Darwin Snail Simulation

Explore natural selection, inheritance, variation and mutation.

This workbook accompanies the Darwin Snail Simulation. Open the website supplied by your teacher.

Student’s name: ____

Class: _______________________ Date: ___________________________

How to use

Follow the exercises in order and record your answers and observations in a separate document.

Choose an investigation using the menu at the top of the instruction panel. The student workbook contains the full questions; the website provides a short guide alongside the simulation.

Use Save histogram to download a graph, then insert the downloaded image into your document and give it the label requested in the instructions. Use CSV to download numeric results. Your evidence notes can be downloaded as a text file.

Save evidence before Reset trial or before switching to a new experiment. Notes are stored only in the current browser when storage is available; download them before leaving.

About the simulation

Shell thickness uses arbitrary model units. Snail colours show thickness; the artwork is stylized. Exercises 1–5 use cloning and fixed thickness after birth. Exercise 6 uses a separate model with sexual reproduction, juveniles and environmental effects.

Darwin Snail Simulation

Prelude

Flat periwinkles are small snails found on seaweed along New England's rocky shores. One of their predators is the European green crab, which reached North America from Europe in the early 1800s. Before 1900, these crabs were not found north of Cape Cod, Massachusetts. Their later spread toward Nova Scotia brought a new predator into periwinkle populations farther north.

Biologist Robin Seeley investigated whether predation by green crabs had caused these snail populations to evolve. She located museum shells collected on Appledore Island, north of Cape Cod, in 1871 and compared them with shells she collected at the same location in the 1980s. The tables below show the shell-thickness data used for this comparison.

SHELLS COLLECTED IN 1982–1984, EIGHTY YEARS AFTER EUROPEAN GREEN CRABS ARRIVED

14	11	12	14	9	11	12	13	14	10	14	10	14	12	13
10	15	13	14	15	15	13	15	11	16	12	18	16	16	17
17	17	15	12	13	15									

SHELLS COLLECTED IN 1871, BEFORE EUROPEAN GREEN CRABS ARRIVED

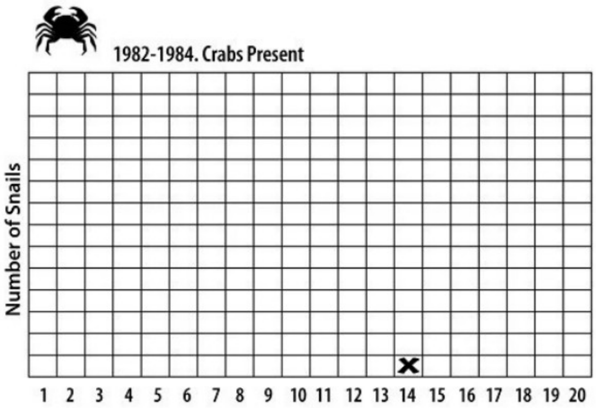
5	8	1	9	4	8	8	8	11	3	9	8	7	8	5
8	8	13	9	10	9	5	2	8	7	5	9	8	8	5
11	12	8	3	3	5	9	8	6	7					

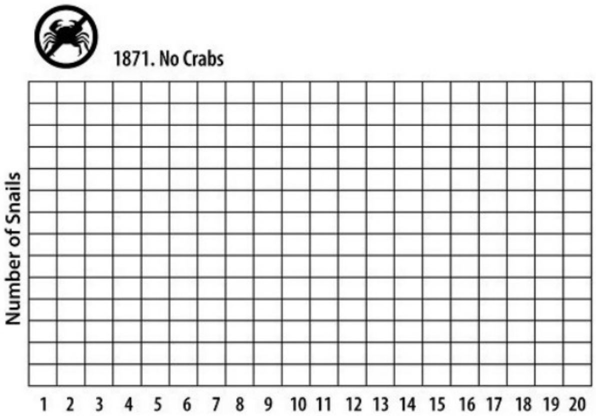
Each value describes one shell, with larger numbers indicating greater thickness. For this activity, Seeley's logarithmic thickness values have been converted to whole numbers. You do not need to work with the original measurement units.

