ACTIVITY 8

Modeling a Method

INVESTIGATION

ACTIVITY 8

Modeling a Method

ACTIVITY SUMMARY

Students explore a model of the method of mark and recapture for estimating population size. They identify the assumptions and limitations of the model and suggest changes to the model based on their analysis. They then conduct their revised models and compare the resulting estimates. Students identify ways in which the model represents or excludes elements of real-world systems.

ACTIVITY TYPE
INVESTIGATION

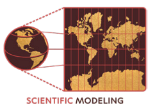
NUMBER OF
40–50 MINUTE
CLASS PERIODS
2

KEY CONCEPTS & PROCESS SKILLS

1 Models can be made more accurate through an iterative process that can involve testing it, refining it based on new evidence, adding or deleting relevant factors, or modifying the relationship between factors.

NEXT GENERATION SCIENCE STANDARDS (NGSS) CONNECTION:
Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system. *(Science and Engineering Practice: Developing and Using Models)*

CONCEPTUAL TOOLS



VOCABULARY DEVELOPMENT

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

TEACHER BACKGROUND INFORMATION

Estimating Population Size

The most accurate method to measure the size of a population is to count all the individuals in that population. This is possible when determining the population sizes of small numbers of slow-moving or stationary organisms, such as snails or trees. If the organism is mobile (such as a bird) or is present in large quantities (such as a colony of ants), counting every individual is difficult. In the case of some ocean species, such as minke whales, estimates have differed by as much as the powers of 10.

The Method of Mark and Recapture

One method often used to estimate population size is mark and recapture in which scientists capture some animals from the population, mark them, and release them. At a later time, the scientists again capture animals from the same population and observe how many of them are marked. The method assumes that the ratio of the actual population to the sample size is the same as the ratio of the number of marked animals to the number marked in the recapture sample. Knowing three of the four values—number originally marked (N_1), recapture sample size (N_2), and number marked in the recapture sample (R)—scientists can calculate an estimate of the actual population size (P).

$$P = (N_1 \times N_2)/R$$

where **P** = total size of population
N_1 = size of first sample (all marked)
N_2 = size of second sample (recapture: some will be marked, some won't)
R = number of marked individuals recaptured in second sample

This estimate makes the following assumptions:

- The population of organisms must be closed, with no immigration or emigration.
- The time between samples must be very small compared to the lifespan of the organism being sampled.
- The marked organisms must mix completely with the rest of the population during the time between the two samples.

Other Methods of Estimating Populations

Another method for estimating population size, the line-transect survey, involves observing every animal seen while they are traveling in a straight line. Although traditionally used for counting land animals, the line-transect survey method has recently been applied to whales, providing more reliable data.

The quadrat method of population estimation involves placing a series of squares, or quadrats, of a set size in the habitat and recording the species found within each quadrat. The quadrats can be used to estimate population abundance, density, frequency, and distribution of less mobile species.

MATERIALS & ADVANCE PREPARATION

FOR THE TEACHER

- JAR FILLED WITH ONE TYPE OF OBJECT (e.g., marbles, pennies, beads)

FOR EACH PAIR OF STUDENTS

- BAG OF 150 PLASTIC DISKS (or other markable objects)
- TIMER
- MASKING TAPE
- CALCULATOR

FOR EACH STUDENT

- STUDENT SHEET 8.1 "Mark and Recapture"

Fill a jar with one type of small object such as marbles, pennies, or beads. The jar should hold enough of the object that it is impossible to count all of them directly. You will use this jar in Teaching Step 2.

TEACHING NOTES

Suggestions for **discussion questions** are highlighted in gold.

Strategies for the **equitable inclusion of diverse students** are highlighted in pink.

GETTING STARTED (10 MIN)

1 **Connect the idea of Fermi estimates to estimating a population size.**

- In Activity 7, students generated Fermi estimates, a mathematical modeling approach to estimating difficult-to-know quantities. Ask, In what situations are Fermi estimates most useful? Review the idea that this type of estimation is helpful when there is limited data and when a rough estimate can provide useful information.
- Hold up the jar of objects you prepared and ask students to estimate how many objects are in the jar. Give students a minute to come up with their estimates. Call on a few students and ask, What is your estimate and what method did you use to come up with that estimate? Some students may say that they simply guessed, while others may already be using a Fermi estimate. Point out that some students may have used proportional reasoning to come up with their guesses. For example, a student might say that they counted the number of marbles they could see along the surface of the jar and then estimated that there were 10 times as many on the inside. So, if they counted 100 marbles on the surface, there would be 1,000 more on the inside, for a total of 1,100 marbles.
- Ask, If the objects were not stationary and they could freely come and go from the jar, would you use the same method to count them? Help students realize that they would probably need to use a different method because they wouldn't know if they were counting the same object more than once. Students would need some way to keep track of the objects.

