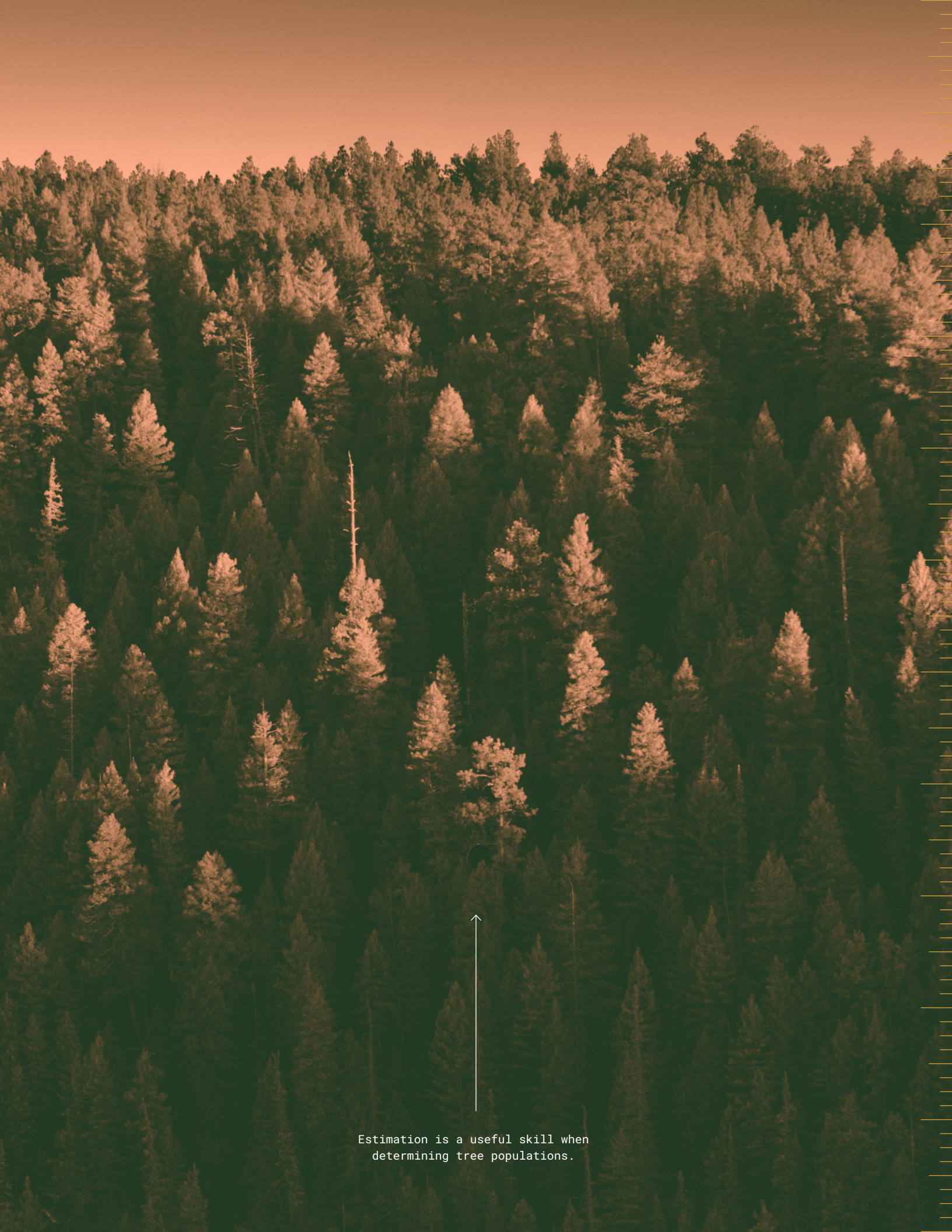
ACTIVITY 7

Fermi Estimations

DATA ANALYSIS



Estimation is a useful skill when determining tree populations.