Use the upper grid on the right for the 1980s sample. Add one X for each shell at its thickness value, stacking Xs when values repeat. The X for the first shell, thickness 14, is already shown. If you work with a partner, one person can read the values while the other plots them.

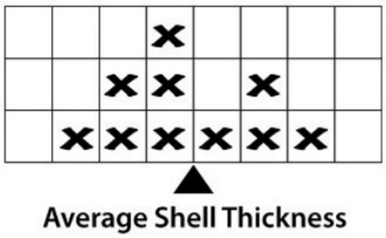
Use the lower grid for the shells collected in 1871.

These graphs are histograms. They show how a trait varies within a population and help you compare the distributions of two populations.



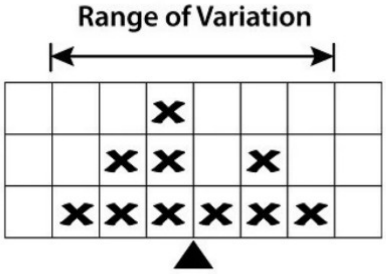


Estimate the average thickness of the 1980s shells and mark it with a triangle on the upper histogram, following the example at right. You do not need to calculate it: imagine the point where the plotted Xs would balance. Mark the estimated average for the 1871 sample in the same way.



[1.1] Which snail population has the larger average shell thickness, the population from 1871, or the population from the 1980s?

Mark the range of thicknesses in each sample with a two-headed arrow, as shown at right. The range is the largest value minus the smallest. In the example, this difference is 6 units.



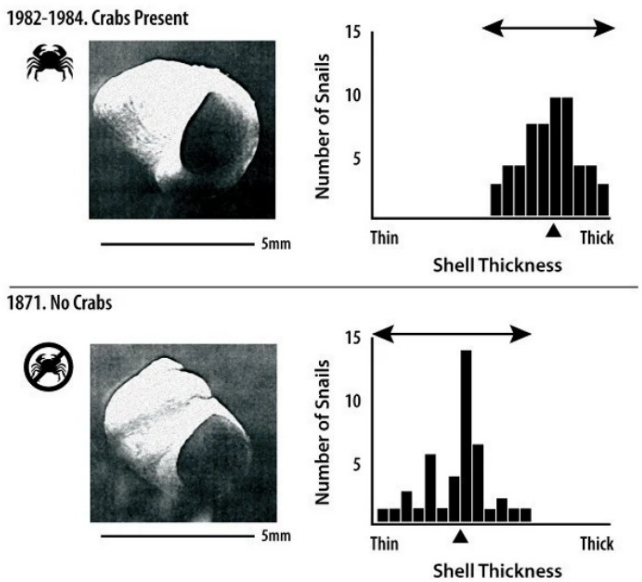
[1.2] Which snail population has the larger range of variation in shell thickness?

An average and a range describe a group of snails. An individual has one shell thickness: it does not have a range of thicknesses, and its thickness may not match the population average. Keep this distinction between individuals and populations in mind as you interpret your graphs.

Seeley predicted that the Appledore Island population had evolved between 1871 and the 1980s. Evolution concerns changes in populations across generations, rather than changes within a single individual. A shift in the average or range of a trait can show that the population's composition has changed; the cause of that change still needs to be investigated.

[1.3] Was Seeley's prediction correct? In other words, is the average shell thickness and/or the range of variation in thickness different for the 1980s snail population versus the 1871 population?

Compare your graphs with the illustration below, which includes shell photographs and histograms based on Seeley's data (Seeley, 1986). The population sampled in the early 1980s had a greater average shell thickness than the population sampled in 1871. Its shell thicknesses also covered a somewhat narrower range.



The early-1980s snails descended from earlier generations on Appledore Island. A population changing across generations illustrates descent with modification, the idea at the heart of evolution.

What could explain this change? In this lab, you will investigate evolutionary processes using a model snail population. You will then apply your findings to Seeley's research.

Exercise 1: A Model of Evolution by Natural Selection

[1] Open the classroom website. Select “1 · A model of natural selection” from the investigation menu.