2 **Share the story of the Azores bullfinch to introduce population estimation methods.**

- The Introduction in the Student Book contains a brief real-life example that can be shared with the class in multiple ways. Read it aloud to the class (using a storytelling approach), have individual students read a paragraph aloud to the class while others follow along with the text, or have students read it individually or cooperatively in their groups of four.
- Reading the Introduction aloud can better support comprehension for many students, including neurodiverse students and emerging multilingual learners who often have more highly developed listening and oral skills than reading comprehension skills. Alternatively, students can read the Introduction independently.

- Help students distinguish between the population estimation method (mark and recapture) and the modeling of that method. Students will model this method for estimating population size. Briefly describe mark and recapture (referred to in the Azores bullfinch story). It estimates populations by capturing individuals, marking them (e.g., banding, tagging), releasing them back to the environment, and then capturing a second sample to determine the proportion of marked to unmarked individuals. Just like the jar example, this method relies on mathematical thinking to determine an estimate. This method is what you might use if the objects could come and go from the jar. In this activity, students will not actually be marking and recapturing real organisms; instead, they will explore a model of this method of population estimation.

PROCEDURE SUPPORT (25 MIN)

3 **Students model the method of mark and recapture for estimating population size.**

- Hand out Student Sheet 8.1, "Mark and Recapture," and direct pairs to begin conducting the model of mark and recapture.
- If your students are finding the math challenging, you may want to review an example, as provided here.

Method of Mark and Recapture

On Day 2, we recaught 4 birds. These 4 birds were 4/20, or 20%, of the total number of birds we caught on Day 2. This means that the 18 birds we caught on Day 1 should be approximately 20% of the total number of birds in the population, N. We can set up the equation this way:

$$\frac{18}{N} = \frac{4}{20}$$

Then solve for N = (18 x 20)/4 = 90
The size of the population is approximately 90 birds.

- A sample student response for Student Sheet 8.1 is provided at the end of this activity.
- Have students evaluate the likelihood of their estimate in terms of powers of 10. Stopping to consider whether their estimate is reasonable can be helpful for sensemaking.
- In Procedure Step 8, students are asked to respond (in their groups) to the following questions about the model. Remind students to focus on the model of mark and recapture and not on the estimation method itself (which also contains assumptions and has limitations).

Sample Student Response, Procedure Step 8

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?)

- *Assumption that the act of shaking the bag perfectly mixes the marked disks back into the unmarked population.*
- *Assumption that the procedure of removing disks from the bag provides a random and unbiased sample.*
- *Assumption that there are no human errors in counting the number of disks marked, the number captured, and the number recaptured.*

What were the limitations of the model? (What could it not explain or predict?)

- *The model of mark and recapture cannot explain or predict real bird behavior or habitat. For example, the bag represents the variety of a bird's habitat, with every bird equally accessible for counting (being taken out of the bag).*

• In Procedure Step 9, students are asked to revise their models by modifying the procedure. Possible changes to the model include:

Sample Student Response, Procedure Step 9

- *Increase sampling time: Taking larger initial and recapture samples by increasing sampling time reduces sampling error and improves the reliability of the population estimate.*
- *Random sampling: Ensures both the initial capture and recapture are random and covers the entire habitat to avoid bias. (For example, close eyes while sampling.)*
- *Repeat the process: Instead of just two samples, I can conduct multiple rounds of mark and recapture to get an average estimate.*

• Students then test their revised models by repeating the procedure with their changes. Assuming that students increased sampling time, improved their sampling of the disks, or averaged multiple samples, their estimates are likely to become more accurate. Students can compare the changes they made to their models to identify which changes most helped improve the accuracy of their population estimates.

SYNTHESIS OF IDEAS (20 MIN)

4 **Students compare estimates of population size obtained by different pairs to discuss why there is variation.**

- Facilitate a brief discussion about why there is variability and what scientists might do about this variability in the data. Scientists might take repeated measures and then take an average; this larger sample size gives them more confidence in the estimate. Point out that the class modeled this process by having multiple pairs take measures. Scientists might also express the population size as a range instead of a single number.

- Ask, What type of model—deterministic or probabilistic—does mark and recapture rely on? Students should understand that it is a probabilistic model because its output, the estimated population size, is not a certain, fixed value. Instead, it is an estimate based on chance and ratios and contains uncertainty. The assumption is that the second sample is taken randomly from the total population, and the probability of capturing a marked individual is assumed to be the same as the probability of capturing an unmarked individual.

- Ask students how they think mark and recapture compares with other methods of population estimation, such as a line-transect survey or the quadrat method (see Teacher Background Information for brief explanations of both methods). Ask, Which type of method would be best for estimating snails? Whales? Sea jellies? The quadrat method is useful for snail populations, mark and recapture (and aerial surveys) for whale populations, and direct sampling from fishing nets for sea jellies. Let students know that scientists have found, through extensive studies, that different methods of estimation can be reliable methods and useful for different types of organisms.

