (SDM) to predict where a species might live in the future. In one study, SDM was used to predict habitat changes for the European common frog (*Rana temporaria*) in subarctic Finland. Finland has long, cold, snowy winters (often below –30°C/–22°F) and short, mild summers. SDM combined data on current frog distribution with environmental factors such as temperature. Scientists studied 179 potential frog breeding sites. They used 3 different versions of the SDM model to predict how much of the area would provide suitable breeding sites under different climate conditions. All 3 models produced similar results, as shown in Figure 2.4. The baseline shows that about 20% of the area currently has suitable breeding sites. The SDM models all predicted that 100% of the area will likely provide suitable breeding sites if average temperatures increase by 3°C (5.4°F) or more.

FIGURE 2.4
Predicted Changes in Frog Habitat from Three SDM Models



3 Have each group member explain their model to the rest of the group. As a group, work together to understand each model by sharing additional ideas and insights. Use this information to complete the first four rows of Table 1 on Student Sheet 2.1. Remember to listen to and discuss the ideas of other group members. If you disagree with others in your group, explain why you disagree.

4 Work together to brainstorm at least one scientific question that could be investigated by using each model. Record your questions in the last row of Table 1 on Student Sheet 2.1.

5 Share your questions with the class. Based on the class set of questions, discuss whether one model could be used to answer different scientific questions.

PART B: MODELS AND SCIENTIFIC QUESTIONS

6 Your group will receive a set of 4 Scientific Question cards. Work together to read aloud the question on each card.

7 Your group will also receive a set of 4 Scientific Model cards. The Scientific Model cards represent the same four models that you just analyzed. Use the two sets of cards to sort and discuss which model(s) could help answer each scientific question. (Note: A question may be addressed by more than one model.)

8 Record your responses and reasoning in Table 2 on the student sheet.

9 With your group, discuss a scientific question about species distribution that you would like to have answered. Then, brainstorm a model you would like to have to help you in addressing this scientific question.

BUILD UNDERSTANDING

1. A team is developing a population model for bass fish in a local freshwater lake ecosystem. The team decides to focus only on two key factors: the population size of bass fish and water temperature.

   a. Identify at least two factors of the real-world lake system that the team is leaving out of their model.

   b. Explain how excluding these factors might lead to an inaccurate prediction about the bass population.

   c. If the team's scientific question is *How does the bass population size change in response to changes in water temperature?*, do you agree with the focus of their model? Why or why not?

2. The following diagram is another type of model that shows that a change in one part of a system causes a specific response in another part of the system.

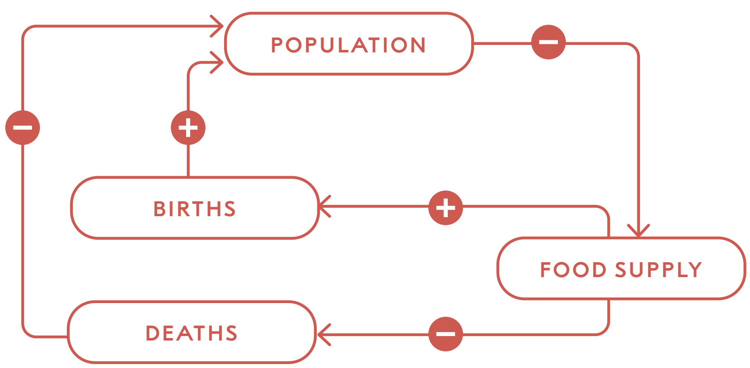


FIGURE 2.5
Population model diagram showing relationship between population, births, deaths, and food supply

Factors such as birth rate, death rate, and food supply can affect the size of a population. For example, when there is more food (+), there can be an increase in births, which increases (+) the population.

   a. According to the model, how would an increase in population affect the food supply?

   b. Revise this model to show the possible effect of at least two additional factors on a population of mice.

   c. List at least one scientific question that could be investigated by your revised model.

CONNECTIONS TO EVERYDAY LIFE

3. Different mapping apps provide different models of the geographic layout of Earth's surface. For example, one model, used for navigation, can tell you the best way to get from one place to another by car, foot, or public transportation as well as an estimate of how long each will take. Another model shows satellite photographs with labels to identify cities and country boundaries. Take a moment to go online to explore both of these mapping models.

   a. What factors are included in a satellite map model but not in a navigation map model?

   b. What factors do both models include?

   c. Given these differences, what is one question that a satellite map model can help address but a navigation map model cannot?

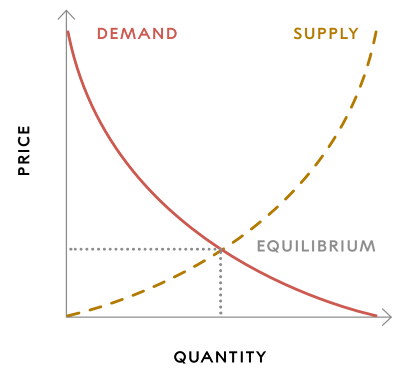
   d. What is one question that both models address equally well?

4. Other fields of study also use models. The graph to the right is one that is commonly used in economics to model the relationship between the price of goods and services based on the supply and demand for them. A clothing retailer uses it as a model to set the price for a popular vintage T-shirt.

   a. When the supplier sets the price exactly at the equilibrium point, what is the model predicting will happen to the number of T-shirts sold?

   b. Identify one limitation of this model.

   HINT: Consider what might happen if the T-shirt became a viral trend on social media.



EXTENSION

Search for additional scientific models online. In what fields of scientific study are these models being used? What scientific questions are being investigated? Share your findings with a friend or someone in your family.

KEY SCIENTIFIC TERMS

species distribution

ACTIVITY 3

Constructing a Model

FIELD TRIP

There are many interactions among local species that can be observed and modeled.

3 : CONSTRUCTING A MODEL

GUIDING QUESTION

How are firsthand observations used in scientific modeling?

INTRODUCTION

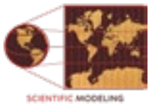
Around the world, organisms are expanding into ecosystems beyond their native range. For example, the nine-banded armadillo, which cannot tolerate extremely hot or cold temperatures, was historically limited to the southern United States. Milder winters are allowing it to spread hundreds of kilometers north. Imagine wanting to model the effect that this species might have on your local ecosystem.

A system is a collection of parts that interact with each other to work together as a whole. You are probably familiar with examples of systems in and around you, such as your digestive system, a coral reef ecosystem, and the Solar System. Scientists represent systems with different types of models to explain phenomena and make predictions. In this activity, you will use your observations of a local ecosystem to construct a food web model.

If you need to review the concept of food webs, you will find a Science Review at the end of this activity.

The nine-banded armadillo has been observed in the northern U.S. states of Nebraska, Iowa, and Illinois.

CONCEPTUAL TOOLS



MATERIALS LIST

FOR THE CLASS

- MAP OF FIELD TRIP AREA

FOR EACH STUDENT

- STUDENT SHEET 3.1 "Making Local Observations"
- UNLINED PAPER
- SPECIES IDENTIFICATION PHONE APP

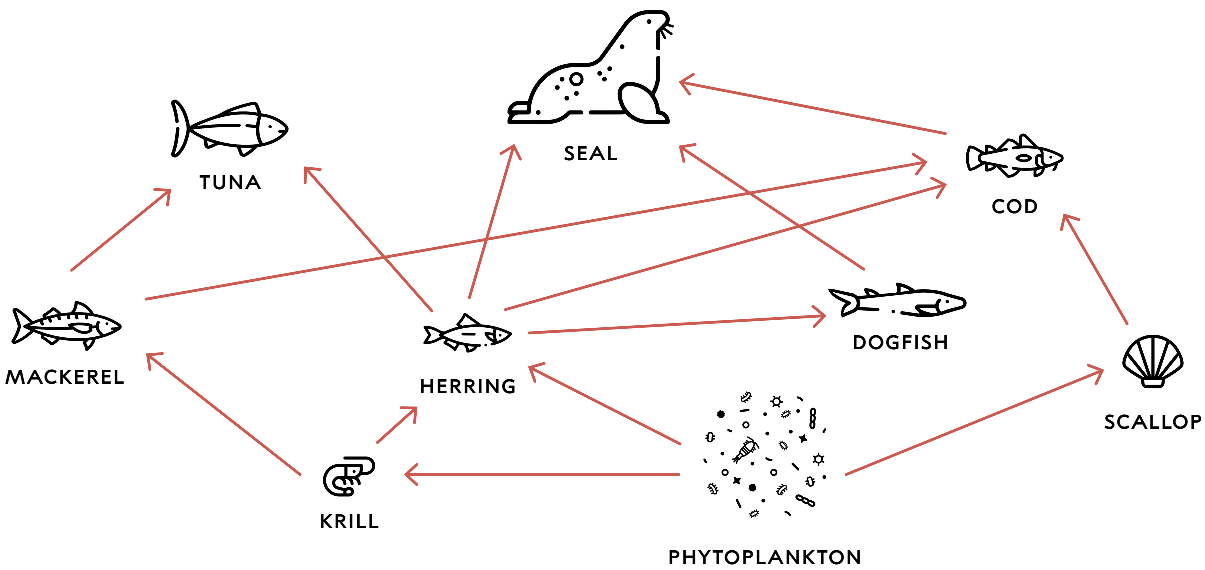
PROCEDURE

PART A: MODELING FROM PRIOR KNOWLEDGE

1. You will be going outdoors to make ecological observations. Consider what you know about the ecosystem you will be visiting. In particular, think about:
   - species that you have observed or that you know live in your area such as birds; insects; reptiles; amphibians; spiders; mammals; and plants, including trees.
   - the feeding relationships that you have observed or that you have knowledge of.
2. Use your prior knowledge about local species and feeding relationships to construct a food web model of the ecosystem you will observe. A sample food web model is shown in Figure 3.1.
   a. Record the names of two local species that you think are likely to have a feeding relationship, each in its own circle or box.
   b. In a food web model, arrows indicate the transfer of energy and matter from one organism to another. For example, an arrow begins at a prey species, such as a mouse, and points to a predator species, such as a hawk. On your model, draw an arrow from the species that is being eaten to the species that eats it.
   c. Add additional species to your model until you have at least five species.

      NOTE: You can place a question mark on any relationships you are unsure of.
   d. As you add each species, think about all the different possible feeding relationships that may exist among the species in your model. To demonstrate these relationships, add additional arrows from the species being eaten to the species that eats it.

FIGURE 3.1
Gulf of Maine Food Web Model



PART B: MODELING FROM FIRSTHAND OBSERVATIONS

3. Your teacher will take you to a local outdoor area to make ecological observations.
4. Find an area a few feet away from others in your class where you can quietly make observations of this local system.
5. Stand or sit silently in this area for 10 minutes and use your senses to observe the system around you. Make sure to look in all directions, including up and down. You may hear some organisms before you can see them.
6. Use a phone app such as *iNaturalist* to help you identify unfamiliar species.
7. Record your observations on Student Sheet 3.1, "Making Local Observations." Make sure to include at least five different observed species and describe any possible feeding relationships, based on your observations and your prior knowledge. (You will record questions you have about organisms and their interactions in Step 13.)
8. On the back of Student Sheet 3.1, add a drawing or a map to your observations. You may want to sketch the entire scene or mark a particular organism's place within the environment. Label parts of your drawing or map as needed.

9 When you return to the classroom, share your observations with your class and discuss the possible feeding relationships among the different species you observed. For example, one person may have observed a dead beetle, and another person may have observed a living ant. A possible feeding relationship you may discuss is *Are ants likely to eat the remains of the beetle? Is a living beetle likely to eat an ant?*

10 Use the firsthand observations made by you and your classmates to revise your food web model. Label your food web model with a word or phrase that describes the system you are modeling.

11 Explain your food web model to your group. Respond to any questions, comments, or suggestions they have and modify your model as needed.

12 Use your revised model to make predictions about the interactions among species. As a class, discuss what would happen to the population of a particular species if the population of another species changed. For example, how could you use your model to predict what might happen to a grasshopper population if a large amount of grass began to grow in this area, or to a lizard population if a large number of owls migrated to this area?

PART C: MODELING FROM RESEARCH

13 Identify at least two questions you have about species or feeding relationships in your model.

14 Research your local environment and use this new information to revise your model.

15 Share your revised model with your class and discuss how this information that was used to revise your model improves your predictions about local species.