[2] You will see a population of snails scattered around the Rocky Coastline on the right. Take a closer look by choosing Select and clicking a snail. A window shows an enlarged illustration and the thickness of its shell. Examine at least 9 other snails in this way. Close the window or use Inspect another snail to continue.

[2.1] Which shell thicknesses are most common? Which are least common?

[3] Look at the histogram below the coastline. It sorts the snails by shell thickness and shows the number of snails in each category. “View counts as a table” provides the same information as numbers.

[3.1] Are the proportions of snails with different shell thicknesses in the histogram similar to the sample of snails you examined in Question 2.1?

You will now become a European green crab. You will feel especially crabby if you are not getting enough to eat, and the best snacks available on the coastline are these tasty-looking snails. All you have to do is crack their shells by pounding on them with your claw.

[4] Before beginning your feast, click Save histogram. Insert the downloaded PNG into a document. Label this graph “Exercise 1: Starting Population” so that you remember what the snails looked like when you first got to the coastline.

[4.1] First, make a prediction. What do you think will happen to the shell thickness distribution in this population of snails as you eat some of them?

Exercise 1 • Play the predator

[5] Begin the simulation by clicking Run. The snails will start to crawl around. The starting population size is 50, as shown by Snails alive below the coastline. Movement is reduced if your device requests reduced motion.

[6] Get your claw ready for action by clicking Claw. You are now officially a European green crab.

[7] Find a snail you want to eat and start clicking on it. When you claw at it enough times, the shell will crack, you will eat what is inside, and the snail will disappear. Snails alive will show that there is one fewer snail on the coastline. You can also use Claw while the model is paused.

[8] Notice Crab happiness below the coastline. This score goes up every time you eat a snail, but it goes down each time you click on a snail with your claw. The more effort you expend to get your meal, the "crabbier" you become. The coastline starts with 50 snails, and it takes 25 snails to fill you up. Keep eating until 25 remain, and try to maximize your score. The website prevents further feeding at 25 survivors.

[8.1] Do you notice any differences in the histogram of shell thicknesses now compared to the starting snail population? If so, explain why this change happened.

You, the crab, go away for a while after your big meal, and the snails have a chance to reproduce.

[9] Click Stop, then Snails reproduce. Each surviving snail generates two new snails by cloning, then dies. Unlike most real snails, there is no mating in this part of the model. Each offspring is identical to its parent when mutation is off and inheritance is on. Switch to Select and inspect nearby sibling pairs. Their parent IDs and thicknesses are shown in the inspection window. You can also open Parent–offspring evidence below the graphs.

[10] You are hungry again! Click Run, choose Claw and have another meal of 25 snails. Keep your happiness score high by eating your snails with the fewest clicks possible.

[11] Digest your meal and let the snails reproduce again by clicking Snails reproduce. Then have one more meal of 25 snails. At the end, reproduce once more so you finish with 50 snails, at generation 4.

Exercise 1 • Add the crabs

[12] After your third meal and the final reproduction, click Save histogram. Insert it into your document and label it “Exercise 1: Generation 4”.

[12.1] Compare the starting histogram you saved earlier to this fourth-generation histogram. Has the distribution of shell thicknesses changed as you predicted in Step 4? Explain.

[13] Playing crab may become tedious after a while. You can add auto-munching crabs to the Rocky Coastline. First click Reset trial to start over with a new population of snails. Save the histogram, insert it into your document and label it “Exercise 1: Before Crabs”.

[14] Click Add crab three to five times. Each click adds one crab to the coastline. The crab count appears next to Remove crabs. You do not need to click the coastline to place a crab.

[15] Click Run and watch the crabs eat snails. Keep an eye on the size of the snail population. The website pauses automatically when 25 snails remain. You can also click Stop at any time.

[16] Save the histogram and insert it into your document. Label it “Exercise 1: After Crabs”. Compare your before-crabs and after-crabs histograms.

[16.1] Which snails tended to get eaten? Which snails tended to survive?

[17] Click Snails reproduce. Click Run again and let the crabs eat until only 25 remain. Reproduce again, run the simulation until 25 remain, and then reproduce once more.

