ACTIVITY 6

Modeling Migration

GAME

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ACTIVITY SUMMARY

Students investigate the similarities and differences between deterministic models and probabilistic models. They begin by constructing a simple deterministic model by graphing the population of a school of bluefin tuna during migration. Students explore a probabilistic model of the same migrating species as they play a board game. The class combines their probabilistic data and compares the outcome with the deterministic model. Students compare the two models while investigating each model's factors and their orders of understanding.

ACTIVITY TYPE
GAME

NUMBER OF
40–50 MINUTE
CLASS PERIODS
2-3

KEY CONCEPTS & PROCESS SKILLS

1 Scientific models are constructed to explain phenomena and make predictions. They represent aspects of the natural world that are too small, too large, too complex, or too difficult to observe or explain directly.

2 Different scientific questions about a single system may be best addressed by different scientific models, or one model may be used to answer multiple questions.

3 When constructing a model, it is helpful to distinguish those factors that have a greater impact on the question being studied from those with a lesser impact. This framework for differentiating among factors is known as *orders of understanding.*

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

SCIENTIFIC MODELING

ORDERS OF UNDERSTANDING

VOCABULARY DEVELOPMENT

deterministic model

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

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

TEACHER BACKGROUND INFORMATION

Bluefin Tuna

There are three recognized species of bluefin tuna: the Atlantic Bluefin *(Thunnus thynnus)*, the Pacific Bluefin *(Thunnus orientalis)*, and the Southern Bluefin *(Thunnus maccoyii)*. Tuna is one of the most important fish in the global food business. Roughly 40,000–68,000 metric tons of all bluefin species combined are caught annually. The global market value is estimated at $2–$2.5 billion.

Bluefin tuna were in rapid decline from the 1970s until around 2010. Since 2009, the population of some species have begun to recover as a result of collaborative fishing rules across the globe. Some populations have recovered by about 50% in 20 years and are no longer considered overfished. The range of the bluefin tuna continues to be impacted by changes in the climate.

Deterministic Models

A deterministic model is one that produces a single, predictable outcome for a given set of inputs. It has no random or uncertain variables. A simple example is a model in the form of an equation that describes a physical system, such as speed = distance/time. This mathematical model will always give the same quantity when calculated, given the same inputs. Deterministic models are useful when future events can be calculated exactly. It is most used when a system is fully understood and the external influences on the system are not significant or negligible.

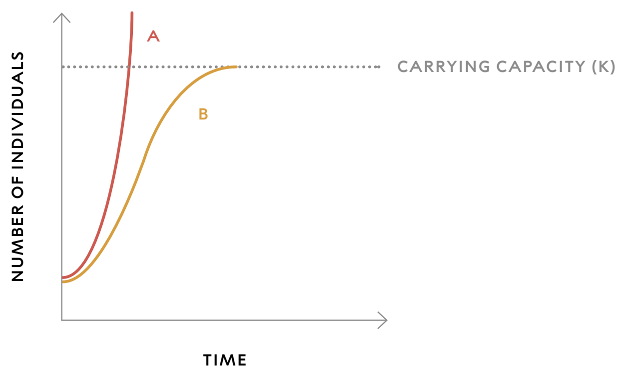
Probabilistic Models

A probabilistic model (sometimes referred to as stochastic model) is one that does not provide a definitive output for a given input, but a probability distribution of possible outputs. A probabilistic model is useful when dealing with uncertainty and randomness in data or phenomena. Probabilistic models are powerful tools for prediction in a complex or incompletely understood system because they can evaluate the potential results of different actions. As new data emerges and processes are better understood, a probabilistic model can update its estimates and become more accurate. An everyday example of a probabilistic model is weather forecasting. For example, a model predicting tomorrow's weather may conclude there is a 70% chance of rain, 20% chance of clouds, and 10% chance of sun based on current conditions and historical data.

Population Growth Curve

In an ecosystem, a population growth curve can vary based on the specific characteristics of the organism or population being studied. These growth curves can vary based on factors such as the initial population size, the rate of growth, and the carrying capacity of the environment. The carrying capacity of an ecosystem is the maximum population size of a species that can be sustained by the environment under study, given the resources available. It corresponds to a population equilibrium, when the number of deaths in a population equals the number of births.

In the following diagram, Curve A shows exponential growth in the absence of a carrying capacity, and Curve B shows logistic growth where the environment has a carrying capacity.



MATERIALS & ADVANCE PREPARATION

FOR THE TEACHER

- VISUAL AID 6.1 "Bluefin Tuna: Deterministic Model"
- VISUAL AID 6.2 "Bluefin Tuna: Deterministic and Probabilistic Models"
- VISUAL AID 1.1 "Interpreting Graphs" (OPTIONAL)

FOR THE CLASS

- CHART PAPER (or a visual aid)
- MARKERS

FOR EACH GROUP OF FOUR STUDENTS

- BLUEFIN TUNA MIGRATION GAME BOARD
- NUMBER CUBE
- COIN
- 4 SMALL GAME PIECES (4 different-colored disks)
- SET OF EVENT CARDS (20 cards, 4 for each of 5 weeks)

FOR EACH STUDENT

- STUDENT SHEET 6.1 "Bluefin Tuna Game Tracker"
- STUDENT SHEET 6.2 "Writing Frame: Evidence and Trade-Offs" (OPTIONAL)

Bluefin Tuna Migration Game

- For each group, make a copy of the two-page game board and tape it together. Check that the game pieces are appropriately sized to fit on the spaces of the game board.
- For each group, print a set of 20 Event cards. Each card needs a front (content of the card) and a back (WEEK # EVENT). The backs of the cards will be face up on the table when students create the 5 piles of cards. These should be printed double-sided. Alternatively, you can write "WEEK # EVENT" on the back of each card.
- The game is designed for groups of four. If played with fewer than four, some trends may not be revealed to group members. In that case, the class data should show these patterns.

In Procedure Part B, student-generated data will be used to create a class graph. Decide how you would like students to share their data (either on a single sheet of chart paper or on a visual aid). Set up the x-axis and the y-axis and post the empty template so each student can record their individual data for each week on the class graph.