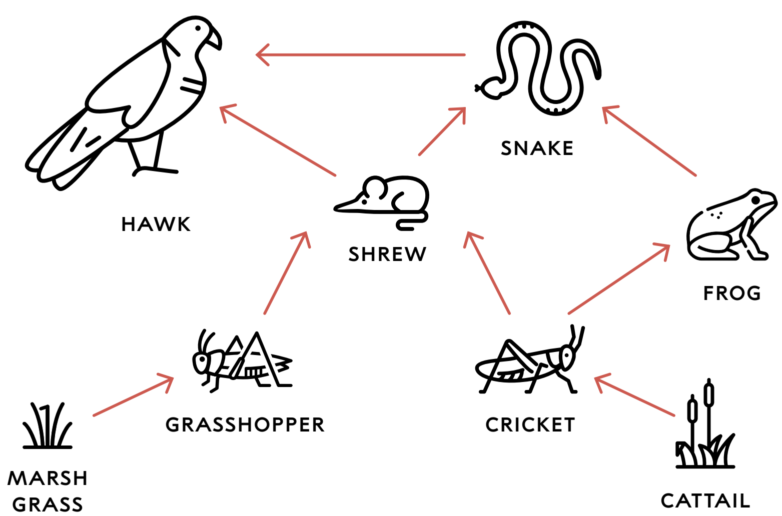
BUILD UNDERSTANDING

1. An ecosystem consists of both living (biotic) parts, such as wildlife, and nonliving (abiotic) parts, such as water.
   - a Which parts are included in a food web model?
   - b What are three examples of nonliving parts that are not included in a food web model?
   - c If you wanted to construct a more complete and accurate model of an ecosystem, what would you do differently?

2. Reflect on the ways in which your initial food web model changed to incorporate new information. Design a more scientific approach to gathering firsthand observations to inform your food web model.

3. Scientific models are constructed to explain phenomena and make predictions. Look at the following food web model.

FIGURE 3.2
Food Web Model



   - a What do you predict would happen to the population of other species if the cricket population declined? Explain your reasoning.
   - b An owl species that eats snakes, frogs, and grasshoppers moves into the area. What do you predict will happen to the populations of the different species?

4. Imagine you visited a park with a small pond and recorded the following observations about the organisms there.

TABLE 3.1
Observations at a Local Pond

ORGANISM	NUMBER	OBSERVATIONS
Turtles	3	One turtle sat on a log in the sun. The other two were eating plants and beetles, and one of them caught a small fish and ate it.
Aquatic beetles	Lots	Beetle larvae eat aquatic plant roots, and adult beetles eat leaves of aquatic plants.
Leafy aquatic plants	Lots	The plants are growing under water in the shallow area of the pond.
Aquatic beetles	At least 50	There are different-sized fish, but they all look similar. The smaller fish are eating the leafy aquatic plants, and the larger fish are eating aquatic beetles.

a. Develop a food web model that shows the pond organisms and their interactions. Be sure to do the following:
   - label each organism in your model,
   - show the interactions between organisms in your model,
   - identify the system your model represents, and
   - describe the feeding relationships shown in your model by explaining at least three species interactions.

b. Use your model to predict what would happen to the population of other species if all the beetles died. Explain your reasoning.

c. Imagine wanting to investigate the possible effect that the arrival of the nine-banded armadillo, which eats insects found in or near the water, could have on your local ecosystem. Use your food web model to predict what might happen. Be as specific as possible.

CONNECTIONS TO EVERYDAY LIFE

5. Think about the physical layout of the building and grounds of your school. You have a mental model of the size, shape, and location of classrooms, offices, and other facilities.
    a. What observations helped you to develop this model?
    b. Does your mental model include any parts of the buildings that you have not observed (for example, a room that you have not been inside)? If so, how were you able to include them in your mental model?

6. A GPS navigation app uses a model to predict the fastest route and arrival time. Think about your own experience with such apps and their relative accuracy.
    a. Think about a situation from your own experience where the model did not correctly predict the fastest route and/or correct arrival time. What happened to affect the model's accuracy?
    b. Could the model be revised to address this type of situation? Why or why not?

EXTENSION 1

Begin to observe species (animals, plants, and fungi) as you move through your community. As a class, record these observations on a map of your school district. This map will provide data on your collective observations about the species in your community over time. Compare the results of your data collection with the observations you made for your food web model. Does the new data support the design of your food web model? If not, what new scientific questions does it raise?

EXTENSION 2

Construct a physical model of an ecosystem using a "bottle biology" model (Figure 3.3). In this sample model, two plastic bottles are cut into two, and the ecosystem is established in the first bottle. The top half of the second bottle is used to seal the system. Many such models utilize soil; water; plants; and, in some cases, invertebrates. Gather more information and design your system. Before building the model, describe the ecosystem the model represents and identify the scientific question that is being investigated.

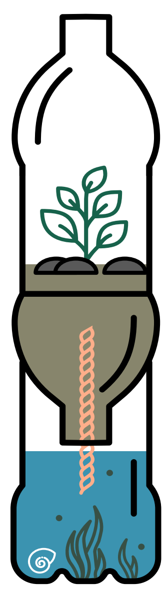


FIGURE 3.3 Model of a pond ecosystem in a bottle

KEY SCIENTIFIC TERM

system

SCIENCE REVIEW: FOOD WEBS

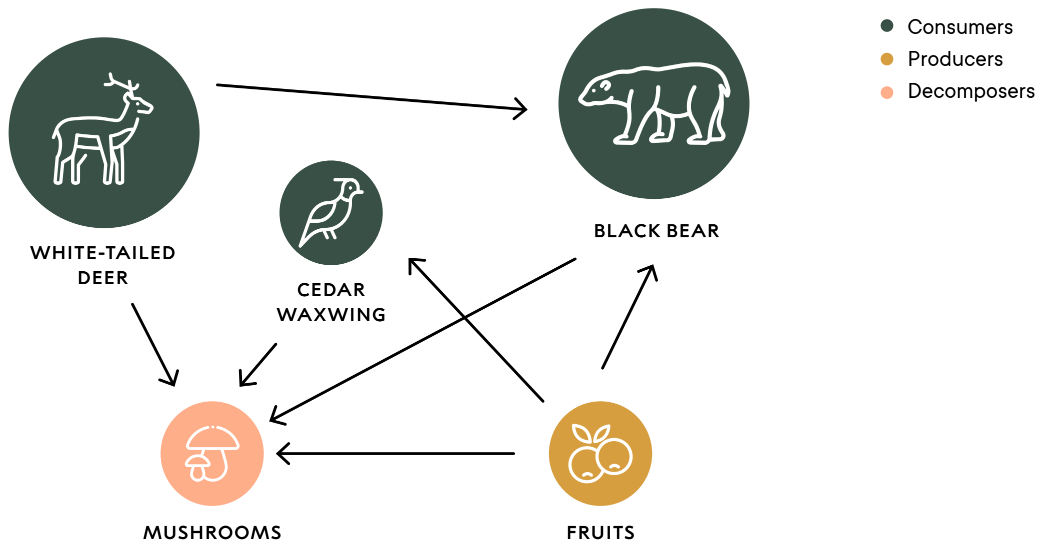
One way scientists classify organisms in an ecosystem is by describing how they obtain energy. An organism's position in a food web, representing a step in the flow of energy, is known as its *trophic level*. Read about these trophic levels in the following table.

TABLE 3.2
Trophic Levels of Organisms in an Ecosystem

TYPE OF ORGANISM	HOW ORGANISMS GET ENERGY TO SUSTAIN LIFE
Producer	Transforms light energy or other energy sources into chemical energy. The chemical energy is stored in carbon-containing molecules such as simple sugars or starch.
Consumer	Feeds on other organisms to obtain energy.
Decomposer	Feeds on other organisms and dead and decaying biological material and wastes to obtain energy.

One way to show these interrelationships between the organisms in an ecosystem is by creating a food web. A food web models the feeding relationships among different species. The arrows show the direction that energy and matter are moving within the ecosystem.

FIGURE 3.4
Trophic Levels in a Food Web



ACTIVITY 4

Modeling Factors Affecting a Population

COMPUTER SIMULATION

v 1.0

Scientists have modeled the range of the painted lady butterfly and learned that it has one of the largest ranges of any butterfly. They are found across every continent except Antarctica and Australia.

4 : MODELING FACTORS AFFECTING A POPULATION

GUIDING QUESTION

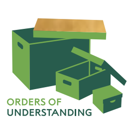
What factors should be included in a scientific model?

INTRODUCTION

Monitoring the distribution of a species over time can help evaluate the health of its population and predict its future geographic range. It can also provide insight into the factors that will most impact its future population. In this activity, you will use two computer models to investigate the factors that most impact changes in the distribution of two fictional butterfly species.

Scientists use computer models to analyze large amounts of data, understand complex systems, and forecast future events.

CONCEPTUAL TOOLS



MATERIALS LIST

FOR EACH PAIR OF STUDENTS

- COMPUTER WITH INTERNET ACCESS

FOR EACH STUDENT

- STUDENT SHEET 4.1 "Butterfly Bluff Simulation: Model 1 Data"
- STUDENT SHEET 4.2 "Butterfly Bluff Simulation: Model 2 Data"
- STUDENT SHEET 4.3 "Butterfly Bluff Simulation: 2050"

PROCEDURE

PART A: BUTTERFLY BLUFF SIMULATION: MODEL 1

1 With your partner, read the following fictional scenario.

OBSERVATIONS OF CHANGE IN BUTTERFLY BLUFF PARK

Butterfly Bluff Park is located in a rural area and has many species of butterflies. Two notable butterfly species are the Crystal Alpine and the Indigo Longwing. The Crystal Alpine's habitat is in the mountains, while the Indigo Longwing is found in low-lying areas. Over time, regular park visitors have observed these species in areas where they haven't been seen before.

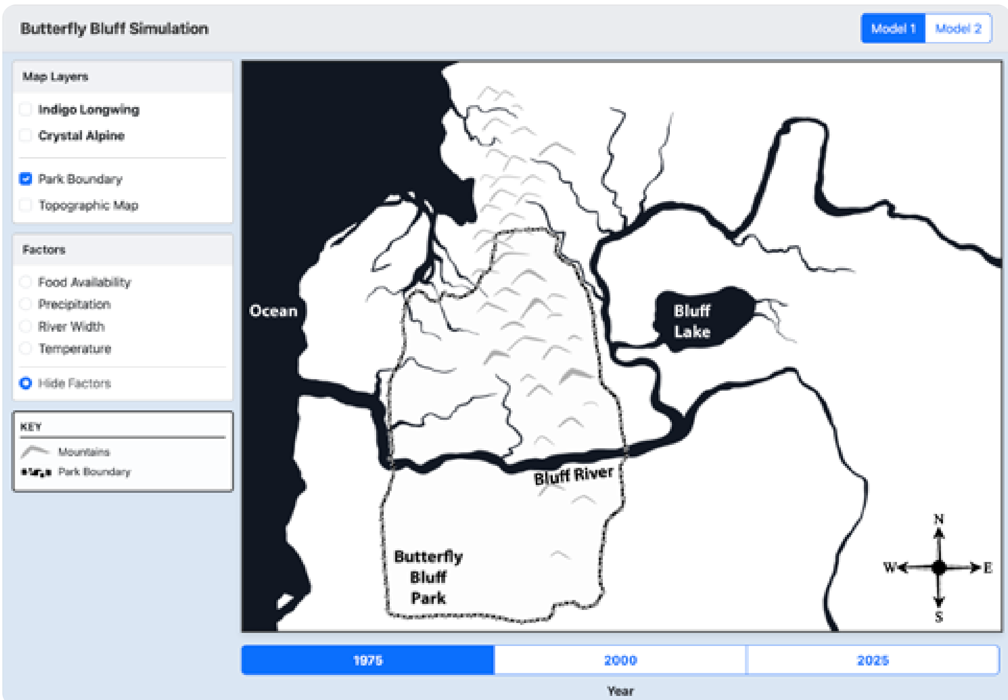
Ecologists at a nearby college have decided to construct a map model to describe how the distribution of the two butterfly species has changed over time. The team is recording data on the butterflies' distribution. The study uses historical data to determine which factors are impacting the species. The goal is to predict where the butterflies might be found in the future.

Another group of scientists used the historical data from the map model to create an additional model to identify the factors that impact the populations the most. This information can help predict how the butterflies will be distributed in the park in the future.

2 As a class, brainstorm reasons why the distribution of butterflies might be changing and record these ideas in your science notebook.