[17.1] How does the evolution of the snail population when predatory crabs are present compare to the evolution of the snail population when you acted as predator?

Website note: Reproduction pauses the simulation so that you can inspect offspring before the next meal. Click Run to resume. Fast speed changes the animation speed, not the selection rule.

Exercise 2: The Requirements for Evolution by Natural Selection

You saw the snail population evolve (change over time) as a result of predation—a form of selection. What is required for such change to take place? This section explores several conditions that affect whether the population will change as individuals are selected.

Choose “2 · What does selection require?” from the investigation menu.

Variation

[1] What if all the snails started out the same? Could the population still evolve? To get a uniform population with no variation in shell thickness, uncheck Shell thickness is variable.

[2] Click Reset trial to get a new population. Changes to starting variation take effect when you reset.

[3] Click Select. Inspect the shell thickness of a few snails. Also look at the histogram.

[3.1] Is there any variation in shell thickness among the snails now?

[4] Click Save histogram. Insert it into your document and label it “Exercise 2: No Variation, Starting Population”.

[4.1] Make a prediction: Do you think this population of snails will evolve as predators start eating them? Explain why or why not.

[5] Now test your hypothesis. Click Add crab three to five times. Click Run and let the crabs eat 25 snails. The website will pause with 25 survivors.

[6] Click Snails reproduce. Save the histogram, insert it into your document and label it “Exercise 2: No Variation, Generation 2”.

[6.1] Was there a change in the distribution of shell thickness among the snails? Explain why this is different from when you or the crabs were eating snails before. Why does the distribution of shell thickness stay the same now, even though predators were eating just as many snails?

Exercise 2 · Inheritance

[7] In Exercise 1, the shell thickness of each snail was identical to that of its parent. Shell thickness was completely genetically determined, so each snail inherited the genes for shell thickness from its parent and its shell was exactly the same thickness as the parent's. What if this were not so? What if shell thickness were not heritable—if there were no genetic basis for it—but each snail instead grew its shell to a random thickness unrelated to its parent's shell? To find out, uncheck Shell thickness is heritable.

[8] Reestablish variation by checking Shell thickness is variable. It should now be checked so that variation is present.

[9] Click Reset trial. Before running the simulation, click Snails reproduce. Choose Select and inspect several offspring. Compare their parent IDs and shell thicknesses, or use the Parent–offspring evidence table. The population temporarily doubles to 100; you will reset it in Step 10.

[9.1] Do the children have the same shell thicknesses as the parent (are the snails identical within each pair as before)?

[9.2] Do you think that the distribution of shell thickness in the population will change over several snail generations as predators start eating snails? Why or why not?

[10] Reset trial again so that you start with 50 snails. Save the histogram and label it "Exercise 2: No Inheritance, Starting Population".

[11] Add three to five crabs. Click Run until 25 snails remain and the website pauses.

[12] Click Snails reproduce, then Run. Let your crabs have two more meals, reproducing after each one.

[13] Save the new shell-thickness distribution, insert it into your document and label it "Exercise 2: No Inheritance, Generation 4".

[13.1] Why are the starting and ending shell thickness distributions similar to each other in shape, even after your crabs had three meals of the thinnest-shelled snails?

Observation note: Random samples will not have exactly identical histograms. Compare their general shapes and explain why a survivor's advantage is not reliably passed to its offspring in this treatment.

Exercise 2 • Selection

[14] Imagine a crab that is especially large and can crack snail shells no matter how thick they are. This crab takes snails randomly, without any preference for thinner shells. Will there still be a change in the distribution of shell thickness over time? To test this, uncheck Survival is selective.

[15] Make shell thickness heritable again by checking Shell thickness is heritable. Shell thickness is variable should also be checked. Survival is selective should be unchecked. Eat random snail(s) and its Number menu will appear.

[16] Reset trial. Do not add crabs. Set Number to 1 and click Eat random snail(s) a few times. Each click removes one randomly chosen snail. Thin-shelled and thick-shelled individuals each have the same chance of being removed. This button works while paused.

[17] Reset trial again. Save the histogram and label it “Exercise 2: No Selection, Starting Population”.