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 **Elicit students' prior knowledge about the fishing industry.**

- Inform students that they are going to play a game to model the migration of a population of bluefin tuna. You may want to share some of the Teacher Background Information with students to emphasize the enormity of the global bluefin tuna fishing industry.
- Probe students to see how familiar they are with tuna as a food source in people's lives. Students may have varied ideas about the concept of tuna and fish as a food source based on family or cultural insights, practices, and personal histories. Acknowledge funds of knowledge as assets to building understanding. Encourage students to respond to this topic or to questions that arise from it by sharing their ideas during small-group or class discussions or by writing reflections in their science notebooks.
- In the mid–20th century, bluefin tuna populations faced severe declines due to intense overfishing. But international management efforts have led to a much more robust population. Let students know that the models in the activity do not reflect any specific time period of the bluefin tuna's history and are generalized to illustrate the function of different kinds of models.

2 **Students consider factors that impact bluefin tuna populations.**

- Use the Think-Pair-Share strategy with students. Ask, What are some factors that may affect how many of the bluefin tuna successfully migrate? Possible responses include food availability, water conditions, and predators such as sharks and fishers. Record student responses on the board so they can refer back to them at the end of the activity. Ask, How might these changes to these factors improve or worsen the size and health of tuna populations in the future? Students may predict that factors such as reducing fishing, increased management, and potential changes in predators or food availability could improve populations. Factors such as food availability or climate change, such as changing water temperatures, could hurt populations.

PROCEDURE SUPPORT (45 MIN)

3 Support students as they explore a deterministic graph model in Procedure Part A.

- You may want to review the brief scenario provided in Procedure Step 1 as a class and provide additional background. In the real-world system, bluefin tuna spend a few years feeding in the feeding ground areas before coming to maturity and migrating back to the spawning grounds to reproduce. The probabilistic game model that students will explore in Part B models the population of a school of bluefin tuna as they travel from the feeding grounds to the spawning grounds and then models the population shortly after they reproduce at the spawning grounds.
- Table 6.1 provides simple mathematical equations for students to calculate the bluefin tuna population as they travel from Week 0 to Week 5. Students use this information to construct a graph. Depending on your student population, you may want to do the calculations as a class or provide the population numbers shown in Table 6.1. Students who have difficulty interpreting graphs (such as students with dyscalculia) can be provided with a copy of the graphs and Visual Aid 1.2, "Interpreting Graphs" in advance.
- Sample data for the line graph is shown in Table 6.1, and a sample graph can be found on Visual Aid 6.1, "Bluefin Tuna: Deterministic Model."

Table 6.1: Bluefin Tuna Population Data

TIME (WEEK)	CALCULATING POPULATION CHANGE	TUNA POPULATION
0 FEEDING GROUNDS	Week 0 population	500
1	(Week 0 population) – (0.05 x Week 0 population)	*475*
2	(Week 1 population) – (0.05 x Week 1 population)	*451*
3	(Week 2 population) – (0.05 x Week 2 population)	*428*
4	(Week 3 population) – (0.05 x Week 3 population)	*406*
5 SPAWNING GROUNDS	(Week 4 population) + (0.2 x Week 4 population)	*487*

- In Procedure Step 3, students are asked to graph their data. A sample response is provided on Visual Aid 6.1, "Bluefin Tuna: Deterministic Model." In Procedure Step 4, ask, What factors could explain the decline in the population? Student responses could include changes in environmental conditions (e.g., pollution, warming ocean temperature, changes in salinity), food availability, disease, and fishing.

TEACHER'S NOTE: The model incorporates an approximately 5% decline of the population over the time period, as indicated by the graph, which is realistic for a population that is overfished.

- Point out the increase in population from Week 4 to Week 5 and ask, What could explain the increase in population? Student responses may mention that an increase occurs at the spawning grounds and is likely due to reproduction.

- At this point in the activity, students have engaged with a deterministic model, but this concept has not yet been introduced. Wait to present this idea and the vocabulary until Part C when students will have an opportunity to compare the deterministic model to the probabilistic model that is explored in Part B.

4 **Support students as they explore a probabilistic game model in Procedure Part B.**

- In this unit, laboratories and card-based investigations use hands-on materials to support student learning. Certain student populations—including girls, gender nonconforming students, and introverted students—often take on roles in which they do not directly engage with hands-on materials, such as recorder and observer. Incorporate strategies to ensure that all students participate over time. For example, in activities like this one in which students conduct the investigation in groups of four, one strategy is to assign roles (such as group leader, recorder, observer, and timekeeper) ahead of time and then rotate them periodically. Another strategy is to create specific groupings of four that might encourage greater participation. Decide which strategy you will use to best support your student population.

- Consider how to best adapt the activity to the needs of your particular student population. Students who need more time processing language (such as students with dyslexia) can be provided with a copy of the cards in advance of the activity.

- Note that the terms *current population* and *ocean currents* appear on Week 5 of the Event cards. For emerging multilingual learners, you might need to distinguish between the use of these terms.

- In Procedure Step 5, review the game rules. You may find it helpful to model one round of the game and demonstrate how to complete Student Sheet 6.1, "Bluefin Tuna Game Tracker."

- Hand out Student Sheet 6.1 and make sure students are recording their progress on it, not only to keep track of their school size but also to note the factors that are impacting the population. A sample student response to Student Sheet 6.1 is provided at the end of this activity.

5 **Students rate the factors in the game model according to orders of understanding.**

- In Procedure Step 11, students compare the final populations for their four schools of tuna and determine which school had the most successful migrations and the least successful migrations, based on population size (larger size indicates more successful migration). Ask, Which factors had the greatest impact on the population? Students should be able to observe from the data recorded on their student sheets that commercial fishing had a greater impact than natural predators. Climate change, in the form of water temperature increases, salinity, and currents, also had a large impact.

- You may want to remind students of the meaning of the term *orders of understanding* by providing an everyday example: a loss of electricity may have a greater impact on food spoilage of food stored in a refrigerator than how old the food is.

- Students should be able to rate the orders of understanding as follows: fishing had the greatest impact, followed by temperature, currents, and salinity. Predation and disease had much less of an impact.

Sample Student Response, Procedure Step 11

- Highest order of understanding: commercial fishing

- Lowest order of understanding: sharks, killer whales, disease

6 **Students graph the data collected in the bluefin tuna migration game.**

- Compile student data and collectively build the probabilistic model. This can be done on a blank visual aid or on chart paper. Each student should mark their data points (one point for each week of the game). Note that students will be graphing two data points from the first column of Student Sheet 6.1: the initial population of 500 (Week 0) and the population at the end of Week 1. A complete sample dataset is shown on Visual Aid 6.2, "Bluefin Tuna: Deterministic and Probabilistic Models."

