INVESTIGATING BARK BEETLE OUTBREAKS

Using Computer Models to Visualize Changes in a Forest Ecosystem

BY LIN XIANG AND APRIL MITCHELL

Over the past two decades, forests in the western United States have dramatically declined due to unprecedented outbreaks of native bark beetles (Bentz et al. 2009). Two species, the mountain pine beetle and the spruce beetle, have attacked and killed enough coniferous trees to cover the entire state of California. Research points to climate change as one of the culprits for the severe outbreaks in recent years, because warm temperatures both decrease beetle winter mortality and increase the rate of beetle growth, development, and reproduction (Bentz et al. 2010).

The bark beetle outbreak is an engaging phenomenon that can develop students' understanding of ecosystems. In this article, we describe a two-week learning sequence in which middle school students in Ogden, Utah, investigate the effect of climate change on bark beetle populations and forest ecosystems (Figure 1). We also present a computer simulation that allows students to investigate changes in a forest ecosystem over time. During the lesson, students engage in authentic scientific inquiry, ultimately using data they collect from the computer model to explain the cause of the recent bark beetle outbreaks.

CONTENT AREA

Ecology

GRADE LEVEL

6–8

BIG IDEA/UNIT

Ecosystem interactions and dynamics; changes to physical or biological components of an ecosystem affect populations.

ESSENTIAL PRE-EXISTING KNOWLEDGE

Organisms have unique and diverse life cycles; animals depend on plants for food and shelter.

TIME REQUIRED

Eight 50-minute class sessions

COST

None

SAFETY

If you choose to visit a forest, follow general safety guidelines for forest field trips. Do not take infested logs with you because bark beetles could spread. Students must wash their hands after handling tree bark and beetle specimens in the classroom.

FIGURE 1: The bark beetle outbreak units

Days	Learning activities	Guiding questions	Assessment
Engage Days 1–2	**Ask questions to obtain information** Students learn about the bark beetle outbreak phenomenon, observe the specimens of tree bark and bark beetle, ask questions, and read to obtain information about the bark beetle life cycle and the interactions between bark beetles and host trees.	• How do beetles depend on trees in the forest? • Is the interaction between the beetles and host trees competitive, predatory, or mutually beneficial? • How does such a tiny beetle kill such a large tree? • Are bark beetles native or invasive, good or bad for the forest? • What is the role or function of bark beetles in a forest ecosystem? • How does your perspective of a beetle outbreak change when you consider different time and spatial scales?	Construct a written explanation for how bark beetles and host trees interact in a forest ecosystem.
Explore Days 3–4	**Develop and use a model to investigate changes in populations** Students conduct a kinesthetic activity to model and understand the interaction between bark beetles and trees and reveal the dynamic nature of the changes over time.	• What caused the bark beetle population to increase? • What effect did this have on the tree population? • What caused the bark beetle population to decrease? • What would happen in our model if we had more trees available to the bark beetles (i.e., a larger forest)? • What would happen if we had run the model for a longer time? Do you think we would see another bark beetle outbreak?	Construct a written explanation for the cause of changes in tree and bark beetle populations over time.
Explain Day 5	**Analyze data to identify possible disruptions to the forest ecosystem** Students analyze climate data collected by scientists to identify a rise in global temperatures over the past several decades.	• What changes in the forest ecosystem have occurred in the last several decades? • How have those changes affected bark beetle populations? How have those changes affected trees in the forest? • What claim can we make from the data? What is a possible cause of the recent bark beetle outbreaks? • Does the data show causal or correlational relationship between global warming and changes in bark beetle populations?	Construct an explanation for why the current bark beetle outbreak is so severe.