[17.1] Do you think the distribution of shell thickness in the population will change over time as your super-crab starts having meals? Why or why not?

[18] With Number set to 1, eat 25 snails by clicking Eat random snail(s) 25 times. Click Snails reproduce.

[19] To speed up the process, set Number to 25. Click Eat random snail(s) once to remove 25 randomly selected snails. Reproduce, have one more meal of 25 snails, and then reproduce again.

[20] Save the histogram, insert it into your document and label it “Exercise 2: No Selection, Generation 4—Trial 1”.

[20.1] Was there a change in the distribution of shell thickness among the snail population? Is this what you expected? Explain.

Exercise 2 · Repeat the random-survival trials

[21] Reset trial. Repeat Steps 18–20, labeling the next histogram “Exercise 2: No Selection, Generation 4—Trial 2”.

[22] Reset trial and repeat Steps 18–20 once more, labeling the histogram “Exercise 2: No Selection, Generation 4—Trial 3”.

[23] Look at all three generation-4 histograms with no selection.

[23.1] Are there changes in the shell thickness distribution from the initial pattern? Are these changes consistent among all three of your trials?

[23.2] Try to explain any changes you observed in the populations. Consider whether the changes happen for the same reason as the changes in distribution in Exercise 1. Could random chance result in any of the types of changes you have seen?

Note: In Step 23, the mechanism of evolution is not natural selection. It is called genetic drift.

Website note: Reset trial begins a new random trial while retaining the settings. It does not replay the same random removals. Save each histogram before resetting.

Exercise 3: Darwin’s Theory of Evolution by Natural Selection

Darwin’s explanation of adaptive evolution connects three conditions:

A. Individuals in a population differ in a particular trait, AND

B. At least some of those differences are inherited: genes passed from parents to offspring contribute to variation in the trait, AND

C. Individuals with certain versions of the trait are more likely to survive and reproduce than others.

When these conditions occur together, the trait’s distribution in the population is expected to shift across generations.

The third condition describes natural selection: survival and reproductive success depend partly on an individual’s traits rather than on chance alone. When the differences that influence success are heritable, natural selection can change the population over generations. This is the central explanation in Darwin’s theory of evolution by natural selection.

[1.1] Using the data from your experiments, describe the conditions under which the snail population will evolve toward thicker shells and the conditions under which it won’t. Refer back to your notes and the histograms you saved as evidence.

Exercise 4: The Source of Variation Among Individuals

In the experiments with a variable starting population, your initial snails had seven different shell thicknesses. In later generations, some thicknesses may have disappeared, but no new shell thicknesses appeared. In real populations, mutations are a source of new genetic variation. For the purposes of this model, a mutation is a change that can occur during reproduction, so an occasional offspring differs from its parent.

[1] Select “4 · Where variation comes from” in the investigation menu.

[2] The new coast has shells up to a thickness of only 4, without thicknesses 5, 6 and 7. Reproduce with mutation is initially unchecked. Add three to five crabs. Let them eat three meals of 25 snails, clicking Snails reproduce and then Run between meals. After the third meal, pause with 25 survivors before Step 3.

[2.1] Is there a limit to how far predatory crabs can drive shell thickness in the snail population? Why or why not?

[3] Check Reproduce with mutation.

[4] Click Snails reproduce. Before running the model again, use Select to examine several offspring and compare each one’s thickness with its recorded parent’s thickness. Open Parent–offspring evidence to compare sibling pairs. The table includes every birth from this generation before any offspring are eaten.

[4.1] Are the children identical to each other (and to the parent)? Are there cases where one of the children is different from the parent? If so, is the change usually towards a thinner shell, a thicker shell, or is it equally likely to be towards either one?

If the answer is not clear from this reproduction, inspect the next generation before predation. Combine evidence across births and trials rather than expecting an exactly equal number of changes in each direction in one small sample.

Website note: A mutation attempt has an equal chance of increasing or decreasing thickness by 1. Thickness cannot fall below 1. Download all mutation events includes attempted changes, including those blocked at this lower limit. Crab presence does not change the mutation rule.