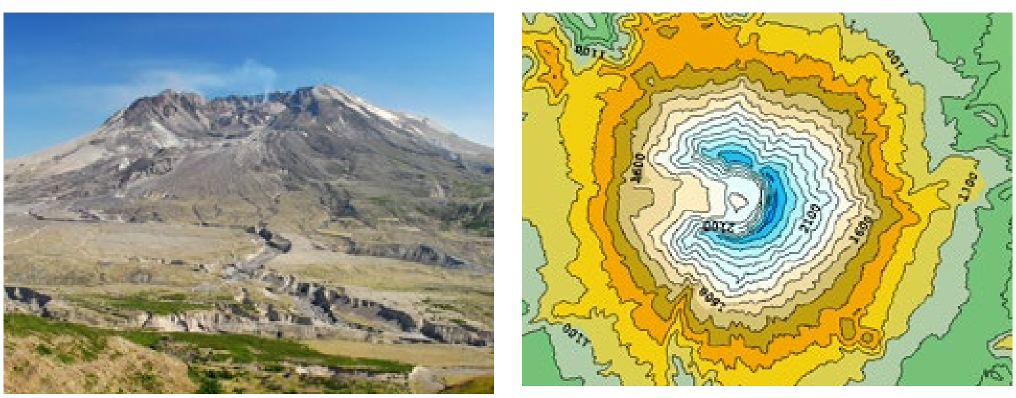
3 Your teacher will assign you and a partner to one of two butterfly species. Follow your teacher's instructions for accessing the Butterfly Bluff Simulation. To begin, use the button on the top right of the screen and select Model 1 (as shown in Figure 4.1).

FIGURE 4.1
Image of the Butterfly Bluff Simulation



4 Explore differences in land elevation by using the key to identify the location of mountains and by selecting the Topographic Map button. As a class, discuss what information is provided by a topographic map, as shown in Figure 4.2.

FIGURE 4.2
Understanding Topographic Maps



Mount St. Helens is a volcano in the U.S. state of Washington. It erupted on May 18, 1980 and lost 122 meters (1,314 feet) in elevation, changing its topography. A *topographic map* is a flat, 2-dimensional map that is a model of the actual 3-dimensional shape of a land surface.

5 Select your assigned butterfly species and then use the time period buttons below the map to investigate how the distribution of your species has changed over time. Be sure to observe its distribution relative to the park's boundary. In Table 1 on Student Sheet 4.1, "Butterfly Bluff Simulation: Model 1 Data," record how your species changed or stayed the same from 1975 to 2000 to 2025.

6 Before looking at how each factor affects the butterfly populations, observe how each factor changes over time. Do this by deselecting the butterfly species, selecting a single factor, and observing it over the time. Record your findings for each factor over time in the "Trend Over Time" column in Table 2 on Student Sheet 4.1.

7 Select your assigned butterfly species. Observe if there appears to be a correlation between each factor and the species' distribution over time and record your ideas in the last column on Student Sheet 4.1. With your partner, discuss possible reasons why each factor could cause the size and range of butterfly populations to change.

8 Share your results with a pair of students who were assigned the other butterfly species. Compare the similarities and differences between what happened to the species distribution over time. Record these in your science notebook.

PART B: BUTTERFLY BLUFF SIMULATION: MODEL 2

9 Go back to the Butterfly Bluff Simulation. Select Model 2 and the species you are investigating. The initial population size of each species is 1,000 butterflies.

10 Review the six factors listed on the left. Slide one factor at a time to see how it affects the population size. Record the data on Student Sheet 4.2, "Butterfly Bluff Simulation: Model 2 Data." Leave the "Relative Impact on Population" column blank at this time.

11 Work with your partner to rate the factors affecting the population in the model, with 1 having the greatest impact and 3 having the least impact. Record your ratings in the "Relative Impact on Population" column on Student Sheet 4.2.

NOTE: You may choose to use the same rating number for factors that appear to have similar impacts. For example, you can label two factors as a 3. You may not end up using every rating number.

12 Your ratings from Step 11 are a way to identify the orders of understanding, which are the factors included in a model based on which factors have a greater impact on the system than others. On Student Sheet 4.2, circle the factors that are a part of the highest orders of understanding (greatest impact) for each butterfly population. Cross out the factors that are a part of lower orders of understanding (least impact or no effect).

13 With your partner, share your results with a pair of students who were assigned the other butterfly species. Discuss which factors appeared to have the greatest effect on the size of the two butterfly populations and which have the least effect.

14 Based on both models, predict the distribution of the two butterfly species in 2050. Draw your predictions on Student Sheet 4.3, "Butterfly Bluff Park: 2050," and explain your reasoning, making sure to explain how each model informed your prediction.

15 With your class, compare your predictions from Step 14. Discuss how each model affected your prediction.

BUILD UNDERSTANDING

1. When constructing a model, it is important to know which aspects of the real world to include and which to leave out. Imagine you were asked to construct a model to investigate a previously unstudied butterfly population in Butterfly Bluff Park. The model should answer the scientific question *Why is the population of this species increasing at lower altitudes?* What factors would you include in the model and why?

2. Butterfly enthusiasts who visit Butterfly Bluff Park are concerned about the changes in the populations of Indigo Longwing and Crystal Alpine butterflies. They are discussing the following four options with local park rangers.

   A. Expand the boundary of Butterfly Bluff Park to the east and north so Bluff Lake and the surrounding areas are maintained as a protected food source for the Indigo Longwing.

   B. Actively plant the host plant at the top of Butterfly Bluff, which is the primary food for the Crystal Alpine.

   C. Increase the treatment of disease for both butterfly species.

   D. Do nothing.

   Which option(s) would you recommend as the highest priority? Support your answer with evidence from the models and identify the trade-offs of your decision.

Many teens use social media apps on their cell phones.

CONNECTIONS TO EVERYDAY LIFE

3. You may spend a lot of time on social media apps. The apps' feeds seem to know what videos you want to watch next. What are three factors you think are incorporated into the apps' models to predict what videos you may like? List these factors according to their impact, considering orders of understanding, and explain your reasoning.

4. Think about how your actions affect your grade in your favorite class. Construct a model to represent the factors that you control that most affect your grade and whether each factor has a positive or negative effect. Be sure to include arrows showing any relationships between factors.

KEY SCIENTIFIC TERM

orders of understanding

ACTIVITY 5

The Role of Models in Science

READING

A scientific question about a species such as the American lobster can be answered by many different models.

5 : THE ROLE OF MODELS IN SCIENCE

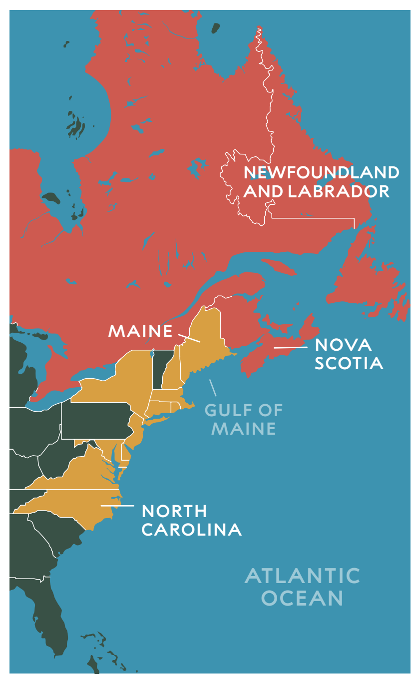
GUIDING QUESTION

How do scientific models represent a system?

INTRODUCTION

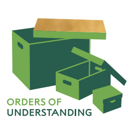
The geographic range of some aquatic species has already altered in response to changing ocean conditions. For example, fish such as cod and pollock are now found farther north (where the water is colder) as local ocean temperatures rise. What does that mean for a person fishing in their local area? One species that can help answer this question is the American lobster, which has been extensively studied because of its commercial value. The lobster catch in the state of Maine fell from a high of almost 60,000 metric tons (over 132 million pounds) in 2016 to about 39,000 metric tons (86 million pounds) in 2024. During the same time period, the lobster catch off the coast of eastern Canada increased from over 2,000 metric tons (5 million pounds) to over 9,000 metric tons (20 million pounds). Identifying such changes requires gathering data that is already available. It does not provide information about what might happen in the future. To better address future projections, scientists use models.

FIGURE 5.1
Distribution of the American lobster along the northeastern coast of the United States and Canada



- Canadian Province
- U.S. States

CONCEPTUAL TOOLS



MATERIALS LIST

FOR EACH STUDENT

3–5 STICKY NOTES

PROCEDURE

1 As you read, follow the Read, Think, and Take Note Guidelines to help you understand the reading.

READ, THINK, AND TAKE NOTE GUIDELINES

Stop at least three times during each section of the reading to mark on a sticky note your thoughts or questions about the reading.

As you read, use a sticky note from time to time to:

- explain a thought or reaction to something you read.
- note something in the reading that is confusing or unfamiliar.
- list a word from the reading that you do not know.
- describe a connection to something you've learned or read previously.
- make a statement about the reading.
- pose a question about the reading.
- draw a diagram or picture of an idea or connection.

After writing a thought or question on a sticky note, place it next to the word, phrase, sentence, diagram, drawing, or paragraph in the reading that prompted your note.

After reading, discuss with your partner the thoughts and questions you had while reading.

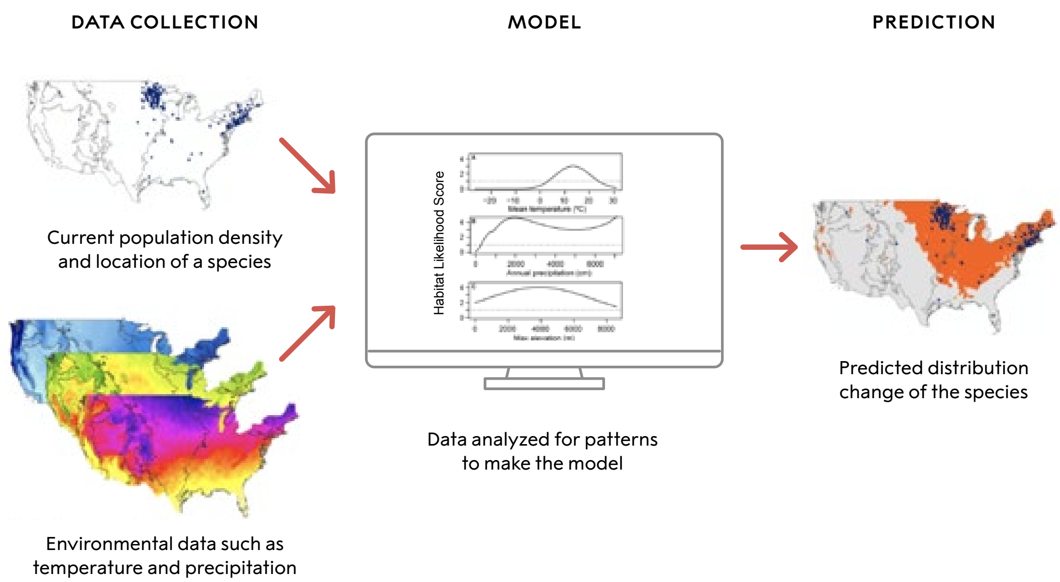
SCIENTIFIC MODELING

Changing Species Distribution

The American lobster lives on the bottom of the ocean along the eastern coast of North America. You can find them from Newfoundland, Canada, all the way down to North Carolina in the United States. Lobsters can handle a wide range of water temperatures, from just above freezing (0°C/32°F) to quite warm (25°C/77°F). But for optimal growth, survival, and reproduction, they thrive in a narrower range of 15°C–18°C (59°F–64°F). As deepwater temperatures along this coast have warmed, the lobster range has moved north. At first, this resulted in higher lobster catches in both Maine and Canada. As ocean temperatures continue rising, Maine's annual catch is on the decline, while Canada's annual catch is on the rise.

Models are a tool that can help project future species distribution. Models can predict how factors such as water temperature will affect the species ability to grow and reproduce. Models are important in the seafood industry. The information they provide is used to set catch limits and plan strategies for long-term sustainability. Early models were simpler. They often relied on smaller data sets, such as the average surface temperature of the ocean for five years. Sometimes they focused on the effect of just a single factor, such as temperature. Today, advancements in data collection and computers have resulted in more complex scientific models.

FIGURE 5.2
Role of Data in Model Prediction



Scientific models are created by collecting and analyzing data for patterns and relationships. In this example, data on a species is combined with environmental data to construct a computer model. The model analyzes how likely the species is to be found under different environmental conditions to predict changes in species distribution.

Models Represent Systems

Scientists represent systems with different types of models to explain phenomena and make predictions. Models represent aspects of the natural world that are too small, too large, too complex, or too difficult to observe or explain directly. The factors, relationships, and processes of a system that are being represented in a model are known as the model's components.

At the University of Maine, Dr. Richard Wahle and his team are leading a project to determine how warming waters near the Arctic will affect lobster populations in the Northwest Atlantic. Their model predicts how ocean circulation and the coastal marine ecosystem of the Northwest Atlantic will change from now to the year 2050. Most importantly, the model predicts how these changes will likely affect lobster distribution and population. Components of Dr. Wahle's model include ocean currents, water temperature, and lobsters. The team is using existing datasets to validate their model.