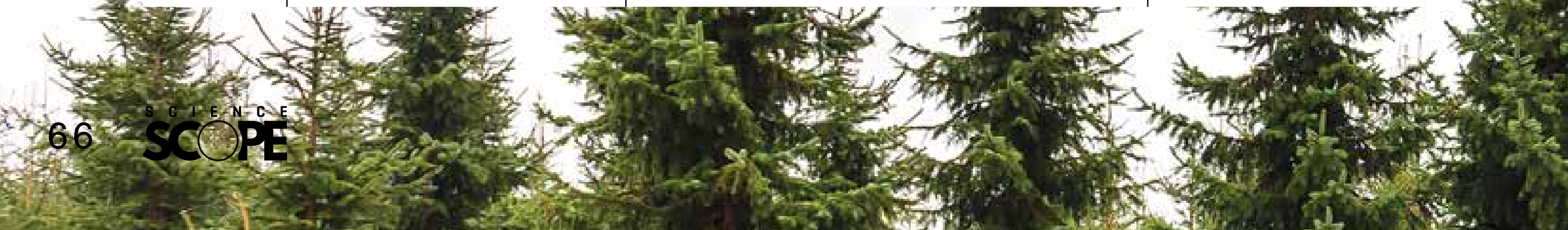
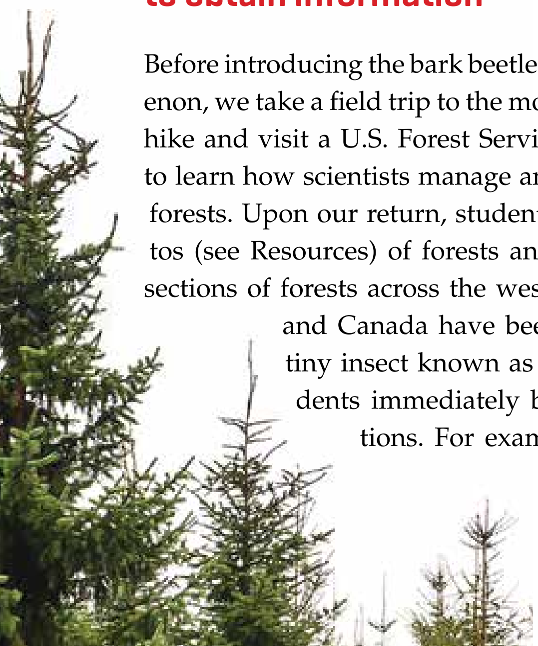


FIGURE 1: The bark beetle outbreak units (continued)

Days	Learning activities	Guiding questions	Assessment
Elaborate Days 6–7	**Use a computer model to investigate the impacts of climate change on bark beetle populations** Students carry out an investigation on the effect of rising temperatures on the severity of bark beetle outbreaks by collecting data at five different mean temperatures.	• How many outbreaks did you observe in a stable forest ecosystem? A disrupted forest ecosystem? • What causes the beetle population to increase and then decrease? • What is the main cause of the recent severe beetle outbreaks? What evidence do you have to support your claim? • Why are computer models so useful to scientists investigating complex systems? • How can computer models be used to make predictions?	Construct a written explanation supported by evidence for the cause of the recent severe bark beetle outbreak.
Evaluate Day 8	**Construct a written argument supported by evidence** Students constructed a written argument about the cause of recent bark beetle outbreaks using the evidence and information from the unit.	• What claim can you make regarding the cause of the recent severe bark beetle outbreaks? • What observable, measurable evidence have you gathered to support your claim? • How does the evidence support your claim? • Is the evidence relevant and sufficient to support the claim? • What disciplinary core ideas can you use as reasoning to support your argument?	Develop an argument that changes in the physical or biological components of the forest ecosystem have affected the stability of populations.

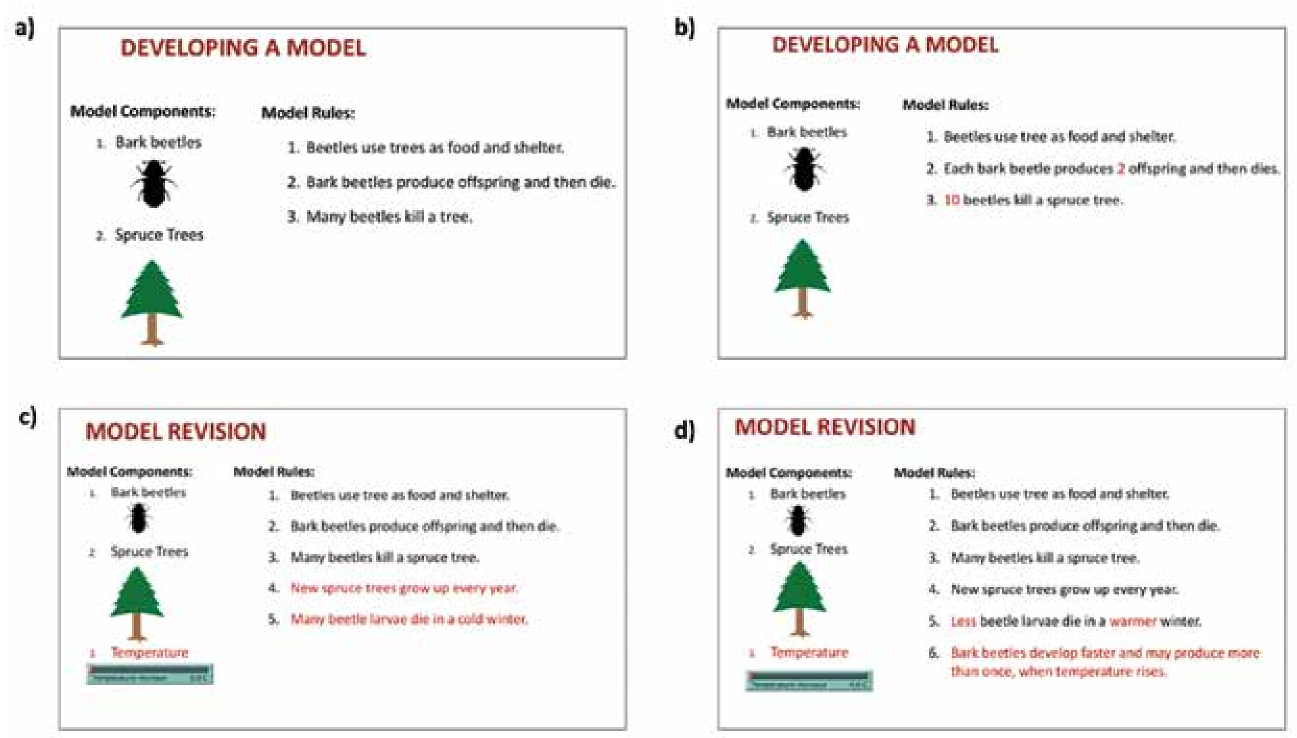
Engage (days 1 and 2): Ask questions to obtain information