Exercise 4 · Mutation and selection

[5] Let your crabs eat at least five more meals of 25 snails, reproducing between meals. Each meal pauses at 25 survivors. Click Snails reproduce, inspect offspring if needed, then click Run to resume feeding. Select Fast speed to shorten the wait.

[5.1] Can you drive the population further towards thicker shells now (with mutations) than you could before (without mutations)? Explain how this can happen, even though a mutation is equally likely to be towards a thinner shell or a thicker shell before selection acts.

Evidence reminder: The living population has already been filtered by predation. To judge the direction of mutation, use the parent–offspring observations made before predation or the complete mutation-event download. Do not judge the production of mutations only from the surviving snails.

Exercise 5: What Makes Populations Evolve?

[1] Reflect on your experiments with the model snail population and consider the following issues:

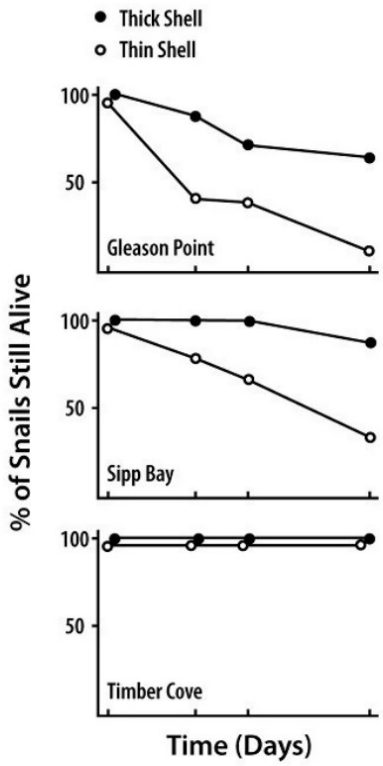
[1.1] After they were born, did the individual snails ever change their shell thickness or color? If the individuals didn't change, how was it possible for the population to change?

[1.2] Did snails grow thicker shells because the snails needed them in order to survive? If not, where did new thicknesses come from?

[1.3] What role did the predators play in causing the population of snails to evolve? Did they create a need for the snails to change—a need to which the snails responded? Or did the predators simply determine which snails survived to reproduce and which didn't?

Exercise 6: CHALLENGE
Evolution by Natural Selection in Flat Periwinkles

Seeley proposed that natural selection explained the changes in Appledore Island's periwinkles. In her explanation, green crabs ate thin-shelled snails more readily, giving thick-shelled individuals a better chance of surviving and reproducing. If offspring inherited this advantage, thick shells would become more common over generations while thin shells became less common.



Seeley tested her explanation in the laboratory and in the field. In the laboratory, each of eight crabs received a thin-shelled snail. All eight ate their snails, taking an average of 42 seconds. Another eight crabs each received a thick-shelled snail. Only one succeeded in eating its snail within eight minutes; many of the others stopped trying.

For the field experiment, Seeley attached snails to intertidal seaweed using fishing line threaded through small holes in their shells. Crushed shell remains on the tethers helped distinguish crab predation from escapes or deaths inside intact shells. Each pair contained one thin-shelled and one thick-shelled snail. She placed 15 pairs at each of three sites: Gleason Point, where crabs were common; Sipp Bay, where crabs were rare; and Timber Cove, where crabs appeared absent.

Survival was recorded after 6, 9, and 16 days. The graphs at left show the results (Seeley, 1986). Solid circles represent thick-shelled snails, and open circles represent thin-shelled snails.

[1] Revisit the three conditions required for evolution by natural selection.

[1.1] What evidence, if any, does Seeley have that the flat periwinkles of Appledore Island vary in the thickness of their shells?

[1.2] What evidence, if any, does Seeley have that snails with thick shells are more likely to survive than snails with thin shells? (Think carefully about this.)

[1.3] What evidence, if any, does Seeley have that shell thickness is heritable? (Again, think carefully about this.)

[2] The results directly support two of the three conditions required for natural selection to produce evolutionary change in this population. Support for the remaining condition is, at most, indirect.

[2.1] For which of the three conditions is the evidence you have seen the weakest? Explain.