- Ask, What does each dot represent? Students should recognize that the dots are the population values for their school of bluefin tuna. Follow up with a more important question. Ask, How would you describe the population of the bluefin tuna for each week? Students may suggest that the best representation is an average, but a better answer would be that the probable population at any given time is better visualized as a range of values. In Procedure Step 12, create a graph on Visual Aid 6.2 of all the class data and connect the top and bottom of the population data to show the range. Students should record these lines (but they do not need all the specific data points) on their own graphs in their science notebooks (from Part A.)

- Ask, Is it possible for the population of bluefin tuna to drop to zero with this model? Students should respond that yes, the probabilistic model showed that sometimes the tuna had bad years, and the population dropped much more than predicted (5%). Because of this variation, there is a chance that a year with numerous adverse events could compound, resulting in a quick decline in population.

7 Compare a deterministic model to a probabilistic model in Procedure Part C.

- In Part C, students compare their graphs from Part B to those from Part A, as shown on Visual Aid 6.2.
- Review the terms *deterministic model* and *probabilistic model* as needed. If you have begun a word wall, add these terms and provide examples as needed. For more information on a Word Wall, see Appendix 1: Literacy Strategies.

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

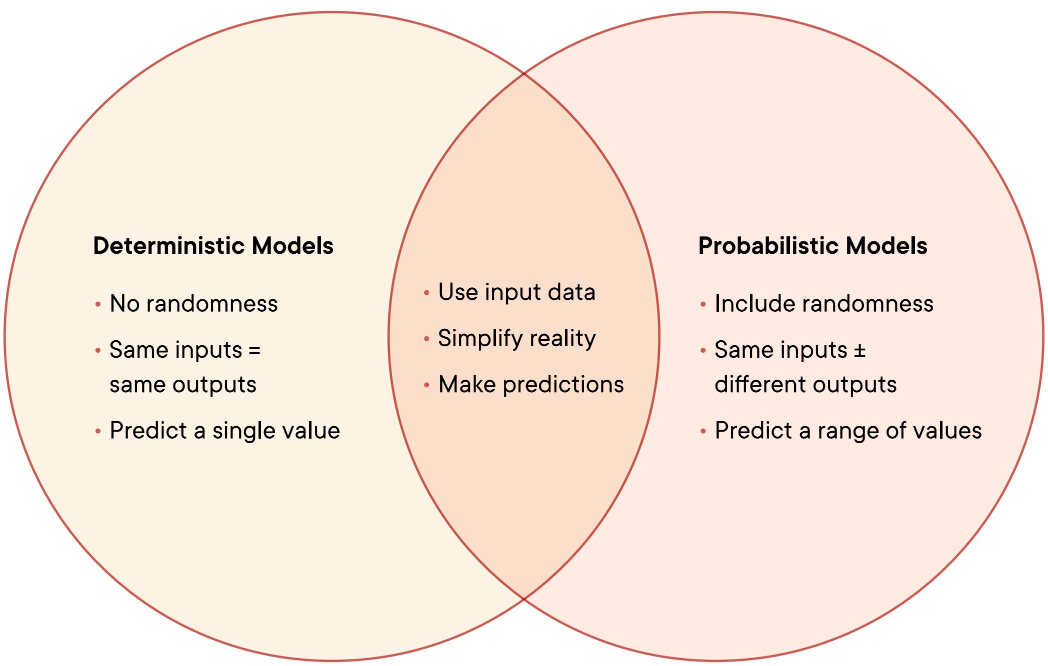
  The tuna model from Part A was a deterministic model.

  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.

  The tuna model from Part B was a probabilistic model.

- Help students understand the similarities and differences between the two kinds of models by creating a Venn diagram. The Venn diagram will help students acquire vocabulary as they compare and contrast the concepts of deterministic and probabilistic models. With the class, designate topics or main ideas for each circle. Have each group brainstorm what to put in each circle of the Venn diagram and then work to come to a consensus on a complete and correct Venn diagram. For more information about Venn Diagrams, see Appendix 1: Literacy Strategies. A sample Venn diagram is shown here.

SCIENTIFIC MODELS



- In Procedure Step 16, students are asked to use the two models to predict what will happen to the population and range of the bluefin tuna during future migrations if nothing changes, fishing limits are introduced, and environmental change continues to warm ocean waters.

  Sample Student Response, Procedure Step 16

  Students will see the trend of decreasing population in both models, although the probabilistic model (from Part B) shows some chance that the population stays the same or increases. If fishing limits are introduced, the probabilistic model predicts that the populations will rise because the quantities of fish lost by commercial catches in the game were very large. The probabilistic model also showed that those in the cooler northern route were more likely to survive, indicating that warmer waters would decrease population.

SYNTHESIS OF IDEAS (10-15 MIN)

8 **Facilitate a discussion about modeling bluefin tuna populations during migration.**

- Ask, Which model is better suited to model the bluefin tuna population during migration? Students should understand that the game is a probabilistic model that incorporated the variability in events that the deterministic model missed and was the better model in this case. Probabilistic models are a good choice for modeling the randomness of nature.

- Point out that there are many cases in which a deterministic model is better for the task at hand, such as when projecting interest payments on an expensive purchase (e.g., a smartphone).

- To help students reflect on the role of the game as a model, first have them offer ways in which the game model could be altered to show a change in the ecological system. For example, if there were more fish caught by fishers in the real world, then more Event cards with fisher events could be added, or the fish quantities could be multiplied by a larger number when the number cube is rolled. To show changes in climate, more factors related to it could replace factors with lower orders of understanding, such as natural predators. Help students understand that the model can be adjusted to project the future by adjusting the factors and their relative importance in the model that best reflects the system that is being modeled.

- Explore with students the aspects of the real-world system that were or were not included in the game model and how they affected the population.

  Factors Representing the Real-World System That Were Included

  - Students may notice that the location where fishing occurred made a difference to their predictions. Many more fish were lost at spawning and feeding grounds vs. during the middle of the migration. This reflects the historical practices of commercial fishers who would wait for schools of tuna to arrive at the spawning grounds.

- Students may have also noticed that some of the Event cards resulted in a greater decrease to the tuna population along the southern route as compared to the northern route. This effect modeled the current real-world negative impact of warming ocean waters on the species. Increased temperatures at the spawning grounds also moved the range of the tuna northward and contributed to reduced reproduction.

