

Beads, Cards and Cycles: A Fox-and-Vole Simulation

Investigation question: If foxes can only survive by catching voles, and voles can only breed if they are not caught, what pattern do the two populations make over twenty rounds, and which one changes first?

Collaborative systems modeling

Groups of 4

1 session

Setup 5 · Activity 40 · Cleanup 5 min

MS-LS2-2 · practice

MS-LS2-1 · supports

Scientific purpose

Students run a rule-based model of a predator and its prey with beads and cardstock squares, record both populations for twenty rounds, graph them on shared axes, and look for the pattern the lesson describes: rises and falls in the predator that trail the rises and falls in the prey. Because nothing in the model changes except the rules, any cycle that appears must come from the predator-prey link itself, which is the controlled comparison that real ecosystems such as Isle Royale cannot offer.

Why this helps students with this chapter

A textbook graph of smooth waves is easy to memorize and hard to believe. When students watch their own foxes starve two rounds after their own voles crash, and then watch the voles recover because the foxes are gone, the lag stops being a fact to recall and becomes something the rules forced to happen. Running the model also makes its limits visible: students see which rules are unrealistic and can say exactly why real data are bumpier.

Standards connections

MS-LS2-2 (practice, the predatory-interaction pattern and its use for prediction): Students generate predator-prey data from a model, identify the lag pattern, and predict what the same rules would do in a different ecosystem. It is practice rather than assessment because the model covers one interaction type; the cross-ecosystem explanation comes in Lab 2 and W6.

MS-LS2-1 (supports, resource limits on population size): The meadow can feed only sixty voles and each fox needs at least three voles to survive a round, which carries the resource-availability idea from Lesson 20 into this model.

Roles (rotate each session)

- **Scatterer:** Counts out the voles for the round, drops them onto the meadow from about 20 cm so they spread randomly, and nudges any that land outside the square back inside the edge.
- **Hunter:** Tosses each fox card from about 20 cm so it lands flat on the meadow, counts the voles it touches, and removes them to the burrow cup before tossing the next fox.

- **Bookkeeper:** Applies the fox and vole rules at the end of each round (who starves, who reproduces, the sixty-vole cap, immigration) and announces next round's starting numbers.
- **Recorder and grapher:** Writes every count in the data table, checks the bookkeeper's arithmetic, and plots both populations on the graph as the rounds go by.

Materials

Item	Quantity	Per	Note
Dried lima beans or pony beads (the voles)	about 70	group	One color per group makes cleanup easy. Larger 'voles' such as lima beans are touched by the cards more often and roll less, so the cycle shows up sooner than with small beads.
Cardstock squares 10 cm by 10 cm (the foxes)	12	group	Cut from file folders or cereal boxes; all the same size.
Meadow: a 30 cm by 30 cm square drawn on paper, taped inside a shallow tray or box lid	1	group	The raised edge keeps beads from rolling onto the floor.
Small cups labeled Burrow (spare voles) and Den (spare foxes)	2	group	
Recording sheet and graph grid	1	student	
Ruler (to check the 20 cm drop height)	1	group	
Two colors of pencil or pen for the graph	1 set	student	

Estimated cost: 6 to 10 per class (an estimate; Estimate. A 500-count bag of pony beads is about \$5 and serves eight groups; cardstock, trays and cups are classroom stock or recycled. Dried beans from a grocery store cost about \$2 per bag.)

Safety

- Beads and beans are a choking hazard for small children and pets; keep them away from mouths and count them back into the burrow cup at the end so none leave the room.
- Beads on a hard floor are a slip hazard; stop and pick up any that escape the tray before continuing.
- Toss cards onto the meadow only, never at a person, and keep the drop height to about 20 cm so beads do not bounce out.
- No chemicals, heat or sharp tools are used; scissors are used only during teacher prep.

Teacher preparation and setup

1. Cut twelve 10 cm squares of cardstock per group and check that they are all the same size; a bigger card catches more voles and will change that group's cycle.
2. Draw or print the 30 cm meadow square on plain paper and tape one into each tray. Tape an X at one corner as the spot the scatterer stands over.