The next investigation is an optional extension with a more complex model. Ask your teacher whether you should complete it.

Plan your own investigation using two model populations with different histories. One has lived without crabs for several generations; the other has experienced crab predation. Use observations and experiments to investigate the following questions:

(i) Is average shell thickness greater in the population with a history of crab exposure? (ii) Are all three conditions for evolution by natural selection present? (iii) Could differences between the populations reflect evolution by natural selection, a developmental response to crab cues, or both?

Exercise 6 · Snail Tanks

To investigate the third question, consider whether inherited differences, responses to the environment, or both explain the shell thicknesses you observe.

The research tools include four tanks, controls for transferring selected snails, and crabs whose claws are held closed with bands. Collect evidence with these tools, then report your methods, findings, and conclusions in a short paper.

Snail Tanks

[1] Choose “6 · Research challenge”. The West population has a crab-free history; the East population has a history of crab exposure. Compare their average thicknesses, ranges, and histograms to investigate question (i). Four empty experimental tanks appear below the source populations. Save the source data you plan to use as evidence.

[2] In this model, adults reproduce sexually, juveniles grow to maturity, mutations sometimes occur, and older snails eventually die. Juveniles have blue outlines. Time advances in the tanks, not in the West and East source samples. Use Advance 1 day for a single step or Run days for automatic progress. Automatic running pauses every 15 days so you can record observations. These intervals are model settings rather than measured rates for wild snails.

[3] Click a snail to select it. Under Move selected snails, you can see its ID, shell thickness, life stage, and thickness at birth. Choose a Destination and click Transfer selected to move it. To study reproduction, place two adults in a tank and advance time. Adults pair within the tank without needing to touch on screen. Mating opportunities begin on day 3 and recur every 3 days.

[4] Select Active crab from a tank’s Crab treatment menu to introduce predation. Each tank supports one crab treatment. An active crab can eat one snail per model day, with thin-shelled snails at greater risk.

Gathering Populations of Snails

[5] Inspect snails and select those with the thicknesses you want to study. Click multiple snails to form a group; clicking one again removes it from the selection. Choose a destination and use Transfer selected. Select 10 juveniles and Select 10 adults offer quick samples from either source population. Transfers also work between tanks. Record IDs to track the same individuals.

Exercise 6 · Scent-of-crab and your investigation

[6] To follow shell development, transfer blue-outlined juveniles into tanks and record their IDs and initial thicknesses. Advance time, then compare the same snails using Tracked individuals and family history. Juveniles reach maturity at age 3 model days. Use Download individual data at every observation so you retain records even if individuals later die.

Scent-of-crab

[7] Chemical cues can allow snails to detect nearby crabs. To investigate responses to these cues without predation, choose Banded crab · cues only from the Crab treatment menu. This treatment represents a crab with its claws held shut, so it cannot eat snails. Compare this treatment with a No crab control.

You as Scientist

Use your experiments to address the remaining research questions:

Does your evidence support all three conditions for evolution by natural selection? Pay particular attention to the condition least directly supported by Seeley’s experiments.

Are the differences between the source populations explained by inherited change across generations, by shell development in response to crab cues, or by a combination of these processes?

Carry out one or more experiments and organize your report into methods, results, and conclusions. The reference list includes Geoffrey Trussell’s paper, which describes a later investigation related to Seeley’s work.

Recording evidence: Save tank data records the treatment, time, population size, average shell thickness, range, and juvenile count. Download individual data provides records of living snails, parent IDs, and recorded deaths. Save your files before using Reset research. Compare similar starting groups at matching observation times, repeat trials, and consider other explanations for your results.

Interpreting the model: Both inherited differences and environmental influences during development can affect shell thickness here. Use the experiments to test explanations within this simplified system. A change in an individual caused by its environment does not, on its own, demonstrate population evolution.

References

Seeley, Robin Hadlock. 1986. Intense natural selection caused a rapid morphological transition in a living marine snail. Proceedings of the National Academy of Sciences, USA 83: 6897–6901.

Trussell, Geoffrey C. 1996. Phenotypic plasticity in an intertidal snail: The role of a common crab predator. Evolution 50: 448–454.