Before introducing the bark beetle outbreak phenomenon, we take a field trip to the mountains for a short hike and visit a U.S. Forest Service research station to learn how scientists manage and protect national forests. Upon our return, students view aerial photos (see Resources) of forests and learn that entire sections of forests across the western United States and Canada have been wiped out by a tiny insect known as a bark beetle. Students immediately begin asking questions. For example: *Why are there so many bark beetles? Where did the bark beetles come from? Are bark beetles a native or invasive species? How does a tiny bug kill an entire forest?* We assign students the task of constructing an explanation based on evidence for the cause of the bark beetle outbreaks.

Students begin their investigation by examining tree bark specimens retrieved from an infested forest. The pieces of bark were riddled with tiny holes and dripping with sticky resin. Twisted tunnels (called "galleries") were carved into the underside of the bark, many still filled with abandoned pupal cases about the size of a grain of rice. Students also observed several species of adult bark beetle provided by the U.S. Forest Service. Note: If you do not

FIGURE 2: Bark beetle–spruce tree model



live near a forest or specimens are not available, simply provide students with photos of infested trees, galleries, and bark beetles (see "Teaching slides" in Resources).

After generating questions and examining specimens, students complete a short reading to obtain information about the bark beetle life cycle and the interdependent relationship between beetles and trees (see "Bark beetle reading" in Resources). Students discover that when hundreds of bark beetles shelter in a host tree, the galleries essentially cut off the tree's circulation (i.e., prevent vertical movement of food and water between the upper and lower parts of the tree). The pine or spruce needles first turn orange, then gray, as the tree succumbs to the mass attack of the beetle.

Given the predatory nature of the beetle, students are surprised to discover that bark beetles are native species that have coexisted with trees in the forest for millions of years. Students then consider the role of native bark beetles in a forest ecosystem. From the reading, students learn that bark beetles typically attack old trees, thereby freeing up resources, such as water and light. Consequently, younger trees often experience a growth spurt following a bark beetle outbreak. Students realize that beetles play an important role in the regeneration of the forest.

Then, students discuss the interactions between bark beetles and a host tree based on a set of guiding questions (Figure 1). Students eventually learn two core ideas: 1) organisms compete with each other for limited resources, access to which consequently constrains their growth and reproduction, and 2) predatory interactions may reduce the number of organisms or eliminate whole populations (see *NGSS* connections, p. 76). As a formative assessment, students complete a short written argument using these core ideas to explain the interactions they have observed between the bark beetles and a host tree. Most responses will likely mention that bark beetles depend on a host tree for food, shelter, and reproduction. The written arguments should include that bark beetles are predatory and depend on a host tree for food, shelter, and reproduction.

Explore (days 3 and 4): Investigating changes in populations

Despite their important role in a forest ecosystem, bark beetles quickly change from regenerative to destructive if the population size increases too dramatically. However, many middle school students hold a static view of population, which prevents them from understanding such change. To address the misconception, ask students: *Do bark beetle populations typically stay the same, or do they change from year to year? What might cause a population of beetles to increase in number? To decrease in number?* To investigate what causes bark beetle populations to change over time, students develop and use a kinesthetic model of the forest ecosystem to simulate the changes.