- Count 70 beads into each burrow cup and 12 cards into each den cup, then run three or four rounds yourself so you know how the counts behave with your beads and cards.
- Copy the data table and graph grid for every student; the graph needs round 1 to 20 on the horizontal axis and 0 to 60 on the vertical axis.
- Write the rules on the board in short form: starve under 3, breed at 6, voles double, cap 60, immigrants 3 and 1.

Investigation design

Independent variable	Round number (time), with the number of foxes and voles changing each round according to the rules
Dependent variable	Number of voles and number of foxes at the start of each round
Controlled	Meadow size (30 cm square) and fox card size (10 cm square); Drop and toss height (about 20 cm); The rules: starve under 3 catches, pup at 6 or more, voles double, 60-vole cap, immigration of 3 voles or 1 fox; Starting numbers: 6 voles and 1 fox
Trials	One 20-round run per group; the class pools the round of the first vole peak and first fox peak from every group on the board.
Comparison	The round of each vole peak against the round of the fox peak that follows it; the model's graph against the textbook's smooth curves and the Isle Royale account.

Student procedure

- Set up the meadow in its tray. Put 6 voles on the meadow and 1 fox card in the hunter's hand. Put the rest in the burrow cup and the den cup. Write '6 voles, 1 fox' in the row for round 1.
- Scatterer: stand at the X corner, collect the voles, hold your hand about 20 cm above the middle of the meadow, and drop them so they spread across it. Move any vole that lands outside the square, or rolls against the tray wall, back onto the meadow a few centimeters in from the edge.
- Hunter: toss the first fox card from about 20 cm so it lands flat somewhere on the meadow. If it lands partly off the square, toss it again. Count every vole the card touches or covers; those voles are caught. Move them to the burrow cup. Repeat for every fox card, one at a time.
- Bookkeeper: decide each fox's fate from what it caught. Caught 0, 1 or 2: the fox starves; put its card in the den cup. Caught 3, 4 or 5: the fox survives. Caught 6 or more: the fox survives and raises one pup; take one extra card from the den cup for next round.
- Bookkeeper: count the voles still on the meadow. Each survivor has a litter, so double the number by adding the same number of voles from the burrow cup. The meadow can feed only 60 voles; if doubling would give more than 60, use 60.
- Immigration: if no voles are left after step 5, 3 voles move in from a neighboring meadow. If no foxes are left after step 4, 1 fox moves in. Record the number of voles and foxes that will start the next round.
- Recorder: fill in the row for the round (voles and foxes at the start, total voles caught, fox fates, voles after breeding, foxes for next round), then plot the two starting counts for the round on the graph. Use one color for voles and another for foxes.

8. Repeat steps 2 to 7 until you have completed 20 rounds. Rotate roles every five rounds so everyone scatters, hunts and keeps the books.
9. Connect the vole points with one line and the fox points with another. Mark the first vole peak with a V and the first fox peak with an F. If the voles sit at the 60 cap for several rounds, the peak is that whole flat top: put the V on the last round at 60, just before the voles start to fall.
10. Answer the recording-sheet questions, return every bead and card to the cups, and count them: 70 beads and 12 cards.

Expected observations

- The single starting fox usually starves in round 1 or 2 because few voles are on the meadow, and an immigrant fox replaces it. Voles climb roughly 6, 10 to 12, 18 to 24, 28 to 46, and reach the 60 cap around round 5 or 6.
- With 60 voles on the meadow the first fox card typically touches 5 to 10 beads, so foxes survive and add pups. Because each fox can add only one pup per round, and an unlucky fox can still starve, foxes build up over five to eight rounds (for example 1, 2, 3, 4, 6, 8) while the voles sit at or near the cap. The voles start to fall for good once there are about seven to nine foxes, usually somewhere between rounds 8 and 14.
- When foxes reach about 8 to 11, they catch most of the voles; voles drop to somewhere between about 10 and 35 (lower when the 'voles' are large and easy to touch), the foxes starve over the next one or two rounds, and the voles recover. In computer runs of these rules about four groups in five see this full cycle by round 20; the rest still have voles at or near the cap, or only starting to fall, at round 20 (fewer with lima beans than with small beads). A second vole peak, when it comes, usually arrives around round 15 to 20.
- Measured from the last round the voles spend at the cap, the fox peak lands one or two rounds later in most groups (three in a few, the same round in a few); the fox low lands zero to three rounds after the vole low. Measured from the round the voles first reach 60, the fox peak is usually three to nine rounds later; that is why the V goes on the last round of the flat top.