Factors Representing the Real-World System That Were Not Included

- The variability of the length of the migration.
- The complexity of spawning from eggs to larvae to juveniles.
- Complex impacts of temperature increases on range and fish metabolism.
- Some aspects, such as the number of fish caught, were also simplified.

9 Review how key content in the activity relates to orders of understanding.

In Build Understanding item 2, students are asked to consider what factor is the most important to model. This supports the key concept and process skill about orders of understanding introduced in Activity 4. Support students as they distinguish those factors that had a greater impact on the tuna population in the game, such as commercial fishing and climate change, from those with a lesser impact, such as disease and natural predators.

10 Revisit the concept of trade-offs and how it applies to fishing laws.

- Build Understanding item 4 asks students to weigh the trade-offs of fishing limits. Trade-offs were introduced in Activities 1 and 4 and are further investigated in this activity. In a decision involving trade-offs, something positive (or desirable) is given up to gain another positive (or desirable) outcome. Since many decisions involve trade-offs, students should understand that a perfect choice that maximizes all goals is often not possible. It is possible, however, to recognize and analyze the trade-offs associated with each decision.
- For students who need support organizing and writing their responses, you may wish to provide optional Student Sheet 6.2, "Writing Frame: Evidence and Trade-Offs," to compose their responses. Students could also use Student Sheet 6.2 only as a reference or as a checklist as they write their responses. A sample student response for this student sheet is shown at the end of this activity. For more information on a Writing Frame, see Appendix 1: Literacy Strategies.
- Finish the activity by revisiting the Guiding Question, *How can models include uncertainty?* Use responses to this question to formatively assess students' understanding of the key concepts and process skills related to how different models can model the same phenomena and make predictions.

SAMPLE STUDENT RESPONSES

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.**
   Probabilistic, because it provides a range of possible population data.

   b **The height of a bouncing ball as it loses energy.**
   Deterministic, because there are equations that can identify exactly where the ball will be located.

   c **The weather for next week.**
   Probabilistic, because there is uncertainty in what can happen in a weather system.

   d **The change in range of a species.**
   Probabilistic, because there is uncertainty due to all the factors in the ecology of an area.

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

   The factors that had the greatest impact were the commercial fishers because they often caught a large number of fish compared to other problems they may have faced, so that is the highest order of understanding. Factors related to climate change, such as increased temperature, poor salinity, and changing currents, had a significant impact, but not as much, so they were the next order of understanding. Things that did not kill as many fish, such as the factors of natural predators and recreational fishers, were lower orders of understanding.

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.**

   One change that I would make is the rate of fish being caught. Since global fishing management strategies have been implemented, I would reduce the fish caught by commercial fishers. The population would likely increase during migration instead of decreasing.

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.**

Student responses may vary. One sample response is provided.

Yes, I would support the law because the decline in fish has been negatively impacting the fishing industry. Stopping local fishing will give the species a chance to survive and rebound its population. Without this change, fishers are going to run out of fish to catch to make a living. The trade-off is that many fishers in the area will not be able to make a living in the short term. People who disagree with my decision might say that the law will make people lose their jobs.

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.**

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

TABLE 6.2
Lines at Local Ice-Cream Shop

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

The most likely length is 2 people in line. This is because 8/20 (or 40%) of the visits had 2 people, which is the highest probability in the data.

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

It would be probabilistic because the data does not show exactly how many people are in line, just the likelihood of each line length. Since the output is unknown for the same input, it would be a probabilistic system.

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.**

On-demand pricing is probabilistic because it forecasts uncertain future events to set the highest price for the seller. The model predicts the probability that the current demand will exceed the current supply in the immediate time window.

TEACHER'S NOTE: While the forecast is probabilistic, the final price often comes from a deterministic calculation within the model. For example, once the probabilistic forecast is complete (e.g., there is a 90% chance of a shortage in Zone 3), the model applies a deterministic rule: If the probability of a shortage is >85%, multiply the base price by 2.5.

REFERENCES

Marine Stewardship Council. (November 2024). Fisheries targeting tuna most at risk from climate change, new research suggests. https://www.msc.org/media-centre/press-releases/press-release/fisheries-targeting-tuna-most-at-risk-from-climate-change--new-research-suggests#:~:text=As%20ocean%20temperatures%20change%2C%20migratory,catch%2C%20potentially%20leading%20to%20overfishing

The PEW Charitable Trusts. (October 2017). The story of Atlantic bluefin. https://www.pew.org/en/research-and-analysis/issue-briefs/2017/10/the-story-of-atlantic-bluefin

STUDENT SHEET 6.1 | BLUEFIN TUNA GAME TRACKER | NAME

Circle one: NORTHERN ROUTE SOUTHERN ROUTE

	WEEK 1	WEEK 2	WEEK 3	WEEK 4	WEEK 5
	Event	**Event**	**Event**	**Event**	**Spawning Grounds**
Event description					
Initial population	500 (WEEK 0)				
Change in population					
Ending population					

STUDENT SHEET 6.1 | BLUEFIN TUNA GAME TRACKER | NAME SAMPLE STUDENT RESPONSE

Circle one: NORTHERN ROUTE SOUTHERN ROUTE

	WEEK 1	WEEK 2	WEEK 3	WEEK 4	WEEK 5
	Event	**Event**	**Event**	**Event**	**Spawning Grounds**
Event description	*commercial fishers*	*great speed*	*killer whales*	*high water temperatures*	*salinity*
Initial population	500 (WEEK 0)	*450*	*450*	*448*	*443*
Change in population	*–50*	*0*	*–2*	*–5*	*443 x 0.10 = +44*
Ending population	*450*	*450*	*448*	*443*	*487*

WRITING FRAME: EVIDENCE & TRADE-OFFS

NAME

There is a lot of discussion about the issue of

My decision is that

My decision is based on the following evidence:

First,

Second,

Third,

The trade-off(s)

People who disagree with my decision might say that

STUDENT SHEET 6.2 | WRITING FRAME: EVIDENCE & TRADE-OFFS | NAME SAMPLE STUDENT RESPONSE

There is a lot of discussion about the issue of

declining fish populations.

My decision is that

there shouldn't be any fishing restrictions.

My decision is based on the following evidence:

First,

fish populations go up and down due to various factors, and we don't know what factors caused the decline.

Second,

we don't know if the decline is short term or long term. It's possible that the fish populations farther out may get larger and come back closer to shore.