When scientists build a model to show how a system works, they try to include only the most important parts of that system. Real-world systems are often very complex and have many factors that affect them. Think about a species' population—it is affected by food, disease, competition from other organisms, and many other things. Because it's impossible to include everything, scientists often choose to focus on one factor at a time or identify which factors have the biggest impact. Dr. Wahle's model is a good example. His model does not include every factor that could affect a lobster population. Instead, the main focus of his model is on how water temperature and ocean currents change lobster distribution. A good model should include the factors that have the greatest effect on the scientific question being studied. It can leave out factors that have only a very small effect. This idea—that the factors included in a model are those factors that have a greater impact on the system than others—is known as *orders of understanding.*

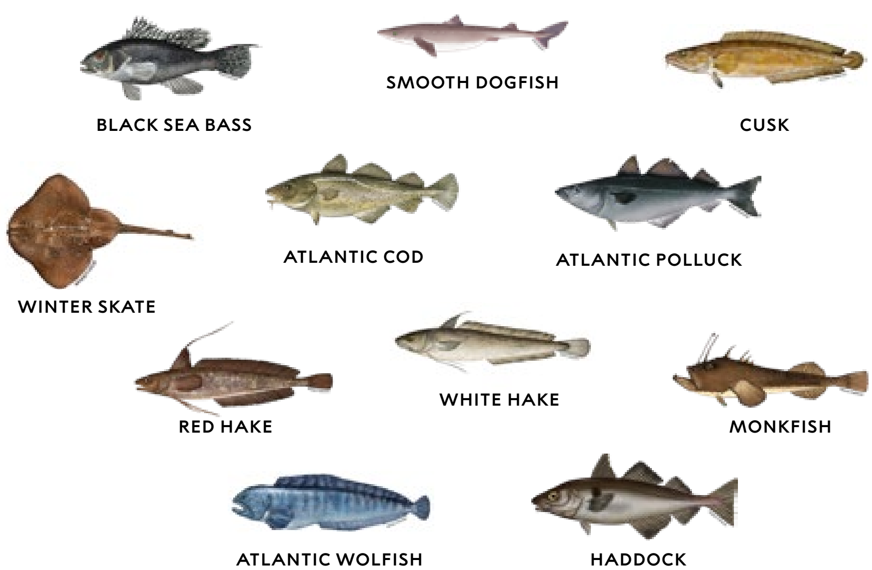
The American lobster is one of approximately 75 species of lobster.

Uncertainty in Predictive Models

Models let scientists learn more about a system by trying out different scenarios. Scientists can explore what might happen if you change certain factors. Models are especially helpful for investigating questions that cannot be tested directly or for making predictions about what may happen in the future. Scientists can use a model to predict what will happen under many different conditions. They can then test the model's predictions against information collected from the real world. This comparison helps scientists evaluate how well the model represents the real system and suggest ways to revise the model so it becomes even more accurate.

Dr. Kathy Mills of the Gulf of Maine Research Institute has been leading a team of researchers to investigate how a combination of changing environmental conditions and predator–prey interactions affect lobster distribution in the Gulf of Maine. Since 2023, the research team has created a model to investigate how ecosystem conditions, such as temperature and depth, and the presence of potential predators affect lobster distribution. In their model, the team included the top 12 species believed to consume juvenile lobsters. The research team plans to use this model to predict the future distribution of both lobsters and their potential predators under different climate change scenarios.

FIGURE 5.3
Fish species likely to prey on juvenile American lobsters



Predictive models are tools to forecast the future. They work because natural events often follow patterns. To calculate the probability of a future outcome, most predictive models use (1) historical data and (2) the current understanding of the relationships among the factors being studied. All predictive models contain a degree of uncertainty because they deal with the future. Sources of uncertainty include situations where the historical data is not predictive of future outcomes or when key relevant factors are unintentionally missing from the model. For example, Dr. Mills' model includes a factor that previous models did not: predator–prey relationships. Revising predictive models with new data, additional factors, or newly discovered relationships can improve their predictions.

Assumptions and Limitations

Models are built on assumptions. These assumptions may not always be correct or applicable in all situations. For example, Dr. Mills' model selected the 12 fish predators most likely to have an effect on lobster populations based on prior studies and research. Her model did not include all possible lobster predators. Recognizing a model's assumptions is essential for understanding how scientific models can be used and revised.

Scientific models have limitations because they are simplified versions of complex systems. As simplified representations, models can never include every single detail of the object or system they represent. For example, an ecological model cannot include every microbe and fungus, even if these organisms affect other species included in the model. Such limitations mean that models can only approximate reality. Their accuracy depends on the quality of the data and the models' designs.

Scientists from the Gulf of Maine Research Institute examine water quality samples in Casco Bay.

When models are used to make predictions, actual data collected from the environment can be compared with data provided by the model. This comparison enables scientists to evaluate how well the model imitates present environmental conditions. Models can be made more accurate through an iterative process that can involve:

- testing it by comparing it to real-world systems,
- refining it based on new data,
- adding or deleting factors, and
- modifying the relationships between factors.

Models and Decision-Making

As global changes continue to affect species distribution, models can play an important role in informing decision-making. For example, in 2018, scientists used advanced computer models to simulate a lobster ecosystem under varying conditions. This allowed scientists to understand the relative impacts of warming waters, conservation efforts, and other variables. The results of their models showed that while water temperature change was the primary contributor to population changes, conservation efforts made a key difference. Their models estimated that from 1984 to 2014, the lobster. population in the Gulf of Maine increased by 515% and declined in southern New England by 78%. One important difference between the two regions is that the fishing industry in the Gulf of Maine typically identifies, marks, and returns large egg-bearing female lobsters to the sea so they can continue to reproduce. The models estimated that even with changing ocean temperatures, using this strategy would have reduced population decline in southern New England from 78% to 57%.

Models can also inform decisions about strategies such as assisted migration, which is when humans deliberately move species from one location to another. In 2010, approximately 10,000 southern rock lobsters were moved hundreds of kilometers north from deep water to inshore sites of Australia. This experiment in assisted migration eventually resulted in improved lobster growth and egg production. How can experiments like this be used to understand species distribution? New scientific models may help provide answers to this question.

BUILD UNDERSTANDING

1. Dr. Wahle and his team are modeling how warming waters near the Arctic will affect lobster populations in the Northwest Atlantic. What are two sources of uncertainty in the model's predictions?

2. Look back at Figure 3.1: Gulf of Maine Food Web Model in Activity 3.
   a. What factor is missing from this food web model?
   b. What do you think is the effect of not having this factor in the model? Explain your reasoning.

3. Imagine that the "bottle biology" model shown in Figure 5.4 represents a pond ecosystem.
   a. Identify which parts of the real-world system are included and which parts are excluded from the model.
   b. Now imagine that the same model is intended to represent planet Earth. Identify which parts of the real-world system are included and which parts are excluded from the model.
   c. Which system—a pond ecosystem or planet Earth—is better represented by this bottle biology model? Explain your reasoning.

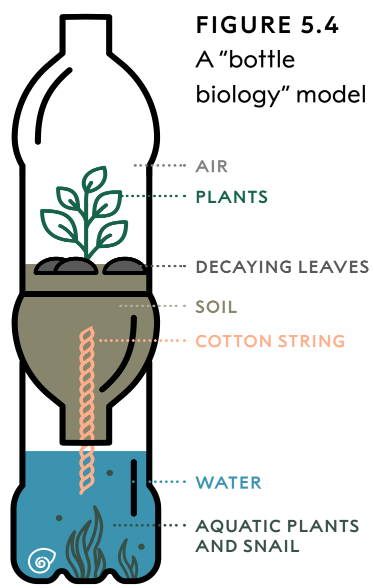


FIGURE 5.4
A "bottle biology" model

4. Climate conditions in the upper Midwestern United States have moved about over 300 kilometers (200 miles) north in 2 decades. The climate typical of southern Minnesota from 20 years ago is now in northern Minnesota. In 2016, the United States Forest Service conducted an experiment in assisted migration at Minnesota's Cutfoot Experimental Forest. They planted seedlings of 8 tree species from seeds collected up to several hundred kilometers farther south. There were 4 native species, while the other 4 species were not native. In 7 of the 8 species, the survival rate was 85%–90%. How would you construct a model to investigate the potential impacts of assisted migration for a species of tree?

   a. Describe your model in detail and the key factors that you would include.

   b. Choose one key factor. Predict what your model would show if you changed that factor and your model was accurate.

   c. Predict what your model might show if the model was inaccurate.

CONNECTIONS TO EVERYDAY LIFE

5. A major online clothing retailer wants to use a predictive model to decide how many of a new style of hoodie to order for the upcoming season. If they overpredict, they waste money; if they underpredict, they lose sales. What key factors would they need to input into their model to forecast demand, especially given how fast trends change?

6. Imagine your school district wants to use a predictive model to help improve student success. The model uses data to predict which current freshman students are most likely to not graduate on time four years later.

   a Identify three different types of data about a freshman student that the school might input into this predictive model.

   b If the model predicts that a specific student has a very high chance of not graduating, this is a prediction, not a certainty. Explain why the model's prediction contains uncertainty.

   c How could the prediction from this model create a useful feedback loop for school administrators to help improve the system and help the student succeed?

KEY SCIENTIFIC TERMS

assisted migration
components
predictive model

ACTIVITY 6

Modeling Migration

GAME

The population of bluefin tuna has changed dramatically in the last 100 years due to multiple factors.

6: MODELING MIGRATION

GUIDING QUESTION

How can models include uncertainty?

INTRODUCTION

As ocean temperatures change, migratory species are changing their routes in favor of cooler waters. For example, the Atlantic bluefin tuna have returned to cooler waters around the United Kingdom after having disappeared from the area decades ago. There are also signs that tuna are moving away from the western Pacific Ocean to the east. As bluefin tuna appear in new areas, they move into parts of the ocean governed by different countries. This is a concern because governments make decisions about how much fish can be caught in their waters.

Models can help build a better understanding about bluefin tuna populations and the factors that impact this species during its migration, which extends thousands of kilometers across the ocean. In this activity, you will model the migration of bluefin tuna by playing a board game.

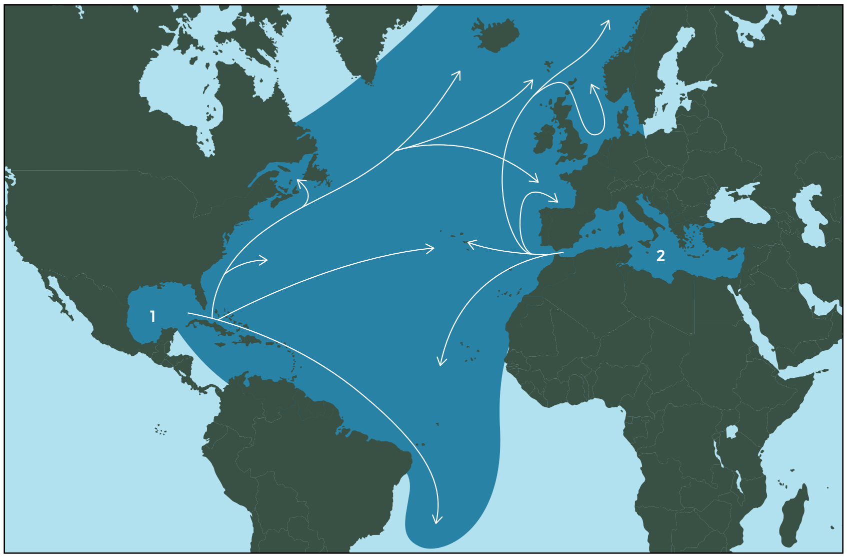
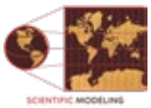


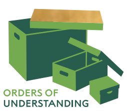
FIGURE 6.1
Map of Migratory Routes of Atlantic Bluefin Tuna

`Two different populations of Atlantic bluefin tuna are expanding their ranges into cooler waters and sharing feeding grounds.`

- ● Atlantic bluefin historic range
- 1 Main western spawning area
- 2 Main eastern spawning area

CONCEPTUAL TOOLS





MATERIALS LIST

FOR EACH GROUP OF FOUR STUDENTS

- BLUEFIN TUNA MIGRATION GAME BOARD
- NUMBER CUBE
- COIN
- 4 SMALL GAME PIECES (4 DIFFERENT COLORS)
- SET OF 20 EVENT CARDS

FOR EACH STUDENT

- STUDENT SHEET 6.1 "Bluefin Tuna Game Tracker"

PROCEDURE

1 Imagine scientists tracked a school of 500 bluefin tuna during their migration from their feeding grounds to their spawning grounds thousands of kilometers away. The population of the school of tuna is affected by environmental conditions and predators during the journey.