Likely difficulties

- Groups argue over whether a bead touching the card's edge is caught. Decide the rule before round 1 (touching counts) and keep it for the whole run.
- The bookkeeper forgets the cap and lets voles climb past 60, or doubles the voles before removing the caught ones. Have the recorder check each row against the rule card.
- Beads bounce or roll into corners so the meadow is not random; the scatterer should drop from 20 cm above the center, not the edge, and spread any obvious pile with one finger before the hunt. Beads lined up against the tray wall are almost never caught, and a ring of them can keep the voles from ever crashing.
- Groups run out of fox cards during a fox boom. Twelve is usually enough; if a group needs more, that is itself a sign the voles are about to crash, and the group can note the shortage and continue.
- Students plot foxes on a separate scale so the lines look the same size. Keep one scale for both; the fox line is supposed to be small.

Structured debrief

1. Pool every group's first vole peak and first fox peak on the board. The fox peak should come one to three rounds after the vole peak in most groups, even though the random tosses differed. Ask why the lag is so consistent: the pup rule only adds foxes the round after a big catch, and the starve rule only removes them the round after a poor one.
2. Line up two or three groups' graphs. The peaks differ in height and timing, but the order is the same: voles up, foxes up, voles down, foxes down. That is what 'a pattern, not a law' looks like, and it is why ecologists can recognize a predator-prey cycle in data from an ecosystem they have never visited.
3. Ask which rule is most unlike real life. Expect 'voles double every round', 'foxes die after one bad round' and 'the cap is exactly 60'. Connect each to the textbook: real prey breed seasonally, real predators can survive lean months, and real food limits change with the weather. These are the 'other factors' that make Isle Royale's lines bumpier than the model's.
4. Close with the prediction question (q7): the same rules with different names give the same shape, which is the point of MS-LS2-2. Then ask what the model cannot show: mutualism, competition, parasitism, or an ecosystem with many predators and many prey. Lab 2 covers those.

Recording sheet: what students fill in

Lab 1 recording sheet: Beads, cards and cycles

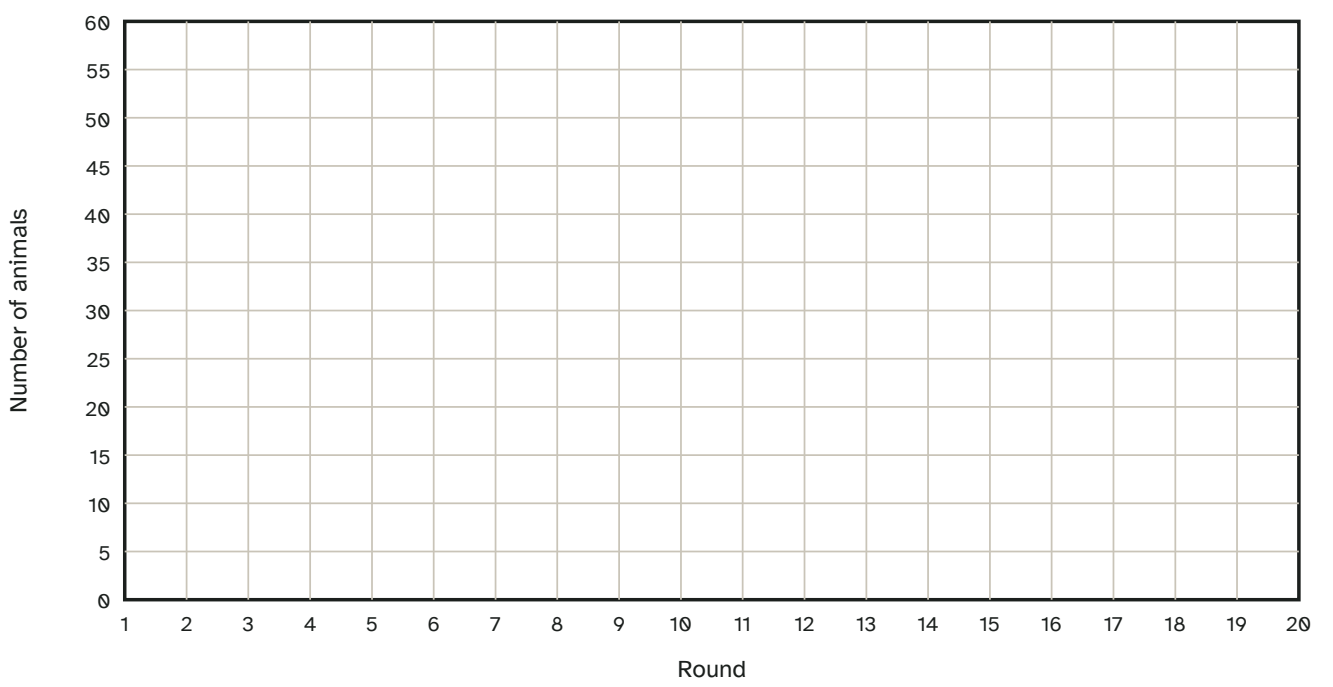
The rules in short — A fox that catches 0-2 voles starves. A fox that catches 3-5 survives. A fox that catches 6 or more survives and adds one pup. Surviving voles double, up to a limit of 60. If voles hit zero, 3 move in; if foxes hit zero, 1 moves in.