First, students identify the relevant components of the forest ecosystem: bark beetles and trees. Then they discuss how the components should interact with one another. Taking inspiration from the bark beetle life cycle, students develop a sequence of steps for their model: Adult bark beetles (1) find a host tree in spring and (2) produce offspring in summer and die soon after laying eggs. If a tree is attacked by too many beetles, then (3) the tree dies (Figure 2a). Each adult bark beetle produces two offspring, and any tree hosting 10 or more beetles is killed (Figure 2b). Students repeat this sequence of steps multiple times to represent the passing of years. One assumption of the model is that the offspring (as larvae in diapause) always survive the winter and emerge from trees as winged adults the following spring to continue the life cycle.

FIGURE 3: Class data table

a)

Year	Number of Beetles	Number of Living Trees	Number of Dead Trees
1			
2			
3			
4			
5			
6			
7			
8			

b)

Year	Number of Beetles	Number of Living Trees	Number of Dead Trees
1	2	12	0
2	4	12	0
3	8	12	0
4	16	11	1
5	32	9	3
6	64	3	9
7	128	0	12
8	0	0	12

c)

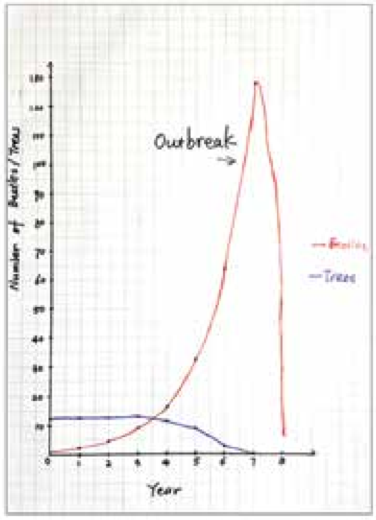
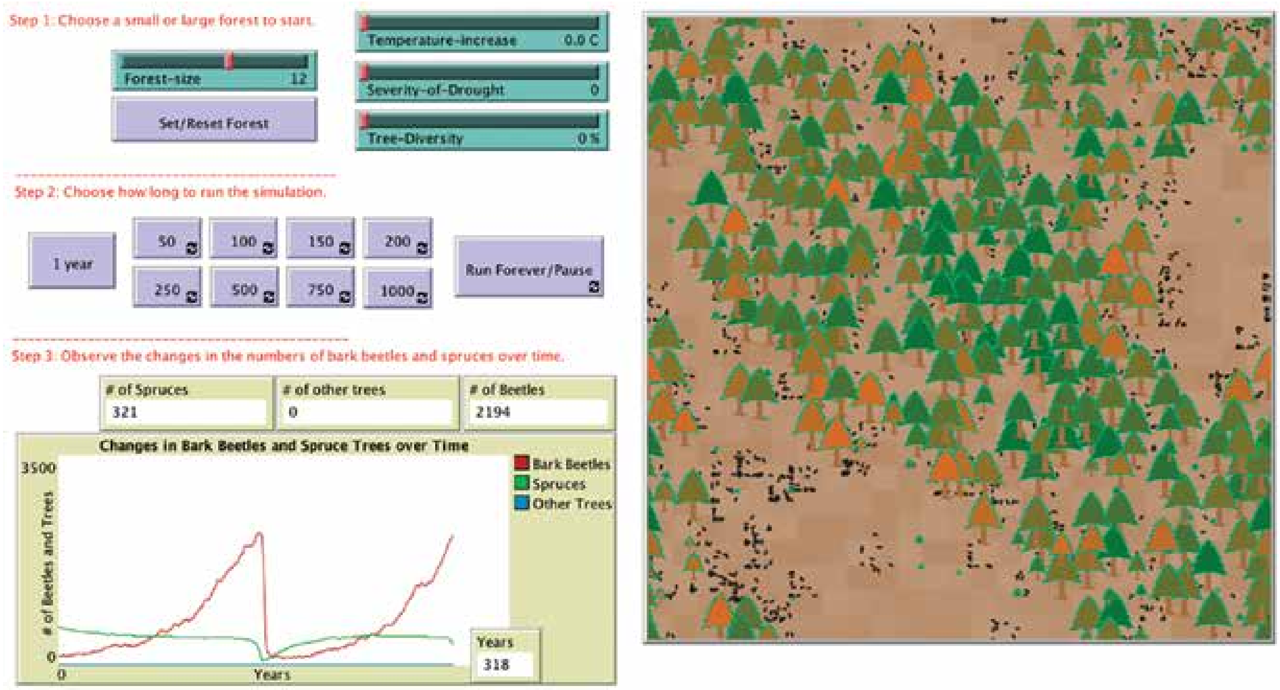