Third,

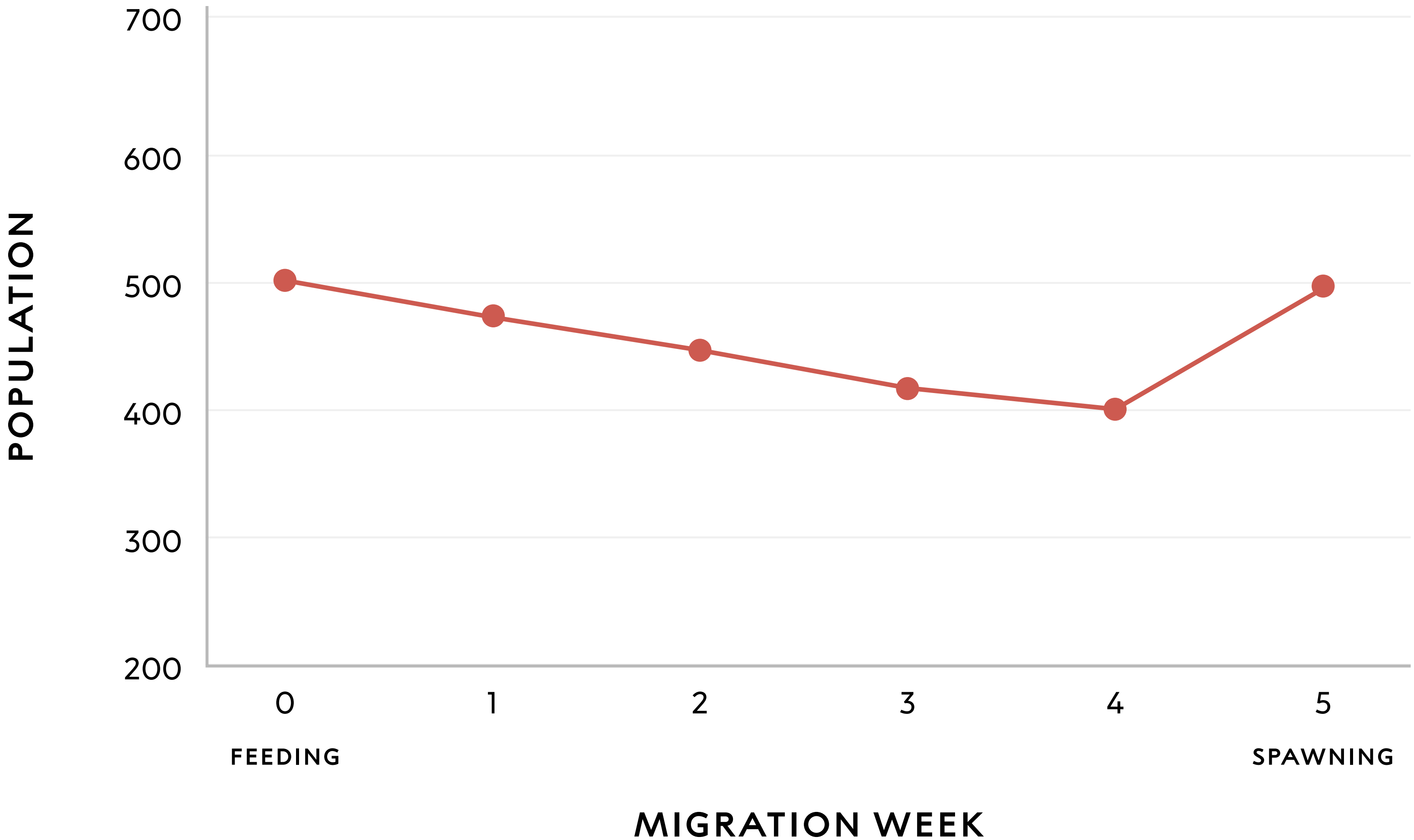
if there are not enough fish to catch locally, the fishers will go farther out without any change in the laws.

The trade-off(s)

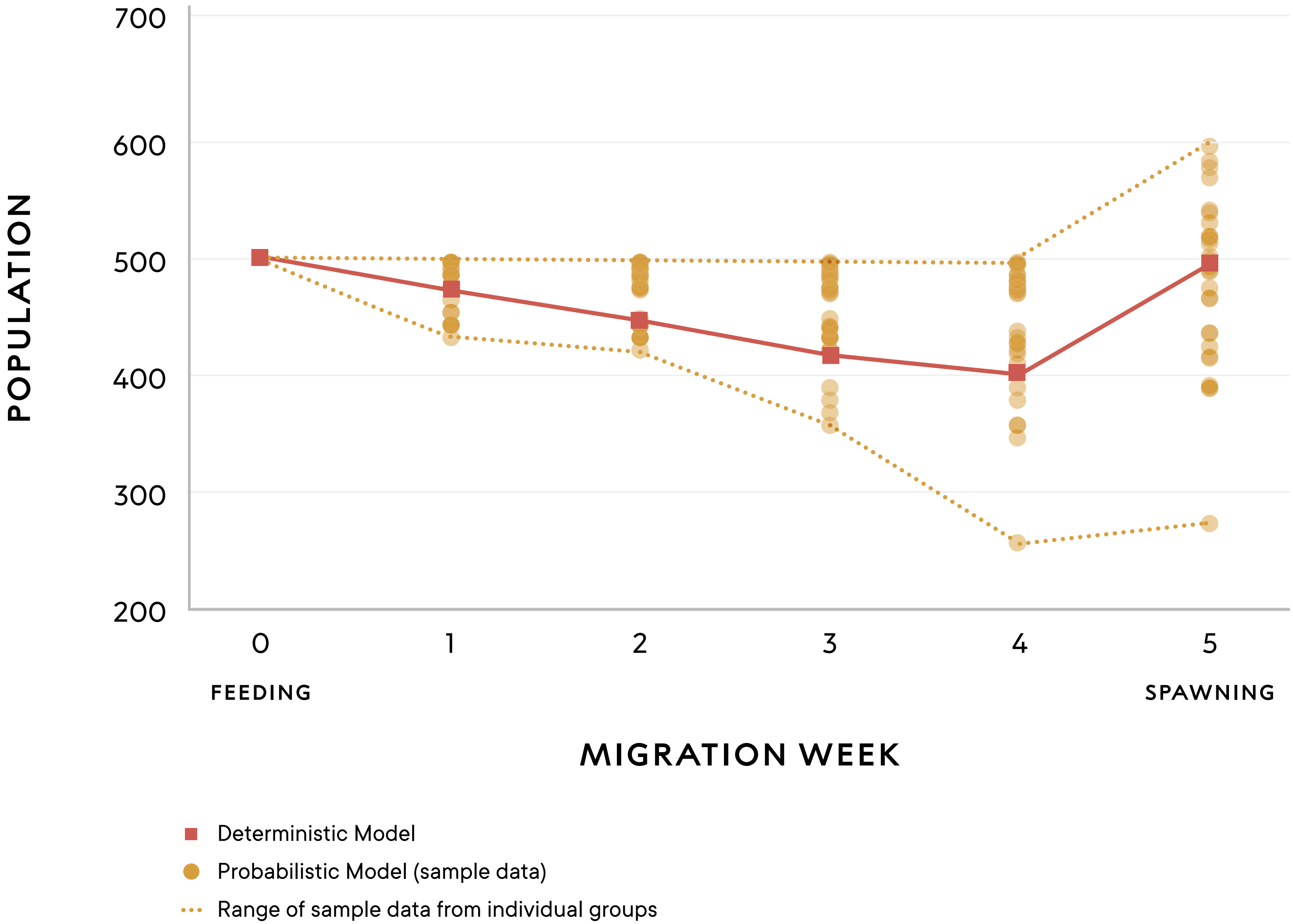
is that the fish closest to shore may be overfished and never recover.