Round-by-round data (counts are at the start of each round)

Round	Voles at start	Foxes at start	Total voles caught	Fox fates (S = survived, X = starved, P = pup added)	Voles after doubling (max 60)	Foxes for next round
1	6	1				
2						
3						
4						
5						
6						
7						
8						
9						

Round	Voles at start	Foxes at start	Total voles caught	Fox fates (S = survived, X = starved, P = pup added)	Voles after doubling (max 60)	Foxes for next round
10						
11						
12						
13						
14						
15						
16						
17						
18						
19						
20						

Voles and foxes at the start of each round



1. In which round did the voles first peak (the last round at the top, if they stayed at 60 for a while), and in which round did the foxes first peak? How many rounds apart are they?

Answer: Answers vary by group. A typical run: voles first reach the 60 cap around round 5 or 6 and stay at or near it until about round 8 to 14; the last round at 60 is the vole peak. Foxes first peak around round 9 to 15. The gap is usually one or two rounds, sometimes three.

Why: The pup rule adds foxes the round after a large catch, so fox numbers keep rising for a round or two after the voles start to fall. Because the cap makes the vole peak a flat top, the gap is counted from the last round at 60. Accept any pair of rounds that matches the student's own table and the stated rule.

- Both peak rounds taken correctly from the table
- Gap computed correctly and the fox peak is later

2. Look at the rounds right after the fox peak. What happened to the voles, and then what happened to the foxes? Use numbers from your table.

Answer: Answers vary. Pattern: in the rounds after the fox peak the voles fell sharply (for example from 60 to about 20) because many foxes were catching them; then, one or two rounds later, the foxes fell (for example from 9 to 3) because most caught fewer than three voles and starved.

Why: This is the second half of the loop: heavy predation lowers prey, then scarce prey lowers predators. Students should cite at least two numbers from their table.

- States that voles fell first, then foxes
- Uses numbers from the student's own table

Analysis questions: answer key

3. Round 9 in one group began with 24 voles and 2 foxes. The first fox card caught 7 voles and the second caught 4. Using the rules, how many voles and how many foxes begin round 10? Show each step.

Answer: 26 voles and 3 foxes. Caught: $7 + 4 = 11$ voles. Survivors: $24 - 11 = 13$. Doubling: $13 \times 2 = 26$, which is under the 60 cap. Fox 1 caught 7 (6 or more), so it survives and adds a pup; fox 2 caught 4, so it survives. Foxes: $2 + 1 = 3$.