PART A: POPULATION GRAPH

2 Table 6.1 shows the rules that predict tuna population size as they migrate. In your science notebook, use the equations in the table to calculate the changing tuna population. (In this model, subtracting 0.05 of the previous week's population represents a 5% decrease in population, and adding 0.2 of the previous week's population represents a 20% increase in population.)

TABLE 6.1
Bluefin Tuna Population

TIME (WEEK)	CALCULATING POPULATION CHANGE	TUNA POPULATION
0 FEEDING GROUNDS	Week 0 population	500
1	(Week 0 population) – (0.05 x Week 0 population)	
2	(Week 1 population) – (0.05 x Week 1 population)	
3	(Week 2 population) – (0.05 x Week 2 population)	
4	(Week 3 population) – (0.05 x Week 3 population)	
5 SPAWNING GROUNDS	(Week 4 population) – (0.02 x Week 4 population)	

3 In your science notebook, create a line graph of the data and describe the trend in population size over time.

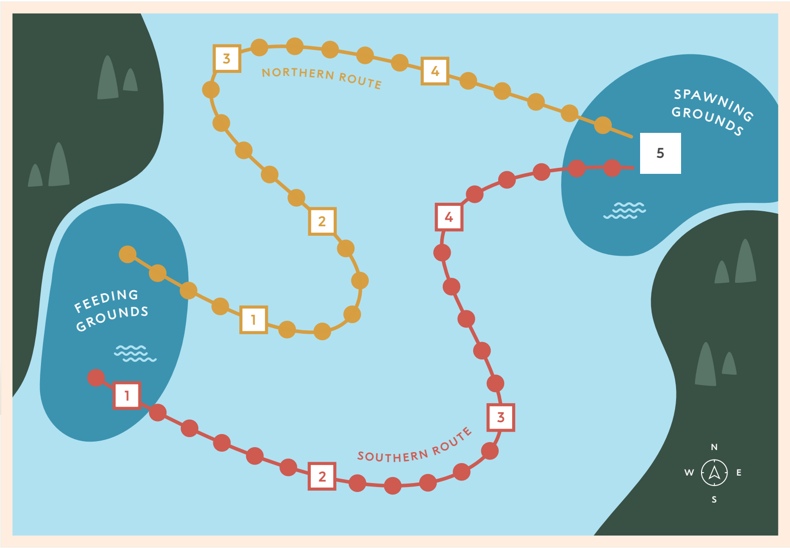
4 The graph is a model that can be used to predict future population size of the bluefin tuna. As a class, discuss what the model predicts and what could explain this pattern.

PART B: POPULATION GAME

5 You will model a population of a school of bluefin tuna on the same migration route and during the same time period as in Part A by playing a game. In this game, you will explore how different factors impact the tuna population. As a class, review the following game rules:

- Each game piece represents a school of bluefin tuna (starting with a population of 500 healthy adults).
- Each turn represents one week of migration.
- Each Event card represents something that happens during that week of migration.

FIGURE 6.2
Game Board



6 Set up the game by placing each player's game piece in the Feeding Grounds area. Divide the Event cards into five piles, according to the week.

7 Determine who starts the game by rolling the number cube. The player with the highest number starts first. Then take turns, moving in a clockwise direction.

8 Begin a turn by rolling the number cube and moving your game piece the number of places shown on the number cube. Start your migration by flipping a coin for either the northern route (heads) or the southern route (tails). Circle your migration route at the top of Student Sheet 6.1, "Bluefin Tuna Game Tracker."

9 When you land on or pass through an event space, draw an Event card from the pile for that week.

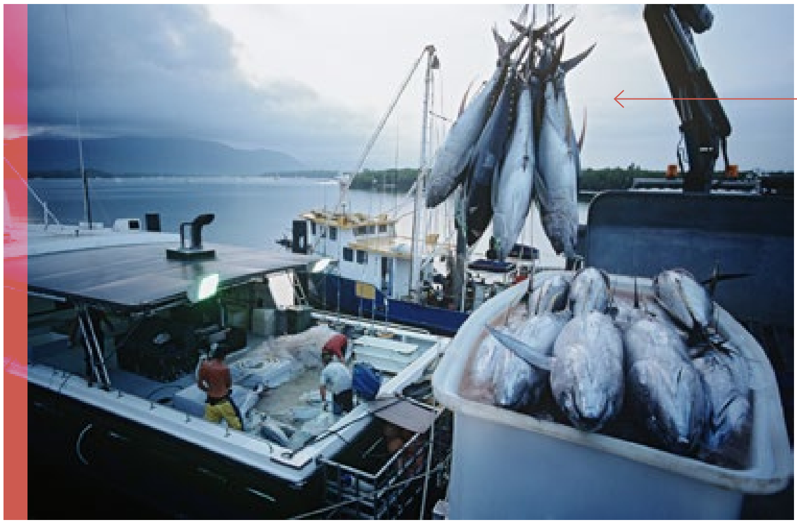
a Read the Event card aloud to your group and follow the instructions on the card.

b You will begin with an initial population of 500 fish in Week 0. Record and calculate the data for each following week on the student sheet. Be sure to record your data, even if there was no change in population.

c Replace the Event card at the bottom of the deck for that week.

10 Continue to play until you reach the Spawning Grounds. (A player needs only a minimum roll, not an exact roll, to enter the Spawning Grounds.) Then,

- draw a Spawning Grounds card and complete the instructions on the card. Record the final population of your school on the student sheet.
- observe the progress of the other players as they move toward the Spawning Grounds.



All three species of bluefin tuna—Atlantic, Pacific, and Southern—are commercially fished. A fully mature bluefin tuna averages about 225 kilograms (500 pounds) and 2–2.5 meters (6–8 feet).

11 In your group, compare the final populations for the four schools of tuna. Discuss what factors determined which school had the most successful and least successful migrations based on population size. Identify the one factor that had the greatest impact and two to three factors that had the least impacts.

12 You will help create a graph of all the class data. On the class chart, record your tuna population for each week (from Student Sheet 6.1).

13 Use your class data to construct a model.

a On the graph of class data, draw a line connecting the highest data points. Then do the same for the lowest data points. This shows the range of the tuna population during migration.

b Copy the class graph onto the graph from Part A that you created in your science notebook. (Use dotted or dashed lines so you can easily tell them apart from the line you drew in Part A.) This graph is a model that can be used to predict the future population size of the bluefin tuna. It shows a range of possible outcomes for the tuna, given the variety of possible events.

PART C: COMPARING MODELS

14 Discuss with your group what each model from Part A and Part B predicts about the future of the tuna population size over time. Under each model, describe this prediction in one sentence.

15 Read the following two definitions. With your group, decide what kind of population model—deterministic or probabilistic—was represented by each model (the one in Part A and the one in Part B).

A deterministic model is a tool that produces a single predictable outcome for a given set of initial conditions.

A probabilistic model is a tool that uses patterns in data to predict the likelihood of different outcomes. It produces a range of possible outcomes for a given set of conditions.

16 Using the two models, predict what you think will happen to the population and range of the bluefin tuna during future migrations if:

a nothing changes.
b fishing limits are introduced.
c environmental change continues to warm ocean waters.

BUILD UNDERSTANDING

1. Which type of model, deterministic or probabilistic, would be most useful for predicting the following phenomena? Explain your reasoning for each example.
    - a The future population of bluefin tuna.
    - b The height of a bouncing ball as it loses energy.
    - c The weather for next week.
    - d The change in range of a species.

2. In the game, what factors are a part of the highest and lowest orders of understanding of the tuna population? Rate the factors included in the game model according to orders of understanding. Explain your reasoning.

3. In this activity, the game was a model of bluefin tuna migration. Consider ways in which the model did or did not represent the real-world system. Describe one change you would make to improve the model, why you would make it, and how it would likely affect the population in this model.

4. Imagine that you live in a coastal town where the economy depends on the fishing industry. The local fish population has declined, and the remaining population has moved farther out to sea where fishing is more expensive and dangerous. A community group has proposed a law to protect the local fish population by severely limiting the number of fish that can be caught locally. Would you support the law? Support your answer with evidence from this activity and identify the trade-offs of your decision.

A coastal fishing town.

CONNECTIONS TO EVERYDAY LIFE

(5) Imagine you visit an ice-cream shop regularly, and you would like to know how many people will be in line when you arrive. Over 20 visits, you observed the following information, shown in Table 6.2.

a What is the most likely line length in the shop? Explain your reasoning.

b If you made a model from this data, would it show a deterministic system or a probabilistic system? Explain your reasoning.

(6) Ride-sharing apps and websites that sell tickets to concerts or shows often use an on-demand pricing model. In this model, the price is determined by the number of people who want the service or the tickets. More demand results in a higher price. Do you think on-demand pricing is a deterministic model or a probabilistic model? Explain your reasoning.

TABLE 6.2
Lines at Local Ice-Cream Shop

LINE LENGTH (NUMBER OF PEOPLE)	FREQUENCY OF THIS LINE LENGTH
0	1
1	4
2	8
3	5
4	2

KEY SCIENTIFIC TERMS

deterministic model
probabilistic model

ACTIVITY 7

Fermi Estimations

DATA ANALYSIS

Estimation is a useful skill when determining tree populations.

7: FERMI ESTIMATIONS

GUIDING QUESTION

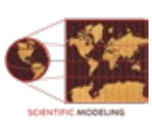
How can you use mathematical modeling to make an estimate?

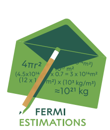
INTRODUCTION

Counting all the individuals in a population is the most accurate way to determine its size. Since counting every fish or bird is usually impossible, scientists can use a model to estimate populations. Estimating involves making general approximations of size, value, or quantity and are often made to the nearest powers of 10. For example, when deciding whether to join a line at an event, you might estimate whether there are 10 or 100 people ahead of you. While the actual number of people might be 14 or 86, you don't need to know the exact number to decide. In science, the powers of 10 are 10 multiplied by itself a number of times, which is often indicated in scientific notation as $10 = 10^1$, $100 = 10^2$, $1{,}000 = 10^3$, and so on, to refer to approximations of size, value, or quantity. Even very rough estimates in the correct powers of 10 can be helpful.

When estimating large numbers, the goal is to make a reasonable estimate. One mathematical modeling approach is known as a Fermi estimate, a method of calculating an approximate value of a difficult-to-know quantity. Named after physicist Enrico Fermi, a Fermi estimate is useful when a more precise answer is not yet known, is too time-consuming, or is too expensive to work out. New tools can help researchers make these estimates on a much larger scale, such as the total number of fish in the entire ocean. One advantage of this type of estimate is that it can help people understand the scale and complexity of a system.