People who disagree with my decision might say that

it's important to give fish the time and space to recover their populations.



The model shows a declining tuna population from week 0 to week 4 and then a significant increase in population from week 4 to week 5. If the trend continues, the model predicts that the population would continue to increase, possibly matching and exceeding the initial population.


700
600
500
400
300
200
POPULATION
0
1
2
3
4
5
FEEDING
SPAWNING
MIGRATION WEEK
Deterministic Model
Probabilistic Model (sample data)
Range of sample data from individual groups

A group of commercial fishers wait near the hunting grounds, anticipating that the school will pass by as it starts migrating.

Determine how many tuna are fished by rolling the number cube and multiplying the number by 10.

The school begins the migration strongly and sets a faster-than-usual pace.

Move up 3 spaces

OR

roll the number cube and move up the number of spaces indicated.

If you pass through an Event space, pick up the next Event card.
If you land on an Event space, pick up the next Event card.

The school has a slow start due to nearby predators.

Roll the number cube to determine the number of tuna that are eaten by sharks:

⚀ OR ⚁ OR ⚂ → no tuna are lost
⚃ OR ⚄ → lose 5 tuna
⚅ → lose 10 tuna

The area near the hunting grounds is filled with commercial fishers.

Roll the number cube to determine the number of tuna that are caught:

⚀ OR ⚁ OR ⚂ → 10 tuna
⚃ OR ⚄ → 20 tuna
⚅ → 50 tuna

WEEK 1
EVENT

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 2: SCIENTIFIC MODELING, ACTIVITY 6: EVENT CARDS

WEEK 1
EVENT

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 2: SCIENTIFIC MODELING, ACTIVITY 6: EVENT CARDS

WEEK 1
EVENT

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 2: SCIENTIFIC MODELING, ACTIVITY 6: EVENT CARDS

WEEK 1
EVENT

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 2: SCIENTIFIC MODELING, ACTIVITY 6: EVENT CARDS

There are great conditions and plenty of prey, so the strong school of swimmers results in great speed.

There is no change in the school population

AND

move ahead 2 spaces.

If you pass through an Event space, pick up the next Event card.

SCIENTIFIC THINKING FOR ALL: A TOOLKIT – UNIT 2: SCIENTIFIC MODELING, ACTIVITY 6: EVENT CARDS

Some of the fish in the school come down with an infection that can be fatal.

If the school is on the Northern route, roll the number cube to determine how many tuna are lost to disease.

If the school is on the Southern route, the warmer water negatively impacts tuna health and tuna are more likely to catch and die from the disease. Roll the number cube and multiply it by 10 to determine how many tuna are lost.

SCIENTIFIC THINKING FOR ALL: A TOOLKIT – UNIT 2: SCIENTIFIC MODELING, ACTIVITY 6: EVENT CARDS

The tuna comes upon a large school of tasty herring. The tuna circle around and feed, but some tuna are caught by local fishers.

Roll the number cube to determine the number of tuna that are caught by fishers:

⚀ OR ⚁ OR ⚂ → lose 1 tuna

⚃ OR ⚄ → lose 5 tuna

⚅ → lose 10 tuna

SCIENTIFIC THINKING FOR ALL: A TOOLKIT – UNIT 2: SCIENTIFIC MODELING, ACTIVITY 6: EVENT CARDS

The school travels and hunts for a while with another school made up of a different species of fish.

There is no change in the school population.

SCIENTIFIC THINKING FOR ALL: A TOOLKIT – UNIT 2: SCIENTIFIC MODELING, ACTIVITY 6: EVENT CARDS

WEEK 2
EVENT

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 2: SCIENTIFIC MODELING, ACTIVITY 6: EVENT CARDS

WEEK 2
EVENT

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 2: SCIENTIFIC MODELING, ACTIVITY 6: EVENT CARDS

WEEK 2
EVENT

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 2: SCIENTIFIC MODELING, ACTIVITY 6: EVENT CARDS

WEEK 2
EVENT

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 2: SCIENTIFIC MODELING, ACTIVITY 6: EVENT CARDS

Because of human activities, the temperature of the water is warmer than the tuna is used to, endangering its metabolism. The school seeks cooler water to the north, but that area has fewer prey.

If the school is on the Northern route, roll the number cube to determine how many tuna are lost to starvation.

If the school is on the Southern route, roll the number cube to determine the number of tuna that are lost in the warmer temperatures:

⚀ OR ⚁ OR ⚂ → lose 10 tuna

⚃ OR ⚄ → lose 20 tuna

⚅ → lose 50 tuna

SCIENTIFIC THINKING FOR ALL: A TOOLKIT – UNIT 2: SCIENTIFIC MODELING, ACTIVITY 6: EVENT CARDS

The school swims near a group of killer whales. The school speeds away but loses some tuna to the predators.

Lose 2 tuna

AND

move ahead 1 space.

SCIENTIFIC THINKING FOR ALL: A TOOLKIT – UNIT 2: SCIENTIFIC MODELING, ACTIVITY 6: EVENT CARDS

The school makes steady progress.

There is no change in the school population.