Why: Checks that students apply the rules in order: remove caught voles, then double, then cap; decide each fox separately.

Also acceptable: Full credit for 26 and 3 with the steps shown; partial credit if the doubling was done before removing the caught voles (gives 37), with the error identified.

4. Which rule in the model causes the fox line to rise after the vole line, instead of at the same time? Explain how that rule stands in for something that happens to real predators.

Answer: The pup rule. A fox only adds a pup after a round in which it caught six or more voles, and the pup only appears in the next round, so fox numbers rise one round after a round of plentiful voles. The starve rule works the same way in the other direction: a fox disappears the round after a poor catch. In real life, predators need time to find mates, carry and raise young, or to starve, so their numbers respond to prey months or years later.

Why: The core of the lag is that reproduction and death happen after the resource condition, not during it. Students should name the rule and the real-world process it represents.

- Names the pup rule (or the pup and starve rules)
- Explains that the effect shows up the next round
- Links the delay to real reproduction or starvation time

5. Describe the overall shape of your two lines across the twenty rounds. Did the pattern repeat? Were the second peaks the same height as the first? Explain why a repeat with different heights still counts as the pattern.

Answer: Two waves that rise and fall in the same order: voles up, foxes up, voles down, foxes down, then voles up again. In twenty rounds most groups see one full cycle and the start of a second. The second peaks are usually a different height or timing (for example a second vole peak of 48 instead of 60, or a fox line that has only begun to climb again by round 20) because the random tosses were different. The pattern is the order and the lag, not the exact numbers, so a repeat with different heights still counts.

Why: This separates 'pattern' from 'identical numbers', which is what the lesson means by a pattern that recurs across ecosystems.

- Describes the order of rises and falls
- Notes whether the cycle repeated and whether heights differed
- States that the pattern is the order and lag, not the exact values

6. Compare your graph to the textbook's account of wolves and moose on Isle Royale. Name one way the model matches it and one way the island is more complicated than the model.

Answer: Match: on Isle Royale, when moose declined in the early 2000s the wolves declined a few years later, and when wolves became scarce the moose increased, which is the same order and lag the model produced. More complicated: the island's moose were weakened by winter ticks and winter weather, and the wolves were hit by disease and inbreeding and later received relocated wolves, none of which exists in the model. The island also has seasons and a food supply for moose that changes from year to year.

Why: Students must use the textbook account for the match and the lesson's accuracy discussion (slides 9 and 11) for the complications.

- One specific match in order or lag
- One specific real-world factor the model lacks

7. Suppose you renamed the beads 'sea urchins' and the cards 'sea otters' and ran the same rules. Predict the graph. Then explain why ecologists expect the same pattern in a kelp forest, a desert and a meadow even though the species are different.

Answer: The graph would look the same: urchins would climb to the cap, otters would rise one to three rounds later, urchins would crash, otters would starve, and urchins would recover. The rules, not the names, make the shape, and the rules stand for things true of every predator and prey: predators need enough prey to survive and breed, prey breed when not eaten, and both responses take time. Because every ecosystem has limited food and something that eats something else, ecologists expect the same pattern wherever a predator depends mainly on one prey.

Why: This is the MS-LS2-2 move: the pattern is a property of the interaction, so it predicts across ecosystems.

- Predicts the same cycling shape
- Explains that the rules, not the species, produce it
- Connects the rules to features shared by all predator-prey pairs

8. List two rules in the model that are not like real life, and for each one say how it might change the shape of the graph compared with real population data.

Answer: Any two of: voles double every round (real prey breed in seasons and not every individual breeds, so real rises are slower and the peaks lower); a fox starves after one bad round (real predators can survive lean periods, so real predator declines are slower and the lag can be longer); the cap is fixed at 60 (real food supply changes with weather, so the prey peak varies from year to year); there is only one predator and one prey (real prey have several predators and real predators switch foods, which smooths the swings); foxes catch voles purely by chance (real predators hunt where prey are dense, which can make crashes sharper).

Why: Full credit needs two rules and a direction of change in the graph for each, not just 'it is not realistic'.

