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

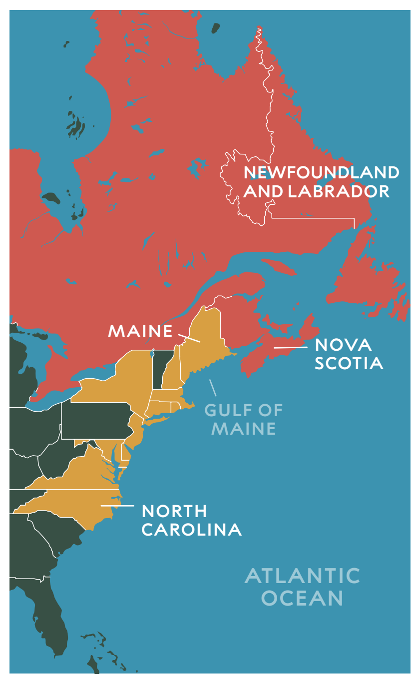
GUIDING QUESTION

How do scientific models represent a system?

INTRODUCTION

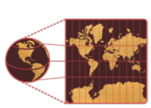
The geographic range of some aquatic species has already altered in response to changing ocean conditions. For example, fish such as cod and pollock are now found farther north (where the water is colder) as local ocean temperatures rise. What does that mean for a person fishing in their local area? 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.

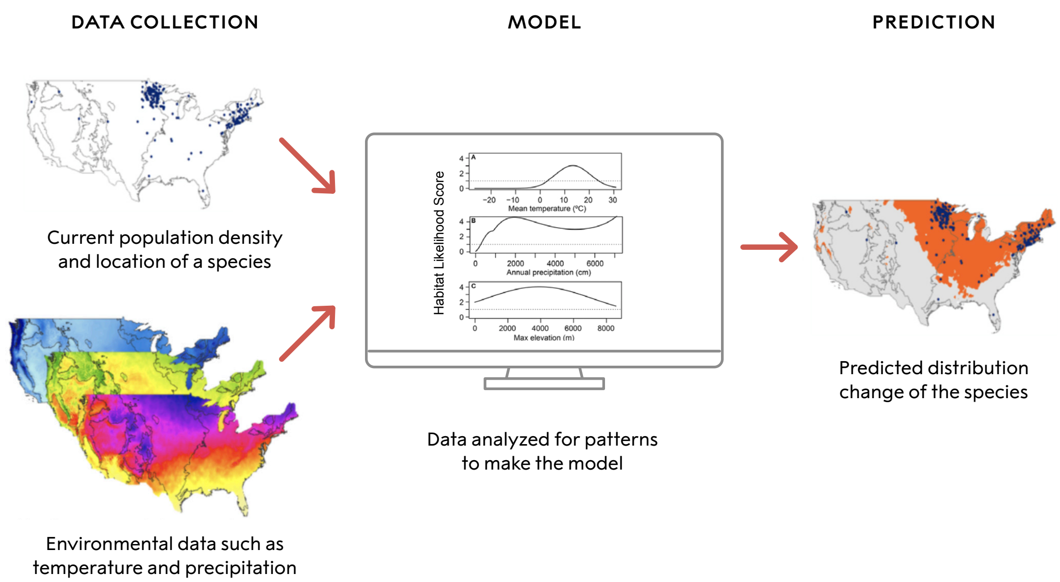
SCIENTIFIC MODELING

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*.

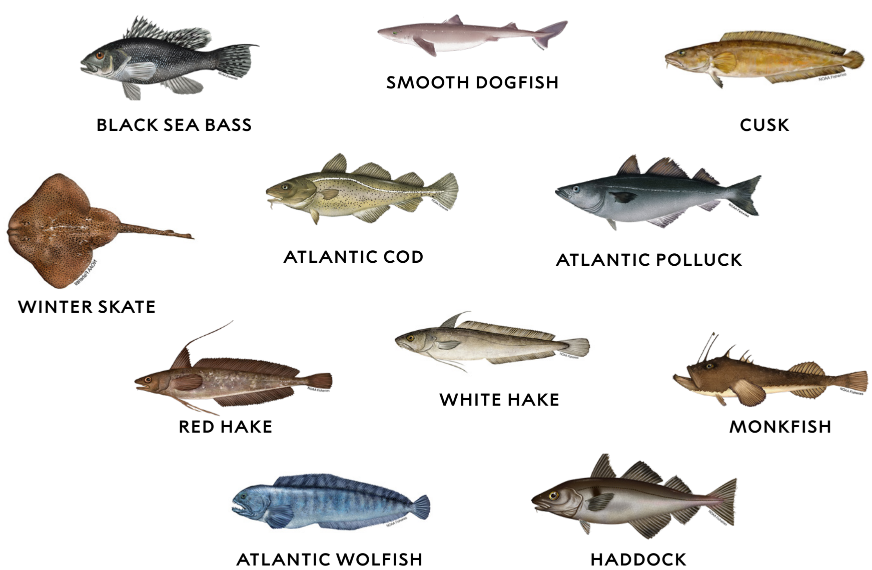
The American lobster is one of approximately 75 species of lobster.

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.

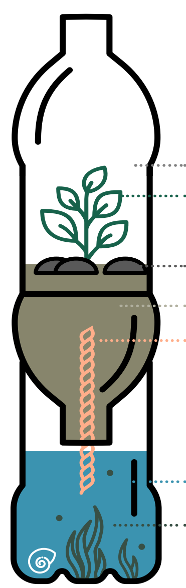


FIGURE 5.4
A "bottle biology" model

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 over-predict, 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