CONCEPTUAL TOOLS





MATERIALS LIST

FOR EACH STUDENT

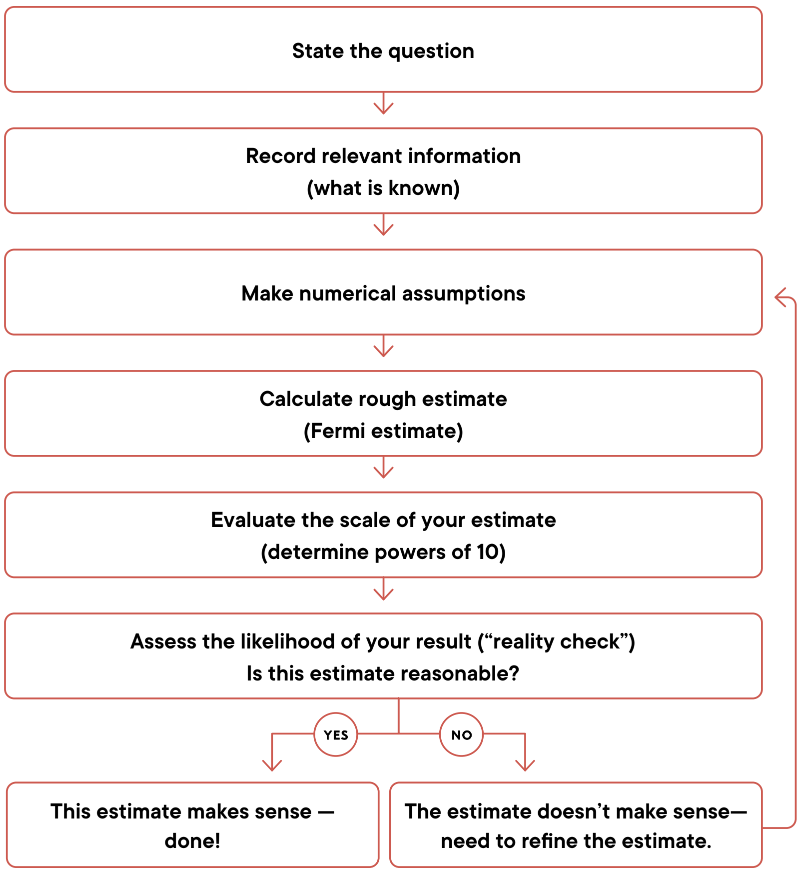
- CALCULATOR
- 2 COPIES OF STUDENT SHEET 7.1 “Making a Fermi Estimate”

PROCEDURE

PART A: HOW TO MAKE A FERMI ESTIMATE

1 Examine the flowchart in Figure 7.1, which provides a simplified set of steps for making a Fermi estimate.

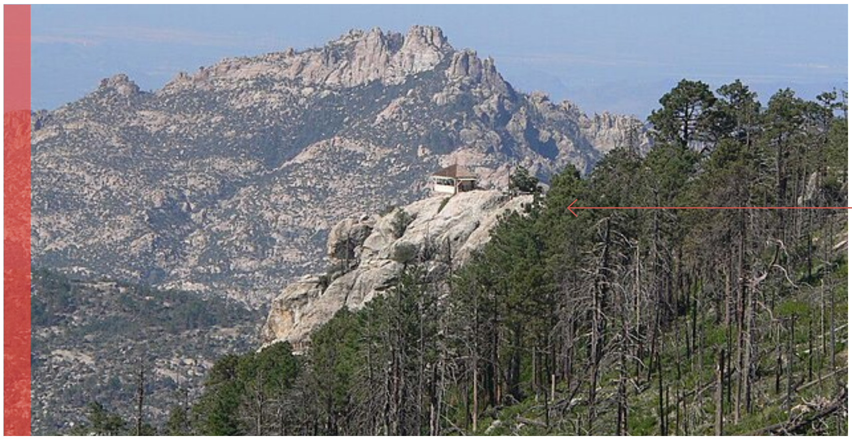
FIGURE 7.1
A Flowchart for Making a Fermi Estimate



2 As a class, you will use the flowchart in Figure 7.1 to help you complete a Fermi estimate. First, read about the following event:

> With global environmental changes, wildfires are becoming increasingly more common in all parts of the world. In 2020, the Bighorn Fire burned 500 square kilometers—about 200 square miles—in the Santa Catalina Mountains northeast of Tucson, Arizona. Imagine that the local community would like to replant some of the lost trees. They need to first estimate how many trees were lost in the fire.

NOTE: A square mile is equivalent to approximately 500 football fields used in American football. A square kilometer is equivalent to 140 standard football pitches (fields) used in soccer.



A fire lookout in the Santa Catalina Mountains, northeast of Tucson, Arizona in the United States.

3 At the top of Student Sheet 7.1, "Making a Fermi Estimate," record what you are making a Fermi estimate for *(the number of trees lost in the Bighorn Fire)*. Then record the question being investigated *(How many trees were likely lost in the Bighorn Fire?)* in the first box of the flowchart.

4 Before you make any calculations, make an initial guess for the nearest powers of 10 (tens, hundreds, thousands, millions, billions) for the number of trees lost in the Bighorn Fire. Circle your guess at the top of Student Sheet 7.1.

5 As a class, work together and continue to use the flowchart in Figure 7.1 as a reference to make a Fermi estimate of roughly how many trees were likely lost in the Bighorn Fire.

6 Be prepared to discuss the following:

- How your Fermi estimate compares to your original estimate.
- The likelihood of the final estimate to the nearest powers of 10.
- The limitations of the assumptions you made in your Fermi estimate and the effect on the relative accuracy of the estimate.
- What decisions might be influenced by this estimate.

PART B: MAKING YOUR OWN FERMI ESTIMATE

7 You and a partner will make a Fermi estimate for the population of one common species, the house sparrow, in your area. Read the following information:

> Beginning in the mid–1800s, house sparrows were intentionally released in the United States, Australia, and New Zealand, often by groups that wanted to introduce familiar birds to their new homes. This bird is now found in most parts of the world. It is a nonmigratory species, meaning it stays within a range of about 8 kilometers (5 miles).

8 Before making your Fermi estimate, record what you are making a Fermi estimate for on your second copy of Student Sheet 7.1. Then, guess, to the nearest powers of 10 (tens, hundreds, thousands, millions, billions), the number of house sparrows in your area. Record your guess on the student sheet.

9 Work with your partner to make a Fermi estimate of the population size of house sparrows in your community. (If there are no house sparrows in your community, your teacher will help you choose a local species.) Record the question you will use to begin your Fermi estimate. Discuss with your partner what you know or have observed about house sparrows in your area and record this information on the student sheet.

10 Read and record the following information. (If you live in another part of the world, your teacher will provide you with alternative data.)

- Cornell University's Lab of Ornithology estimates that the population of house sparrows in the United States is about 82 million.
- The area of the continental United States is approximately 7.8 million square kilometers (3 million square miles).

11 Think of and record at least two assumptions you can make about house sparrows in your area. Consider what you might know or have observed about a house sparrows' habitat, distribution, likely range, and so on.

12 Calculate your Fermi estimate by using your information and assumptions to estimate the number of house sparrows in your area to the nearest powers of 10. Record your calculations on the student sheet.

13 Compare your Fermi estimate to your initial guess by discussing the following questions with your partner:

- Was your initial guess at the same powers of 10 (tens, hundreds, thousands, millions, billions) as your Fermi estimate?
- What additional information would you need to determine a more precise estimate of house sparrows in your area?

14 Compare your Fermi estimate with others in your class. Discuss:

- the similarity or difference in the powers of 10 of your estimates.
- how you made your calculations.
- assumptions you made.

BUILD UNDERSTANDING

1. Explain whether or not it is reasonable to make a Fermi estimate in each of the following situations.
   - a the total number of squirrels in the United States
   - b the possible side effects of a new medication
   - c how much money it would take to empty all the trash cans in national parks
   - d the geographic range of a species

2. The National Audubon Society, a nonprofit birding organization, estimates that the population of house sparrows is approximately 740 million.
   - a Compare this population estimate with your Fermi estimate. How might this information affect your Fermi estimate? Include the powers of 10 in your response.
   - b Upon closer reading, you notice that the National Audubon Society estimate is based on the global population of house sparrows. How would this affect your understanding of your estimate?

3. After the Bighorn Fire, the U.S. Forest Service planted 43,000 ponderosa pine trees to help restore the ecosystem. Based on your Fermi estimate from Part A, should they plant more trees? Support your answer with evidence (including the powers of 10) and identify the trade-offs of your decision.

Planting trees is one approach to restoring ecosystems.

CONNECTIONS TO EVERYDAY LIFE

4. Guess the number of hours you spend on your phone in a year. Then take a few minutes to make a calculated Fermi estimate and show your work.
   - a How close was your initial guess to your Fermi estimate?
   - b What assumptions did you make?
5. Think about a situation in your everyday life when you use estimation. What happens when your estimate is incorrect by the powers of 10?

EXTENSION

In this activity, your first Fermi estimate was of the number of trees burned in a fire. Look online to further investigate ways to estimate the number of trees on an area of land. You may find many different ways in which people make this calculation. What assumptions do you think are being made? How could you refine these assumptions to improve the accuracy of the estimate? Discuss your findings with your class.

KEY SCIENTIFIC TERMS

Fermi estimate
powers of 10

ACTIVITY 8

Modeling a Method

INVESTIGATION

Estimating the population size of the Azores bullfinches was key to its conservation.

8: MODELING A METHOD

GUIDING QUESTION

How can you revise a model for estimating population size?

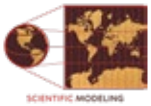
INTRODUCTION

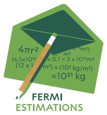
The Azores bullfinch, a small bird found in a limited range in the Azores archipelago, an autonomous region of Portugal in the mid-Atlantic Ocean, lives in high-altitude forests and shrubland. In 2000, it was declared endangered. By 2016, its population had increased significantly, and it is now classified as "vulnerable," which is a lower risk of extinction. Successful conservation efforts have included monitoring the size of the population through mark and recapture—a method of estimating population size by catching as many organisms as possible during a certain period, marking and releasing them, then returning at another time to repeat the process, and this time recording how many newly captured organisms were marked as having been captured before.

Mark and recapture is one common method scientists use to estimate population size. Counting all individuals in a population is the most accurate way to determine its size. Since this is often not possible, scientists usually estimate the total population based on a smaller measured number. In this activity, you will model the method of mark and recapture for estimating populations.

Mark and recapture is used to estimate the population of different aquatic species. It is used in both closed systems (such as lakes and ponds) and open systems (such as rivers and oceans).

CONCEPTUAL TOOLS





MATERIALS LIST

FOR EACH PAIR OF STUDENTS

- BAG OF PLASTIC DISKS
- TIMER
- MASKING TAPE
- CALCULATOR

FOR EACH STUDENT

- STUDENT SHEET 8.1 "Mark and Recapture"

PROCEDURE

1. With your partner, obtain a bag of disks, a timer, and some masking tape. You will model the method of mark and recapture for estimating the size of a population. In this model, the bag represents a forest, and each disk in the bag represents a bird in the forest.
2. Have one person "capture birds" by reaching into the bag and taking out a disk—one at a time—while the other person times that person for 15 seconds. In the box for Day 1 on Student Sheet 8.1, "Mark and Recapture," record the number of birds caught.
3. Mark each bird with a small piece of masking tape and return it to the forest by returning the marked disks to the bag.
4. Shake the bag for 20 seconds to simulate the passage of time. This allows the marked birds to mix back in with the rest of the population.
5. Switch roles and "capture birds" for Day 2. Have one person reach into the bag and take out a disk—one at a time—while the other person times them for 15 seconds. Count and record both the total number of birds and the number of marked birds you caught on Day 2 in the boxes for Day 2 on the student sheet.

6 Use the proportion of marked birds you caught on Day 2 to estimate the total size of the bird population, as shown in the following equation. Calculate and record your population estimate on the student sheet.

$$\text{estimated population size} = \frac{\left(\text{Number of birds caught on Day 1}\right) \times \left(\text{Number of birds caught on Day 2}\right)}{\text{Number of marked birds caught on Day 2}}$$

7 Your teacher will tell you the total number of disks in the bag. Compare your estimate to that number.

8 The bag and disks are a physical model of how the method of mark and recapture works in the real world. As a group, discuss the following aspects of the model.

HINT: Think about how the model does or does not represent the real-world system.

- What assumptions were made about how well this physical model represented the real-world method of mark and recapture? (How might the model not represent the method of mark and recapture correctly?)
- What were the limitations of the model? (What could it not explain or predict?)

Counting the total number of individuals in a population of birds in flight is difficult.

9 Based on your discussion from Step 8, revise your model by modifying the procedure. Record your planned changes to the model and an explanation for the changes on the student sheet.

10 Test your revised model by repeating the procedure with your changes. Calculate and record your population estimate from the revised model on the student sheet.

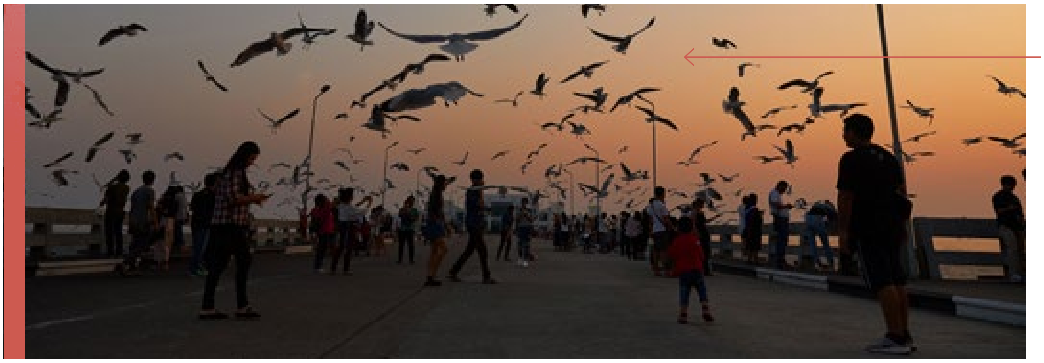
11 Evaluate changes to the model by comparing your first population estimate with your second. With your partner, discuss which estimate you think is more accurate and why.

12 Share the changes you made to your model and your population estimates with the class. Compare the range of population estimates and discuss which changes to the model resulted in more accurate estimates.