FIGURE 4: Paper trees and bark beetles

The class uses this model to track the number of beetles in the forest over time, as well as the number of living and dead trees. The class collects data in a table (Figure 3a). To begin the activity, start with a small forest of 12 paper trees and one female bark beetle (Figure 4; see "Bark Beetle Outbreak Kinesthetic Activity" in Resources). A student, acting as the female bark beetle, identifies a tree and places her two offspring there. The female bark beetle then dies (sits down), but her offspring stay warm inside the tree trunk over winter. At this point, the year 1 data consist of two bark beetles, 12 living trees, and zero dead trees (Figure 3b).

The following spring, the offspring mature into winged adults and fly away—that is, the teacher

FIGURE 5: Screenshot of computer simulation



removes the paper beetles from the tree and hands them to two new students. Next, the two new students, representing a new generation of adult bark beetles, find a tree, reproduce (place two offspring on a tree), and then die (sit down), resulting in the year 2 data of four bark beetles, 12 living trees, and zero dead trees. As the class repeats this process, the population of bark beetles will double each round. Students do not place beetles on a tree that has had 10 beetles (i.e., fully occupied). Trees with 10 beetles will die (flip over) at the end of each round (Figure 4). After about eight rounds, all the trees will die. Ask students to predict what will happen to the beetle population in the following year. The class can easily foresee the beetle population will crash as a result.

Students plot the class data on a graph in their science notebooks (Figure 3c), then discuss the results in small groups. We provide the following questions to help guide small-group discussions: *How did the beetle and tree populations change over time? What caused the beetle population to increase? To decrease? What caused the tree population to decrease? What can the model tell us about the cause of changes in populations?* We use the graph to explain that an outbreak occurs when a bark beetle population grows exponentially and the host tree population significantly declines, eventually reaching to a new core idea: ecosystems are dynamic in nature; their characteristics can vary over time (see *NGSS* connections, p. 76).

Students use the disciplinary cores ideas from the lessons and the data collected from the model as evidence to construct a written explanation in their science notebooks describing what causes bark beetle populations to change over time. When beetles have trees for food and shelter, the population increases; when beetles run out of food, the population decreases. Before finishing the lesson, discuss any limitations of the kinesthetic model. For instance, only a very small forest is involved, and not all bark beetle larvae survive the winter in the real world. Use students' written explanations as a formative assessment.

Explain (day 5): Identifying possible environmental disruptions to the forest ecosystem

Historical records indicate that bark beetle outbreaks

Bayerischer Wald and Sumava mountains with hills, meadows, and forest devastated by bark beetle infestation, seen from the hiking trail below Grosser Rachel Hill in the Bayerischer Wald mountains

have occurred once every few decades or once every few centuries. Typically, an outbreak neither lasts more than a few years nor kills all the trees in an entire forest, because winter cold snaps wipe out most of the dormant beetle larvae under the tree bark. Scientists estimate that in the early 1900s, less than 20% of bark beetle larvae survived the winter. But currently, 60% to 80% of larvae survive the winter (Logan et al. 2010). The increase in survival correlates with the rise in global temperatures over the past century, suggesting climate change is a major driver.

To help students understand why the current outbreak across the West is so unusual, invite students to analyze a data set and generate claims. The data set includes climate data, aerial photographs, maps, and graphs showing the amount of land affected by bark beetles in Colorado and across the western United States (see "Teaching slides" in Resources). Students will discover that mean temperatures, locally and globally, have increased about 1°C over the last 50 years (see "Teaching slides"). Based on the information from a reading in a previous lesson that warmer temperature may foster beetle growth, development, and reproduction, students may claim that rising temperatures are triggering an outbreak in bark beetle populations. Here, we suggest showing a TEDx video talk called "The Great Mountain Pine Beetle Outbreak" by Diana Six, a professor of entomology and pathology at the University of Montana who studies the mountain pine beetle. Six explains the underlying mechanism of an outbreak and why warming temperatures pose such a threat to our forests. Another suitable bark beetle outbreak video may also be used in class (see both in Resources).

Conclude the lesson by emphasizing that an ecosystem is a complex system with many physical and biological components affecting the size of bark beetle populations. Introduce three disciplinary cores ideas: (1) growth of organisms and population increases are limited by access to resources, (2) ecosystems are dynamic in nature; their characteristics can vary over time, and (3) disruptions to any physical or biological component of an ecosystem can lead to shifts in all its populations (see *NGSS* connections, p. 76). Then prompt students to use these disciplinary core ideas to explain the underlying mechanism of a severe bark beetle outbreak. Students record their explanation in a science notebook, which we used as a formative assessment.