- Have students briefly share their ideas about how population estimation data might be used in the real world. Accept all reasonable responses.

5 **Identify ways in which the model of mark and recapture did or did not represent real-world systems.**

- In this activity, students modeled a real-world method for estimating population. Ask, What aspects of real-world systems were included in the model and what elements were excluded? Student responses should indicate that the model used disks to represent the entire population of a species as individual organisms in a habitat (the disks in the bag). It did not address bird behavior (e.g., hiding), births, deaths, migration, disease, predation, or weather—all of which are factors that could affect the size of a population in a real-world system.

- Finish the activity by revisiting the Guiding Question, *How can you revise a model for estimating population size?* Use responses to this question to formatively assess students' understanding of the key concepts and process skills related to how models can be made more accurate through the process of iteration.

SAMPLE STUDENT RESPONSES

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?

    Possible responses include:

    - The marked species (the disks) will completely reintegrate into the population.

    - In subsequent captures, the probability of capturing a marked organism is the same as that of capturing any (unmarked) member of the population.

    - The marks (tags) will not be lost.

    b Select one assumption and explain how it would affect the population estimate if the assumption was false.

    Possible responses include:

    If the species (the disks) does not reintegrate, the model will underpredict the total population size because it mistakenly assumes that because a high percentage of the sample was marked, the total population must be small.

    If the probability of capturing a marked organism is not the same as that of capturing any (unmarked) member of the population (because the person sampling is choosing the marked disks, for example), the model will underpredict the total population size. This is because it mistakenly concludes that since a high percentage of the sample was marked, the total population must be small.

    If marks (tags) are lost, the model will overpredict the total population size because the number of recaptures suggests that the small number of marked organisms must have been spread throughout a very large total population. In reality, the marked organisms were simply hidden by missing tags.

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.**

      The first model only included two factors to estimate population. These factors may not have been the ones that have the greatest effect on the population. The mark and recapture estimate was based on a sample of the seagulls present at the site on three days and then averaged. If those three days were representative of the number of seagulls on most days, this estimate is likely more accurate.

   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.**

      The model could include food availability and birth rates. It assumes that the presence of tourists is the primary source of food, but there may be other sources. It also does not take into account how the population may be growing from year to year, for example, by having lots of offspring.

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?**
   Mark and recapture would be the most useful because it uses probability to estimate the population. It doesn't require counting every bird; it just requires estimating the ratio of marked to unmarked birds in a sample.

   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?**
   You could use a Fermi estimate because the trees are not moving. You can estimate the size of the area, the density of trees, and the percentage of mature oak trees, and then calculate a rough estimate.

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.**

   I could include local traffic conditions and weather, because it seems to take longer than it should to get from my home to school.

REFERENCES

International Fund for Animal Welfare. (2025). 15 animals that recovered from being endangered. Retrieved from: https://www.ifaw.org/journal/animals-recovered-being-endangered

Data From Original Model

NUMBER OF BIRDS CAUGHT ON DAY 1	
ESTIMATED SIZE OF BIRD POPULATION	N

NUMBER OF MARKED BIRDS CAUGHT ON DAY 2	
NUMBER OF BIRDS CAUGHT ON DAY 2	

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

Calculations for population estimate:

Planned changes to the model and my explanation for the changes:

Data From Revised Model

NUMBER OF BIRDS CAUGHT ON DAY 1	
ESTIMATED SIZE OF BIRD POPULATION	N

NUMBER OF MARKED BIRDS CAUGHT ON DAY 2	
NUMBER OF BIRDS CAUGHT ON DAY 2	

Calculations for population estimate:

Data From Original Model

NUMBER OF BIRDS CAUGHT ON DAY 1	18
ESTIMATED SIZE OF BIRD POPULATION	N

NUMBER OF MARKED BIRDS CAUGHT ON DAY 2	4
NUMBER OF BIRDS CAUGHT ON DAY 2	20

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

Calculations for population estimate:

$\frac{18}{N} = \frac{4}{20}$ $\quad N = \frac{(18 \times 20)}{4} = 90$ *Estimated population = 90 birds*

Planned changes to the model and my explanation for the changes:

We plan to increase the sampling time from 15 to 20 seconds so we can have larger initial and recapture samples. This should result in a more accurate estimate.

Data From Revised Model

NUMBER OF BIRDS CAUGHT ON DAY 1	25
ESTIMATED SIZE OF BIRD POPULATION	N

NUMBER OF MARKED BIRDS CAUGHT ON DAY 2	6
NUMBER OF BIRDS CAUGHT ON DAY 2	24

Calculations for population estimate:

$\frac{25}{N} = \frac{6}{24}$ $\quad N = \frac{(25 \times 24)}{6} = 100$ *Estimated population = 100 birds*