- Two unrealistic rules named
- Each linked to a specific change in the graph's shape

9. Round 14 began with 60 voles and 7 foxes. The seven fox cards caught 9, 8, 6, 5, 3, 2 and 1 voles. How many voles and foxes begin round 15? Show your work.

Answer: 52 voles and 8 foxes. Caught: $9 + 8 + 6 + 5 + 3 + 2 + 1 = 34$. Survivors: $60 - 34 = 26$. Doubling: $26 \times 2 = 52$, under the cap. Fox fates: 9, 8 and 6 catches each survive and add a pup (3 pups); 5 and 3 catches survive; 2 and 1 catches starve. Surviving foxes: 5; plus 3 pups = 8 foxes.

Why: A fuller version of q3 with a starvation case. Common error: counting the two starved foxes as survivors (gives 10) or forgetting the pups (gives 5).

Also acceptable: Accept 52 and 8 with work shown; partial credit for correct voles with a fox error identified.

Individual evidence of learning

Each student submits their own completed data table, graph with the V and F peaks marked, and written answers to q1 through q9. The graph and q1, q2 and q4 are the evidence for the lag target; q7 is the evidence for predicting the pattern in a different ecosystem; q8 is the evidence for understanding the model's limits.

Assessment criteria

Criterion	Proficient looks like
Data and graph	All twenty rounds recorded with the rules applied correctly; both populations plotted on one set of axes in two colors; first vole and fox peaks marked.
Pattern and lag	States that the fox peak followed the vole peak, gives the number of rounds between them, and explains the delay using the pup and starve rules.
Prediction across ecosystems	Predicts the same cycling shape for otters and urchins (or another pair) and explains that the pattern comes from the predation relationship, not from the species.
Model limits	Names at least two unrealistic rules and connects each to a specific way real data differ from the model.

Accessibility adaptations

- Use large wooden beads or lima beans and a tray with high sides for students with limited fine-motor control; the hunter role can be done by sliding a card instead of tossing it.

- Provide a data table with rounds 1 to 3 completed from the teacher's practice run, and a graph with the axes already scaled, for students who need more support.
- Allow the recorder to speak each number aloud for a partner to write, and accept spoken answers to q4 through q8 recorded on a device.
- Print the rule card in large type with the three fox outcomes color-coded, and provide a multilingual card for vole, fox, starve, pup, cap and peak.

Low-cost alternative

Use dried beans or torn paper squares for voles, squares cut from a cereal box for foxes, and the inside of a copy-paper box lid as the meadow. If class time is short, run at least 15 rounds: by round 15 more than half of groups (most groups with lima beans) have seen the vole rise, the fox rise, the vole crash and the fox decline, while a 12-round run often stops before the crash.

Model limitations

This activity has not been physically tested by the authors. The expected counts come from a computer run of these exact rules many times, using the area a card covers (a 10 cm card covers about one ninth of the meadow, a little more when touching beads count), so your beads and cards may cycle faster or slower; in those runs about one group in five using small beads had not finished a full cycle by round 20. The model has one predator, one prey, no weather, no disease, no seasons and instant reproduction, and foxes starve after a single bad round, so its cycles are sharper and more regular than any real population data. The 60-vole cap also flattens the top of the vole curve, which real prey populations rarely show so neatly. It shows why a lag appears; it cannot show how large real swings are or how long real cycles take.

Teacher notes

Check q3 and q9 for the order of operations: remove caught voles, double, cap; judge each fox separately. For q1 and q2 grade against the student's own table, not a standard answer. If a group's foxes never took off (voles stayed at 60 with a single fox for many rounds), their cards were probably too small or the toss too gentle; their q8 answer can use that as a limitation. Keep one group's graph to project beside the fox-vole teaching graph on slide 8. The vole peak is usually a flat top at the 60 cap, so tell groups before they graph to put the V on the last round at 60; counted from the first round at 60, the lag looks like four to six rounds instead of one or two, which is a fair observation but not the comparison the questions ask for. If a group's voles are still at or near 60 at round 20, the cycle has not finished yet: let them run a few more rounds if time allows or use a neighboring group's graph for q1 and q2, and credit a q8 answer that explains why (lucky tosses, small beads, beads against the walls).