Elaborate (days 6–7): Investigating the effects of climate change

Students may be skeptical that a change in temperature of just 1°C can significantly alter a forest ecosystem. We use a computer simulation to support student thinking about complex systems (Xiang 2017). The simulation allows students to investigate interactions among bark beetles and spruce trees under different environmental conditions, including rising temperature and drought, over hundreds of years (Figure 5). Students use the computer model to collect data on changes in populations over time and engage in authentic scientific work. The computer model was developed using NetLogo (Wilensky 1999) and is available for free (see "Bark beetle epidemic simulation" in Resources).

To introduce students to the computer model, discuss the limitations of the previous kinesthetic model of the forest ecosystem, which tracks only 12 trees over eight years. Using technology, we can now investigate a much larger forest for hundreds of years under different environmental conditions. Explain that computer models are powerful tools used by scientists to investigate complex systems.

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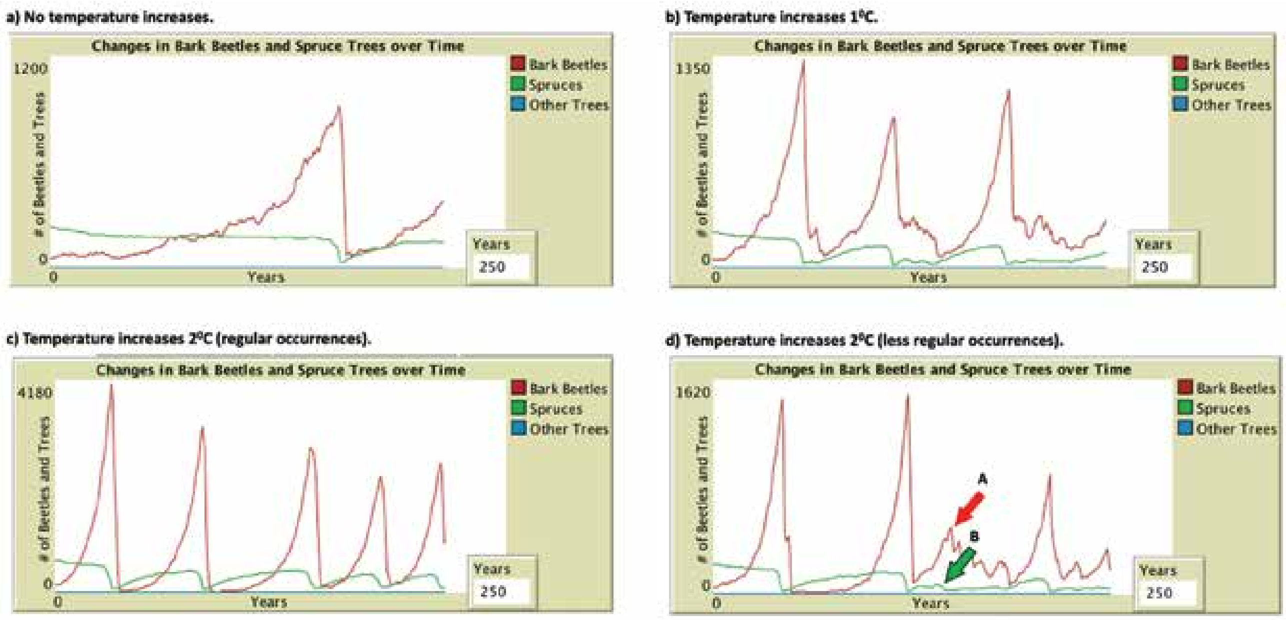
First, work with students to expand the kinesthetic model to the model embedded in the computer simulation (Figure 2c). The revised model includes forest regeneration and overwinter mortality of beetle larvae. Then, demonstrate how to use the model by running the simulation for 250 years with environmental conditions set at default (i.e., no temperature increase or drought in the forest ecosystem and only one tree species in the forest). Students will notice the beetles and trees coming and going in the forest over time. At year 250, stop the simulation to interpret the data that have been produced by the computer model. A line graph shows the change in population size over time for both beetles and trees (Figure 6a). The higher the peak, the more beetles (or trees) you have in the forest. For this trial, we counted one outbreak in a time span of 250 years.