7: FERMI ESTIMATIONS

GUIDING QUESTION

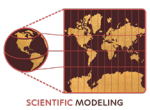
How can you use mathematical modeling to make an estimate?

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

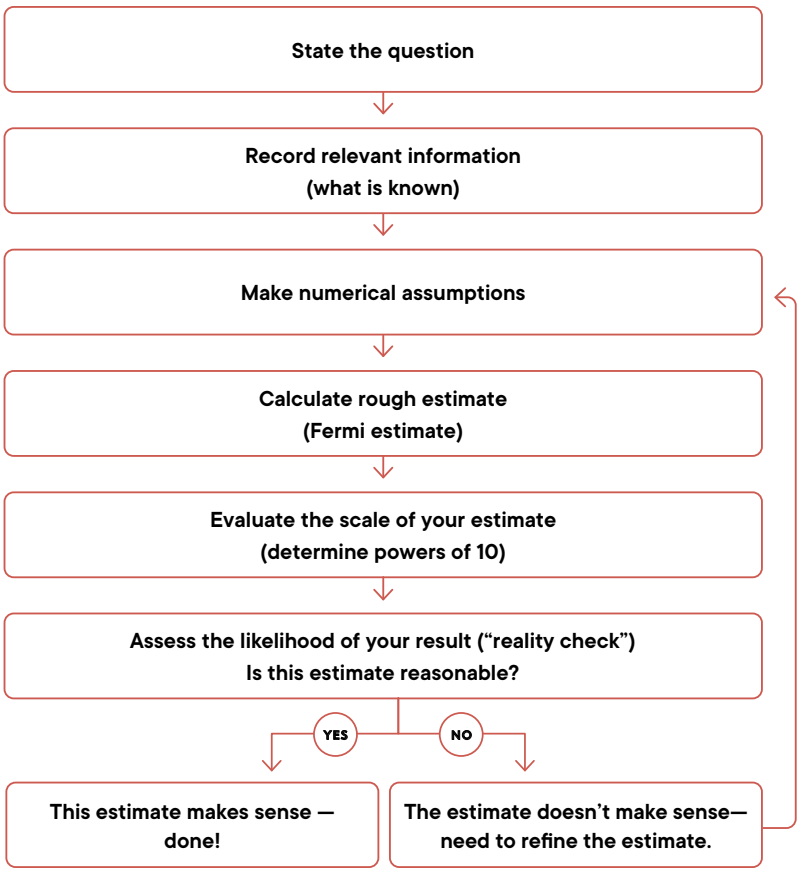
- CALCULATOR
- 2 COPIES OF STUDENT SHEET 7.1 "Making a Fermi Estimate"

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.

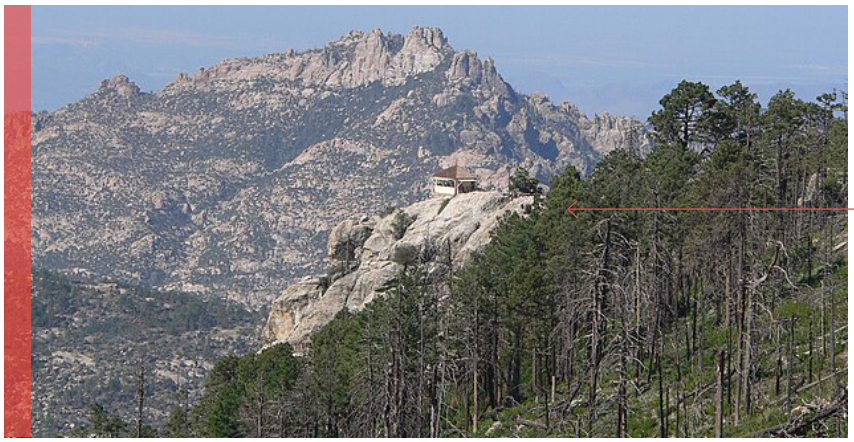
FIGURE 7.1
A Flowchart for Making a Fermi Estimate



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