SCIENTIFIC THINKING FOR ALL: A TOOLKIT – UNIT 2: SCIENTIFIC MODELING, ACTIVITY 6: EVENT CARDS

The school accidentally swims near a small group of commercial fishing boats. The school speeds away but loses some tuna to the predator.

Move ahead 2 spaces and lose 50 tuna

OR

roll the number cube and multiply it by 10 to determine how many tuna are lost.

If you pass through an Event space, pick up the next Event card.

SCIENTIFIC THINKING FOR ALL: A TOOLKIT – UNIT 2: SCIENTIFIC MODELING, ACTIVITY 6: EVENT CARDS

WEEK 3
EVENT

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 2: SCIENTIFIC MODELING, ACTIVITY 6: EVENT CARDS

WEEK 3
EVENT

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 2: SCIENTIFIC MODELING, ACTIVITY 6: EVENT CARDS

WEEK 3
EVENT

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 2: SCIENTIFIC MODELING, ACTIVITY 6: EVENT CARDS

WEEK 3
EVENT

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 2: SCIENTIFIC MODELING, ACTIVITY 6: EVENT CARDS

The school makes steady progress.

There is no change in the school population.

SCIENTIFIC THINKING FOR ALL: A TOOLKIT – UNIT 2: SCIENTIFIC MODELING, ACTIVITY 6: EVENT CARDS

As the school approaches the end of its journey, a group of commercial fishing boats awaits its arrival.

Determine how many tuna are lost by rolling the number cube and multiplying the number by 10.

SCIENTIFIC THINKING FOR ALL: A TOOLKIT – UNIT 2: SCIENTIFIC MODELING, ACTIVITY 6: EVENT CARDS

Outside the spawning grounds is an area full of prey, so the school circles and eats. One tuna is caught and released with a tracking device put on it by a group of ecologists.

There is no change in the school population.

SCIENTIFIC THINKING FOR ALL: A TOOLKIT – UNIT 2: SCIENTIFIC MODELING, ACTIVITY 6: EVENT CARDS

As the school approaches the end of its journey, a group of commercial fishing boats awaits its arrival.

Roll the number cube to determine the number of tuna that are caught by fishers:

⚀ OR ⚁ → lose 10 tuna

⚂ OR ⚃ OR ⚄ → lose 20 tuna

⚅ → lose 100 tuna

SCIENTIFIC THINKING FOR ALL: A TOOLKIT – UNIT 2: SCIENTIFIC MODELING, ACTIVITY 6: EVENT CARDS

WEEK 4
EVENT

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 2: SCIENTIFIC MODELING, ACTIVITY 6: EVENT CARDS

WEEK 4
EVENT

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 2: SCIENTIFIC MODELING, ACTIVITY 6: EVENT CARDS

WEEK 4
EVENT

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 2: SCIENTIFIC MODELING, ACTIVITY 6: EVENT CARDS

WEEK 4
EVENT

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 2: SCIENTIFIC MODELING, ACTIVITY 6: EVENT CARDS

Because of human activities, the temperature in the spawning grounds is too high for successful egg laying. Some tuna's eggs are not viable. Those who move farther north to spawn found less food availability and more predators.

Add 5% of the current population to represent new juvenile tuna added to the school combined with the adult tuna that do not survive in the new location.

The ocean currents in the spawning grounds have shifted from changes in weather patterns due to human activities. The shifts result in fewer eggs surviving and less food for those that do.

Add 10% of the current population to represent new juvenile tuna added to the school combined with the adult tuna that do not survive in the new conditions.

SCIENTIFIC THINKING FOR ALL: A TOOLKIT – UNIT 2: SCIENTIFIC MODELING, ACTIVITY 6: EVENT CARDS

The spawning grounds have been protected by a fishing limit law, so the tuna are able to reproduce at typical rates.

Add 20% of the current population to represent new juvenile tuna added to the school.

SCIENTIFIC THINKING FOR ALL: A TOOLKIT – UNIT 2: SCIENTIFIC MODELING, ACTIVITY 6: EVENT CARDS

The salinity of the ocean at the spawning grounds has increased due to human activities. Larvae survival rates decrease as a result.

Add 10% of the current population to represent new juvenile tuna added to the school.