BUILD UNDERSTANDING

1. In this activity, you modeled the method of mark and recapture for estimating populations.
   - a What are two assumptions of the model of mark and recapture?
   - b Select one assumption and explain how it would affect the population estimate if the assumption was false.

2. Imagine a city uses a model to predict the number of seagulls on the main public beach to better plan for trash management. The model included 2 factors: the number of tourists and the time of year. The model predicted an average of 200 seagulls per day in July. Local researchers then used data from the method of mark and recapture from 3 days in July to estimate that the average number of seagulls per day in July was 350 seagulls.
   - a Why are the two estimates different, and which is likely to be more accurate? Explain your reasoning.
   - b Describe two specific ways the city could revise their model to improve its accuracy by adding specific real-world factors that were initially left out.



Seagulls find many sources of food near shoreline piers.

③ Imagine you are studying a forest ecosystem in which a nonnative bird species has recently been seen. Which estimation method would be most useful in addressing each of the following scientific questions? Explain your reasoning.

Question A: What is the population size of this newly introduced bird species?

Question B: You observe that the nonnative bird species nests only in mature oak trees. How many mature oak trees are there in this area?

CONNECTIONS TO EVERYDAY LIFE

④ Imagine you built a simple model on your phone to help you get to school on time. Your model predicts the exact time you need to leave your home to arrive at school on time. In your model, you include the time you woke up and the total time it took you to get to school yesterday. After the first week, you realize that you are still arriving at school after the bell rings. Suggest two specific ways you could revise your model to make it more accurate.

KEY SCIENTIFIC TERM

mark and recapture

ACTIVITY 9

Constructing Predictive Models

PRESENTATION

Historical data, such as where coyotes have been observed over time, inform predictive models.

9: CONSTRUCTING PREDICTIVE MODELS

GUIDING QUESTION

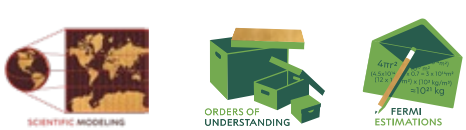
How can a model be used to predict changes to the distribution of a population?

INTRODUCTION

A weather forecast relies on models that incorporate how different factors—including temperature, precipitation, and wind—interact and then predict, or forecast, what conditions will look like hours or days in the future. Accurate forecasting is helpful in all kinds of decision-making. With changing global conditions, ecologists are increasingly using models, based on large datasets of observations, to predict future changes in ecosystems. Known as *ecological forecasting*, this is a growing field that requires skills in data analysis, ecological modeling, quantitative reasoning, and computing. In this activity, you will begin to explore aspects of this process.

People often check weather forecasts before participating in outdoor activities.

CONCEPTUAL TOOLS



MATERIALS LIST

FOR EACH STUDENT

— STUDENT SHEET 9.1 "Developing Model Components"

— STUDENT SHEET 9.2 "Developing Fermi Estimates"

PROCEDURE

1 In this activity you will begin to develop a model to explore the future distribution of a species in your community. Work with your partner to choose a species (excluding humans) that you observed on your field trip or that is common in your community and record it at the top of Student Sheet 9.1, "Developing Model Components."

2 Work with your partner to develop a scientific question that you have about the species and its future distribution in your community. Record your question on Student Sheet 9.1.

HINT: You may want to consider the possible effects of a single likely change in your community on your species (such as an increase in human structures or a changing climate pattern).

3 Work with your partner and use your knowledge and observations of your community to brainstorm a list of five factors that could most affect the distribution of your local species in the future. Record those factors in the first column of the table on the student sheet. Consider how these factors are likely to change over time. For example, traffic may be a factor that affects the population size of some species, and traffic may be predicted to continue to increase.

4 Decide which factors to include in your model by completing the following columns of the table on the student sheet.

Column 2: For each factor you listed in the first column, describe its present and likely future effects on the population distribution of the local species and if that effect is likely to change over time.

Column 3: Based on your scientific question, identify the orders of understanding. Rate the factors affecting the population in the model with 1 having the greatest impact and 3 having the least impact.

NOTE: You may choose to use the same rating for factors that appear to have similar impacts (for example, labeling two factors as 3) or not use some rating numbers.

Column 4: Decide which three factors you will incorporate in your model and mark them with an "X" or a check mark.

5 You will use the following model (Figure 9.1), which you first saw in Activity 2, to help you construct your model. Begin by discussing with your partner what you can conclude from this model. Note that arrows show relationships between related factors: a "+" indicates a positive effect or an increase, and a "–" indicates a negative effect or a decrease.

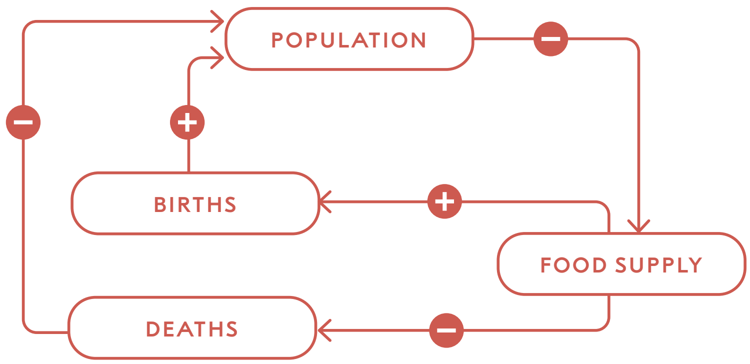


FIGURE 9.1
Sample Model

6 On the reverse side of Student Sheet 9.1, construct a model that reflects your scientific question by:

- centering the main factor you are investigating (for example, population size)
- adding the three factors that you identified that you will incorporate in your model.
- drawing arrows to show relationships between related factors.
- adding + or — signs along each arrow to indicate predicted changes in your species.
- writing at least three sentences describing the relationships shown in your model.

7 Explain your model to the other half of your group. Respond to any questions, comments, or suggestions they have and modify your model as needed.

8 On Student Sheet 9.2, "Developing Fermi Estimates," work with your partner to make two Fermi estimates of the population size of the local species—one in the present and the other 50 years in the future. Be sure to identify any assumptions that you are making and show your calculations.

- Based on your food web model from Activity 3, make a Fermi estimate of the population size of this species **today**.
- Consider how each factor in your model would likely be affected under future conditions.
- Make a Fermi estimate of the population size of this species **50 years in the future**.

9 Discuss the following questions with your group:

- What data would you want to collect to test your model?
- If the data did not support your model, how would you revise it?
- How could this type of data help make your Fermi estimates more accurate?

10 Present your model to the class and explain how you can use your model to make a prediction of the future population size of your species. Discuss any similarities and/or differences you notice among the models presented by others who chose the same species.

BUILD UNDERSTANDING

1 A local group wants to use your model to help determine land use, such as the location of housing vs. open space.

a What would you tell them about sources of uncertainty in your model?

b How could you test your model to evaluate its accuracy?

2 Imagine that a new species is accidentally introduced into your community. It can successfully outcompete your local species in wooded areas but not in other spaces. Explain how you would modify your model (in words or in a drawing) to account for this new species.

A model can be used to determine the probability of everyday events.

CONNECTIONS TO EVERYDAY LIFE

3. A high school soccer coach wants to create a simple predictive model to guess the probability of winning the next game.

   Model 1: This model uses the team's number of game wins over the last five seasons.

   Model 2: This model uses the number of goals scored per game, plus three other factors: the number of rained-out games, the number of games played on the weekend, and the number of injuries in the previous season.

   Which model would you use and why?

EXTENSION

On the Internet, you can find student-friendly computer programs to model complex systems that explore cause-and-effect relationships and test ideas. Find one of these tools to construct your population model and explore how the factors in your model interact.

ACTIVITY 10

Applying Models to Decisions

CARD-BASED INVESTIGATION

Models can represent different scales of systems.

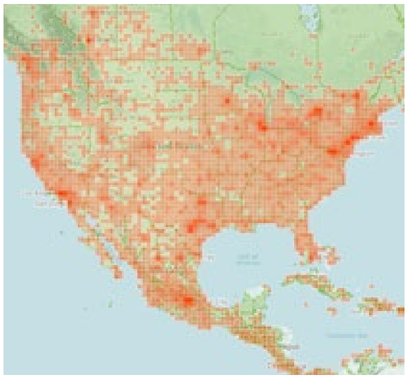
10: APPLYING MODELS TO DECISIONS

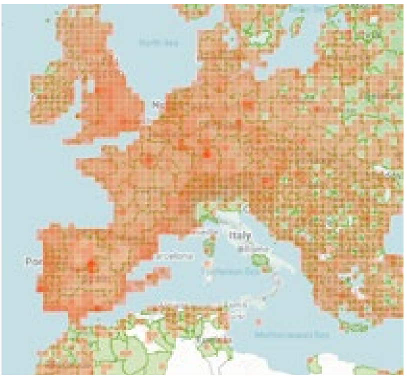
GUIDING QUESTION

What role can models play in making a conservation decision?

INTRODUCTION

In 2008, biologist Ken-ichi Ueda turned his graduate project into a website called *iNaturalist* where people could post pictures to identify species. Today, *iNaturalist* is an app with over 7 million users who have recorded over 150 million observations of 430,000 species. In the fall of 2020, large numbers of migratory birds, such as geese and sparrows, were found dead in people's backyards in parts of the United States. *iNaturalist* set up a project to gather more data. Researchers compared the community-provided data to datasets about wildfire, air quality, extreme weather, and land cover. They found a strong correlation between the dead birds and wildfires. Scientists are now working to better understand how wildfires affect birds by developing models of how wildfire smoke moves over landscapes and how the resulting smoke affects birds. People use models to explain, predict, and inform. In this activity, you will apply your knowledge of models to understand the role that models play in decision-making.





The house sparrow is native to most of Europe, Asia, and North Africa. These images show reported observations on the *iNaturalist* app of house sparrows in the United States (left) and in parts of Europe (right).

CONCEPTUAL TOOLS

MATERIALS LIST

FOR EACH GROUP OF FOUR STUDENTS

- SET OF 4 MENANDA SITE CARDS

FOR EACH STUDENT

- STUDENT SHEET 10.1 "Evaluating Sites"
- STUDENT SHEET 10.2 "My Site Model"
- STUDENT SHEET 10.3 "Estimating Factor Impact on Population in 50 Years"

PROCEDURE

PART A: SETTING UP YOUR MODEL

1 Read the following fictional scenario.

The county of Menanda continues to be concerned about its shrinking frog population. The successful effort to daylight a creek, which now connects two marshes, has improved the frog habitat and appears to be having a positive effect on the frog population. But some residents are still worried about the mosquito population, which may carry infectious diseases. They would like to do more to address this issue.

Scientists studying the Menanda frogs have identified 5 factors that appear to have the greatest impact on local frog populations: food availability, predation, yearly rainfall, average annual temperature, and traffic. Moderate to high rainfall can boost populations by providing breeding sites and mating, while extreme rainfall or drought can cause declines. Warmer temperatures can increase the potential range of populations, while increased average temperatures can disrupt reproduction and survival. Traffic negatively affects frog populations through death from cars, barriers to movement, and indirect effects such as stress from noise.

Currently, frogs can be found in 25 sites around the community, and the county has, at present, set aside funds to protect and improve the frog habitat at 1 site. Community residents at 4 sites have requested funding. You will role-play scientists investigating the frog population at each of the 4 sites.

2 Your group will receive a set of 4 Menanda Site cards. Each group member will read and analyze one card.

3 Use the information on the Menanda Site card to rate the factors affecting the frog population at your site by considering orders of understanding, with 1 having the greatest impact and 3 having the least impact.

NOTE: You may choose to use the same rating for factors that appear to have similar impacts (for example, labeling two factors as 3) or not use some rating numbers.

4 On Student Sheet 10.1, "Evaluating Sites," record the orders of understanding for the factors at your site in the appropriate column in Table 1: Orders of Understanding for Each Site.

5 Share the orders of understanding for the factors at your site with your group and use the group information to complete Table 1. Remember to listen to and discuss the ideas of other group members. If you disagree with other group members, explain why you disagree.

6 In Table 1 on the student sheet, circle your site number and the two factors that have the greatest impact on your frog population. (You will complete Table 2 in Part B.)

7 On Student Sheet 10.2, "My Model Site," construct a model (like the one shown in Figure 10.1) to explore the future of the frog population at your site. Arrows show relationships between related factors: a "+" indicates a positive effect or an increase, and a "—" indicates a negative effect or a decrease.

- Center the factor (population size) you are investigating.
- Add the two factors that you identified in Procedure Step 6.
- Draw arrows to show relationships between related factors.
- Add + or — signs along each arrow to indicate predicted changes in your species.
- Write 2–3 sentences describing the relationships shown in your model.