After students investigate the changes in beetle and tree populations with default environmental conditions, add an additional component to the model: temperature. What are the rules for temperature? If we increase the mean temperature, by one degree Celsius or half a degree Celsius, then two things happen: More larvae survive the winter, and adult bark beetles reproduce more than once (Figure 2d). Emphasize that because the beetles select host trees at random, students will obtain slightly different results each time they run the model—even when environmental conditions are the same. Thus, students should try running multiple trials for an environmental condition and look for patterns in the data, which resembles the authentic investigation.

At this point, invite students to play with the model and explore its capabilities in preparation for planning an experiment. You can expect students to gravitate toward testing worst-case scenarios with high temperatures and severe drought. After playing with the model for about 10 minutes, prompt students to prepare a table in their science notebooks to systematically collect data from the computer simulation with respect to the impacts of rising temperature on bark beetle outbreaks. Students can record the number of outbreaks for each change in temperature rising up to 0.5° and 1°C, including results from at least three trials. Students may also fill out a provided data collection worksheet (see Resources) while conducting the trials.

Students may need to be reminded that a good experiment, or a fair test, only changes one variable at a time. Because we are changing temperature in our experiment, all other parameters, such as drought and tree diversity, should remain on default settings. Note that temperature is our independent variable. The number of bark beetles or the number of bark beetle outbreaks is our dependent variable.

FIGURE 6: Graphs showing changes in populations with and without temperature increases



After students carry out their investigation, discuss the results as a class. We asked if students noticed any patterns in the data. Students identified that when they increased the temperature, the number of bark beetle outbreaks increased. For example, with no temperature change, one outbreak is typically observed every 250 years. With a temperature increase of 1°C, three outbreaks are typically observed every 250 years (Figure 6b). Students conclude that rising temperatures cause the number of bark beetle outbreaks to increase. Mention that the number of bark beetles per outbreak, indicated by the height of peak, also increases, providing evidence that rising temperatures influence the severity of an outbreak as well. Then invite students to further consider that rising temperatures allow bark beetles to enter the areas that used to be too cold for them to survive. What would it look like when more intense beetle outbreaks take place in multiple forest ecosystems simultaneously?

Next, discuss how a computer model allows us to make predictions. Ask students: *What will happen to forest ecosystems as global temperatures continue to rise?* Our students predicted that more outbreaks would take place. Indeed, they did observe that when the temperature increased by 2°C, four or five outbreaks typically occurred in 250 years (Figure 6c). If students have difficulty deciding whether a peak represents an outbreak, have them examine the changes in both beetle and tree populations. For example, in Figure 6d, arrow A points to a moderate increase in beetle population size, which might be an outbreak, but arrow B points to a relatively small change in the tree population. Our students decided this peak did not count as an outbreak because the change in the beetle population was small and forest decline was not significant. Once students set this criterion, they should use it consistently in their experiments. Occasionally the simulation may stop running, indicating the beetle population crashed because there is not enough forest to provide necessary food and shelter. If that happens, have students discard this trial and collect another data point.

If time permits, students may plan additional experiments to determine the effects of drought and tree diversity (i.e., availability of host trees) on bark beetle populations. Note that changing the severity of a drought weakens tree defenses and therefore reduces the number of beetles it takes to kill a tree. Conclude by connecting to the core idea—disruptions to any physical or biological component of an ecosystem can lead to shifts in all its populations (see *NGSS* connections p. 76)—and emphasizing that small changes in the physical components of an ecosystem, i.e., a temperature increase of 1°C, can have a large effect on both bark beetle and tree populations.

Timber damaged by bark beetles

While the simulation can be run using an internet browser, the bark beetle simulation runs much faster and more smoothly if it is downloaded. We suggest teachers install both NetLogo (see Resources) and the bark beetle simulation on a set of school computers or laptops for students to use. Neither the NetLogo software nor the bark beetle epidemic simulation are compatible with tablets, iPads, or Chromebooks. Also, we intentionally use a kinesthetic model before the computer model. We find that students better understand the computer model if they first act out the sequence of steps, or model rules. Collecting data in the kinesthetic model also prepares students to interpret the graphs produced by the computer simulation.

Evaluate (day 8): Constructing an evidence-based argument

Before students begin to write their arguments, review the evidence they have gathered over the past few days, including evidence from the reading, the climate data, and the data they collected using the computer model. Prompt students to choose at least three pieces of measurable evidence to support their argument. Also, encourage students to use the disciplinary core ideas to develop their reasoning. Ensure the disciplinary core ideas are visible to students as they prepare their written arguments.