SCIENTIFIC THINKING FOR ALL: A TOOLKIT – UNIT 2: SCIENTIFIC MODELING, ACTIVITY 6: EVENT CARDS

WEEK 5

SPAWNING GROUNDS

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 2: SCIENTIFIC MODELING, ACTIVITY 6: EVENT CARDS

WEEK 5

SPAWNING GROUNDS

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 2: SCIENTIFIC MODELING, ACTIVITY 6: EVENT CARDS

WEEK 5

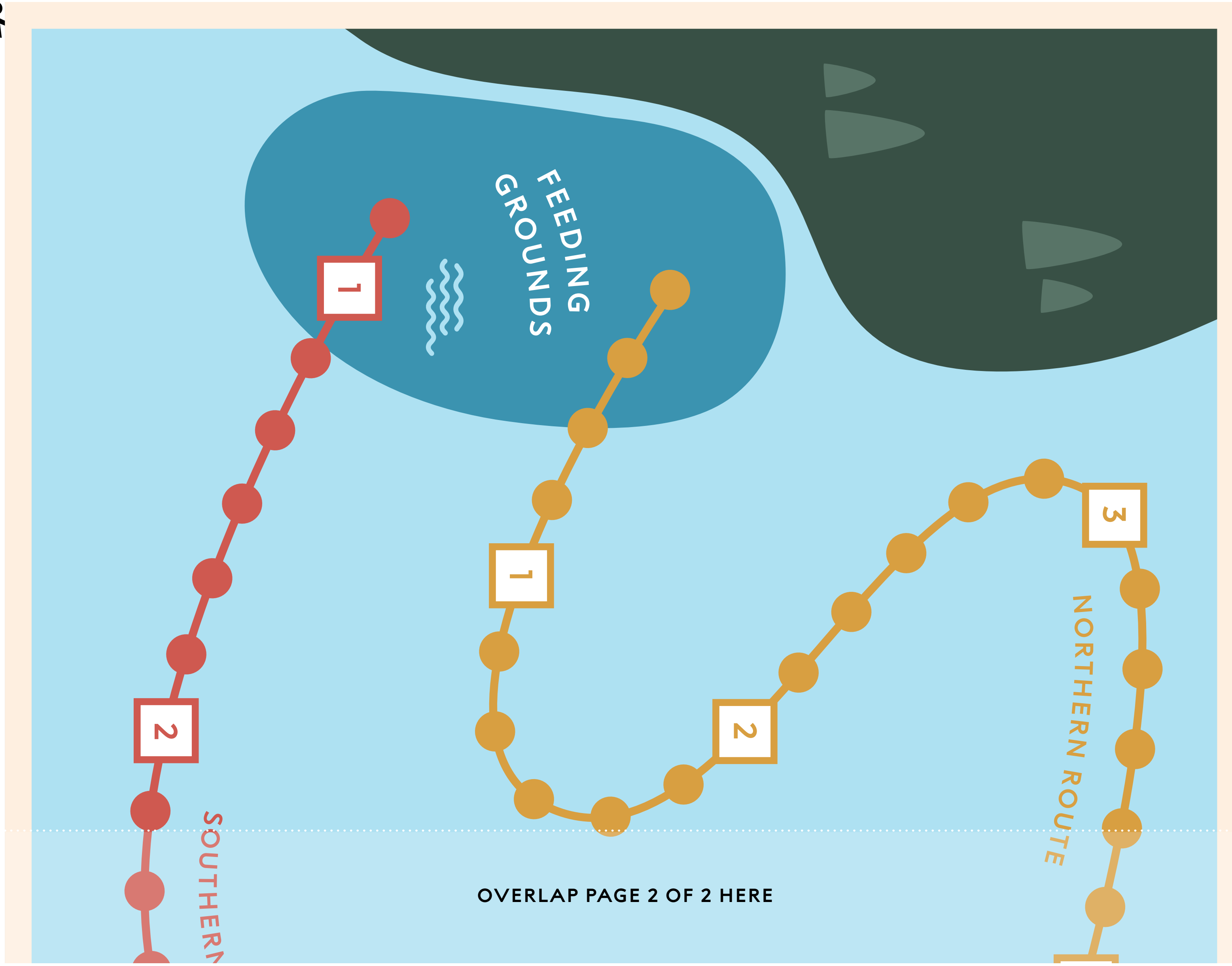
SPAWNING GROUNDS

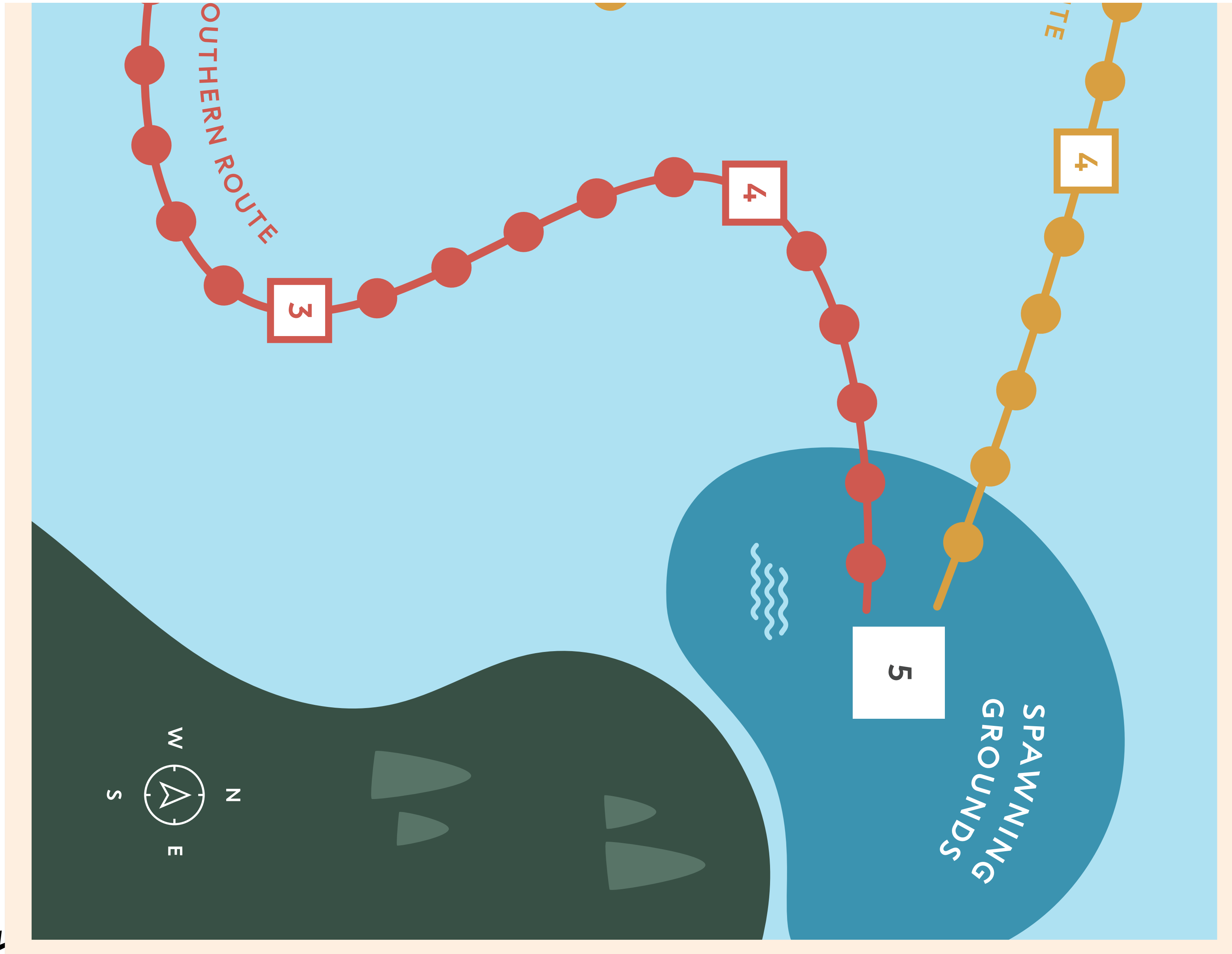
SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 2: SCIENTIFIC MODELING, ACTIVITY 6: EVENT CARDS

WEEK 5

SPAWNING GROUNDS

SCIENTIFIC THINKING FOR ALL: A TOOLKIT
UNIT 2: SCIENTIFIC MODELING, ACTIVITY 6: EVENT CARDS


FEEDING GROUNDS
1
2
1
2
3
NORTHERN ROUTE
OVERLAP PAGE 2 OF 2 HERE


OUTHERN ROUTE
TE
3
4
4
5
SPAWNING GROUNDS
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