You will complete Student Sheet 10.2 for Build Understanding item 1.

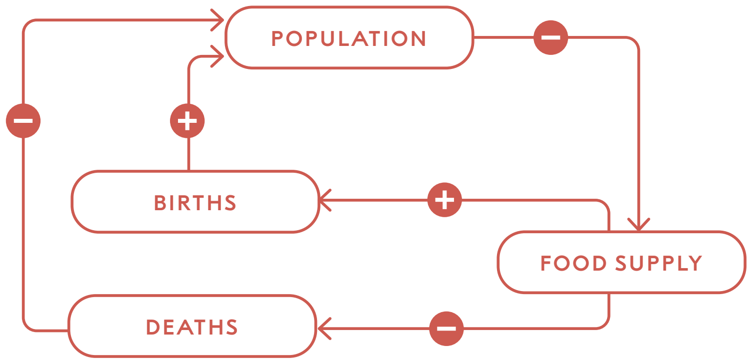


FIGURE 10.1
Example of a Population Model

8 Explain your model to the rest of your group. Respond to any questions, comments, or suggestions they have and modify your model as needed.

PART B: ESTIMATING FUTURE POPULATIONS

9 Examine Figure 10.2, which provides the current estimated frog population at each site. Go back to Student Sheet 10.1 and record this information in the first column of Table 2: Present and Future Frog Populations for Each Site.

10 When there is limited data on a particular species, scientists sometimes use models based on data from similar species. The frog population of a nearby species has doubled every 25 years. Use this information to predict the future frog population for each site and record it in the second column of Table 2 on Student Sheet 10.1. Discuss with your partner the assumptions that you are making, how they affect your predictions, and how reasonable you think your predictions are.

11 Discuss with your partner how each factor in your model would likely be affected by future conditions and, in turn, affect the future size of the Menanda frog population.

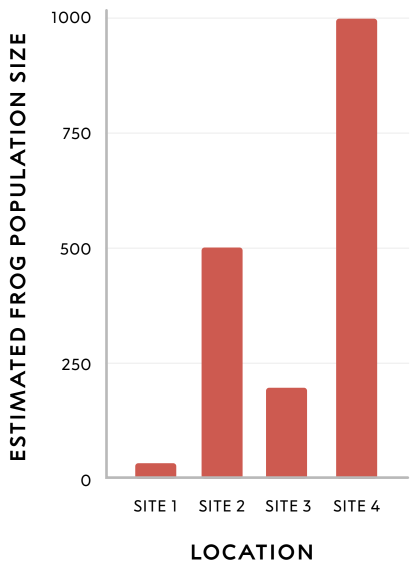
12 On Student Sheet 10.3, "Estimating Factor Impact on Population in 50 Years," make a Fermi estimate of the **impact of the factors** at your site on the size of the frog population **50 years in the future**. Circle your site number at the top of the student sheet. Be sure to identify any assumptions that you make and show your calculations. Record your population prediction in the last column of Table 2 on Student Sheet 10.1.

13 Share your model, prediction, and Fermi estimate with your group. As other group members share, record population data for the other sites in Table 2 on Student Sheet 10.1. Discuss:

- the factors you took into account.
- how those factors may change over time.
- sources of uncertainty in your prediction.

Respond to any questions, comments, or suggestions, and modify your estimate as needed.

FIGURE 10.2
Current Estimated Frog Population at Each Menanda Site



PART C: MAKING A DECISION

14 Consider the factors, models, estimated population, and predicted population for each site. Use this information to decide which site you would recommend funding to protect and improve frog habitats.

15 Share your recommendation with your group. Work with your group to:

- describe other future events that might cause you to change your decision.
- brainstorm additional information you would like to have to support your decision-making.

16 Share your recommendation and the evidence supporting your decision with the class.

BUILD UNDERSTANDING

1 In Procedure Step 7, you constructed a model and described it. Complete Student Sheet 10.2 by:

a identifying the two most high-impact factors affecting the population at this site.

b explaining what your model predicts about the effect of the two factors on the frog population at your site.

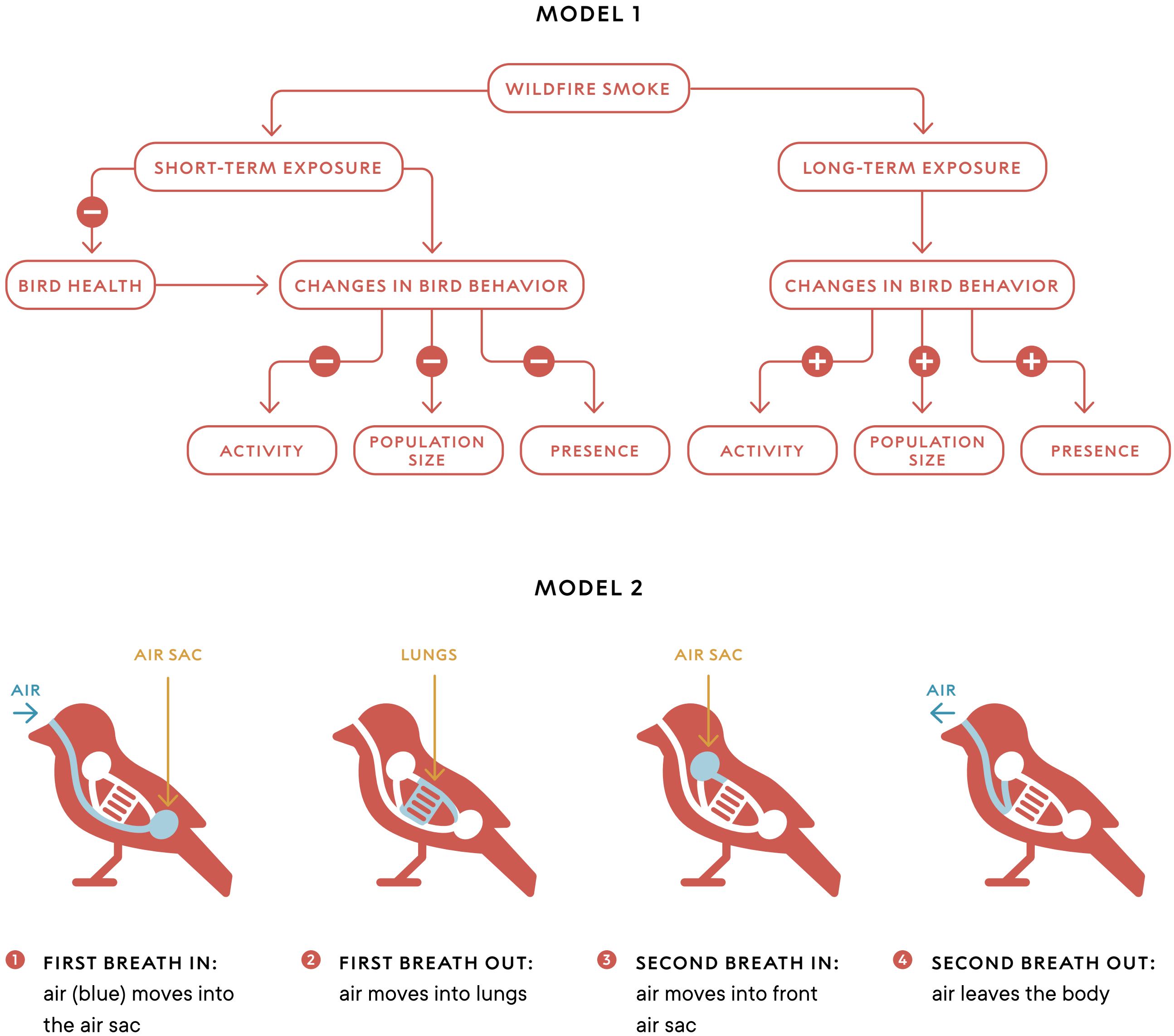
c describing at least one source of uncertainty in your model.

2 Which site do you recommend for funding to protect and improve Menanda frog habitats? Support your answer with evidence from the activity and identify the trade-offs of your decision.

3 A researcher creates a model to predict the local deer population over the next 5 years. At the end of the first year, the model's prediction for the population size was 40 deer, but the actual count was 25. Should the researcher revise the model? Explain what you think the researcher should do and why.

4 In the Introduction, you learned that scientists are constructing models to explore the effects of wildfire smoke on house sparrows. Explain how each of the two models in Figure 10.3 might be used to begin to investigate this question.

FIGURE 10.3
Two House Sparrow Models: Wildfire Effects (Model 1) and Respiration (Model 2)



CONNECTIONS TO EVERYDAY LIFE

5. This activity explored *population dynamics*—the study of how and why the size, structure, and distribution of a population change over time. Consider the ways in which people rely on and interact with different populations of organisms such as for food, recreation, conservation, and so on.

   a. Create a question about population dynamics that investigates a relationship between humans and an organism's population.

   b. List the factors that would be most relevant to creating a model to investigate this question.

STUDENT GLOSSARY

accuracy
the closeness of a measured value to a standard or true value

assisted migration
when humans deliberately move species from one location to another

assumption
a statement or condition that is accepted as true to make the model work; because of the complexity of real-world systems, they are necessary simplifications that allow a model to run and make predictions

components
factors, relationships, and processes of a system that are being represented in a model

computer model
a model that uses computers to simulate real-world conditions

conceptual model
a model that outlines relationships among different parts of a system, such as a food web

data
information gathered from an experiment or observations

daylighting
uncovering a stream that was previously buried underground in drains and pipes and restoring its natural, above-ground flow

deterministic model
a tool that produces a single predictable outcome for a given set of initial conditions

ecological forecasting
models based on large datasets of observations used to predict future changes in ecosystems

ecosystem
the living and nonliving parts of a physical environment that interact with each other in a specific area

factor
something that actively contributes to the production of a result. In scientific modeling, a factor is a variable that has an effect on another variable within the model

Fermi estimate
a method of calculating an approximate value of a difficult-to-know quantity

food web
a model of the feeding relationships among different species where arrows show the direction that energy and matter are moving within the ecosystem

forage
to search for food, especially plants and fungi

habitat
the particular ecosystem where a given organism lives and which provides it with necessary resources such as food and water

iteration
the revision of an idea or process

limitations of a model
areas of uncertainty that prevent the model from perfectly representing the real world

mark and recapture
a method of estimating population size by catching as many organisms as possible during a certain period, marking and releasing them, then returning at another time to repeat the process, and this time recording how many newly captured organisms were marked as having been captured before

mathematical model
a model that describes relationships in a system by using mathematical equations or graphs

migration
movement of animals from one region to another, often seasonal

model
see *scientific model*

orders of understanding
the factors included in a model based on which factors have a greater impact on the system than others

organism
an individual animal, plant, or other living life-form

phenomenon
a pattern, situation, or system that is observed

physical model
a concrete representation of an object, such as a miniature metal model of a car or a plastic model of a human cell

population
a group of individuals of the same species that live in the same general area and are able to reproduce with one another

population dynamics
the study of how and why the size, structure, and distribution of a population change over time

population graph
a visual tool (such as a bar chart or line graph) that shows how the number of individuals in a species changes over a specific period of time or across different age groups

powers of 10
10 multiplied by itself a number of times, which is often indicated in scientific notation as $10 = 10^1$, $100 = 10^2$, $1{,}000 = 10^3$, and so on, to refer to approximations of size, value, or quantity

predation
an interaction where one organism (known as the predator) kills and eats another organism (known as the prey)—for example, predators such as wolves eat prey such as caribou (Herbivory is a type of predation where animals eat plants.)

predictive model
a tool to forecast the future

probabilistic model
a tool that uses patterns in data to predict the likelihood of different outcomes. It produces a range of possible outcomes for a given set of conditions

range
in ecology, the total geographic area where a species lives and is found during its lifetime—including where it migrates or hibernates

scientific model
a representation of an idea, object, process, or system

scientific question
a specific question about the natural world that can be answered by gathering evidence through experiment, observation, or modeling

species
a group of individuals that can interbreed in nature

species distribution
the pattern of occurrence of a species within a geographic range

species distribution model (SDM)
a computer model that combines species location data with environmental factors to predict where the species is most likely to live now and in the future

system
a collection of parts that interact with each other to work together as a whole

topographic map
a flat, two-dimensional map that is a model of the actual three-dimensional shape of a land surface

trade-off
a desirable outcome given up to gain another desirable outcome

trophic level
an organism's position in a food web, representing a step in the flow of energy

uncertainty
a range of possible values within which the true value of the measurement lies

wildlife crossing
structures such as bridges and underground tunnels that allow animals to safely cross barriers such as roads, railroads, and pipelines

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