Constructing an evidence-based argument is difficult for many middle school students. Encourage students to use the previous writings in their science notebooks to help them assemble their argument. The writing prompts provided at the end of each previous lesson were intentionally designed to scaffold the writing process for students. Equally important, the daily writing prompts allow students to check their understanding and practice new vocabulary in a meaningful context. Students can be prompted to include academic vocabulary in their written arguments by providing a word bank. Sentence frames (Figure 7) also support the writing process for students, especially English Language Learners.

After students construct their written arguments, they can work with a partner to get critical feedback. Our students also enjoy using colored pencils or highlighters to color-code their claim, evidence, and reasoning. The arguments can be assessed using a grading rubric (see Resources).

Conclusion

The current severe bark beetle outbreak is an engaging phenomenon that can deepen students' un-

FIGURE 7: Sentence frames

Claim	Evidence	Reasoning
• Bark beetle outbreaks have increased in recent years due to: • We can conclude that: • This result tells us:	• My evidence is: • A pattern in the data was: • We observed that: • We measured/counted:	• This means that: • This happened because: • The reason is: • This evidence supports my claim because: • This makes sense because we know: • This is important because:

derstanding of core ideas about ecosystem interactions and dynamics. We find the computer model to be especially useful for helping students visualize dynamic changes in a forest ecosystem that occur on a large time scale. Because computer models are a powerful tool increasingly used by scientists to investigate a wide variety of phenomena and complex systems, it is important to provide students with opportunities to use computer models in the science classroom. We hope the curriculum described here will help your students deepen their understanding of ecosystems and open their eyes to the widespread effects of climate change on organisms around the world. ●

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RESOURCES

Aerial photos—*www.fs.usda.gov/detail/r2/forest-grasslandhealth/?cid=stelprdb5447223*

Bark beetle outbreaks video—*https://science360.gov/obj/video/78f76a11-8996-4718-ba58-d4338dc0686a/bark-beetle-outbreaks*

Bark beetle outbreak teaching materials (Teaching slides, bark beetle reading, bark beetle outbreak kinesthetic activity, data collection worksheet, CER grading rubric, bark beetle epidemic simulation)—*https://sites.google.com/view/3d-science-abm/ecology/bark-beetle-epidemic*

NetLogo—*https://ccl.northwestern.edu/netlogo/download.shtml*

TEDx Talk— The great mountain pine beetle outbreak | Diana Six | TEDxUMontana *https://www.youtube.com/watch?v=iSIEzq0fofk*

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Connecting to the *Next Generation Science Standards* (NGSS Lead States 2013)

- The chart below makes one set of connections between the instruction outlined in this article and the *NGSS*. Other valid connections are likely; however, space restrictions prevent us from listing all possibilities.
- The materials, lessons, and activities outlined in the article are just one step toward reaching the performance expectations listed below.

Standard

MS-LS2 Ecosystems: Interactions, Energy, and Dynamics
www.nextgenscience.org/dci-arrangement/ms-ls2-ecosystems-interactions-energy-and-dynamics

Performance Expectations

MS-LS2-1. Analyze and interpret data to provide evidence for the effects of resource availability on organisms and populations of organisms in an ecosystem.

MS-LS2-4. Construct an argument supported by empirical evidence that changes to physical or biological components of an ecosystem affect populations.

DIMENSIONS	CLASSROOM CONNECTIONS
Science and Engineering Practices	
Analyzing and Interpreting Data	Students analyze and interpret the data about climate change and the changes in bark beetle and tree populations from a kinesthetic activity and a computer simulation of forest ecosystem.
Engaging in Argument From Evidence	Students use collected data as evidence to construct an argument for the effect of rising temperature on number of bark beetle outbreaks.
Disciplinary Core Idea	
LS2.A: Interdependent Relationships in Ecosystems • Organisms, and populations of organisms, are dependent on their environmental interactions both with other living things and with nonliving factors.	Students use disciplinary core ideas about ecosystems to understand the interconnections among environmental factors, bark beetle and host trees, to reason about the data from authentic research and the data from kinesthetic activities and computer simulation, and to identify the relationship between rising temperatures and current severe bark beetle outbreaks.
Crosscutting Concepts	
Patterns	Students identify patterns in climate data and in data collected from a kinesthetic activity and a computer simulation.
Cause and Effect	Students identify the cause of the increasing number of bark beetle outbreaks based on the data patterns.
Systems and System Models	Students develop, use, and expand models of a forest ecosystem (i.e., a kinesthetic model and a computer simulation) to identify factors that cause changes in populations.
Stability and Change	Students discover the stable dynamic in bark beetle and spruce tree populations and global warming (e.g., a change of 1°C in average temperature) is disrupting the stability of forest ecosystems, causing bark beetle outbreaks to increase in number and intensity.