

Four Cups of Duckweed: Which Resource Runs Out First?

Investigation question: When a real duckweed population gets light but no added nutrients, nutrients but no light, or everything it needs but a crowded start, how does it change over two weeks, and which resource limits each cup?

Classroom field investigation

Groups of 4

3 sessions

Setup 10 · Activity 75 · Cleanup 10 min

MS-LS2-1 · assesses

MS-LS1-5 · supports

Scientific purpose

Students census a real population. Each group floats common duckweed, a tiny plant that multiplies by budding off new fronds, in four identical cups. Cup B gets nutrient water and bright light; each of the other cups differs from B in exactly one way: no added nutrients (A), no light (C), or four times as many fronds at the start (D). Over two weeks students count fronds, score their color and estimate how much of the surface is covered, then calculate growth factors, pool the class data, and name the resource that limited each cup. The lab gives the chapter its evidence from living organisms, both for population size and for the condition of individual plants.

Why this helps students with this chapter

Students have been told that populations need resources; here they watch a population respond to them. Duckweed is ideal because it doubles in days, floats where it can be counted, and each frond is an individual. Comparing every cup with one full-resource cup makes each comparison a fair test of one resource, and the crowded cup shows something the textbook only asserts: individuals of the same species compete with each other, so more plants means less for each. Because real data are messy, pooling eight groups and using the median teaches students how scientists separate a real effect from one cup's bad luck.

Standards connections

MS-LS2-1 (assesses, the whole PE: analyzing data on how light, nutrient and space availability affect a population and the individual organisms in it): Students collect and analyze their own counts of a living population under abundant and scarce resources, compute growth factors, compare against a full-resource cup and pooled class medians, and use the data as evidence for the effect of each resource on population size and on frond health. That is the PE as written.

MS-LS1-5 (supports, environmental factors (light, nutrients, crowding) influencing the growth of individual plants): Frond color and size in the dark cup and the unfed cup show that resources change how individual plants grow, which is one of this PE's own examples (fertilizer increasing plant growth). In the California integrated sequence MS-LS1-5 is a Grade 6 PE, so it appears here as background students should already have met, not as a target.

Roles (rotate each session)

- **Cup keeper:** Sets up and labels the cups, measures water to the line, tops up evaporation on count days, and reads the thermometers in the light and inside the dark box.
- **Counter 1 (cups A and C):** Counts fronds with a toothpick and hand lens using the counting rule, and gives the color score and surface estimate for those two cups. Works fast on cup C so it spends as little time in the light as possible.
- **Counter 2 (cups B and D):** Counts the two fastest-growing cups, counting cup D one quarter at a time on the '+' paper, and gives their color scores and surface estimates.
- **Recorder and checker:** Fills the tables, recounts any cup whose number looks wrong, photographs the cups from above if a camera is allowed, and computes the growth factors.

Materials

Item	Quantity	Per	Note
Clear plastic cups, 9 oz (about 270 mL), all of the same brand	4	group	Label A, B, C and D with masking tape and the group name.
Common duckweed (<i>Lemna minor</i>), healthy green fronds	about 70 (10 + 10 + 10 + 40) plus a few spares	group	From an aquarium or pond shop or a biological supply company. Grow a starter culture for one to two weeks so the class has about 600 fronds. Do not collect from local ponds or creeks.
Aged tap water (left in an open jug for one to two days) or bottled spring water	about 1 L	group	Use the same water for every cup and for every top-up.
Nutrient water: liquid houseplant fertilizer mixed by the teacher at one quarter of the label's houseplant strength in aged tap water	about 5 L	class	Each group needs 600 mL (200 mL each for cups B, C and D), so 8 groups need about 4.8 L. Label the jug 'Nutrient water: not for drinking'.
Shoebox or other lightproof box with a lid, big enough for one cup	1	group	
Bright growing spot: a bright window out of direct midday sun, or an LED grow light or LED desk lamp on a timer (about 14 to 16 hours a day)	1	class	LED lamps stay cool. Do not use incandescent or halogen bulbs; they get hot and warm the cups.
Plastic wrap squares with 3 or 4 small holes poked in each	4	group	
Graduated cylinder or measuring cup marked at 200 mL	1	group	
Toothpicks and a hand lens	2 toothpicks, 1 lens	group	

Thermometer (classroom or stick-on aquarium type)	2	group	One stays with the cups in the light and one inside the dark box. Two per class is enough if groups sit together.
White paper with a large '+' drawn on it, for counting a crowded cup by quarters	1	group	
Recording sheet, colored pencils (4 colors) and a ruler	1 set	student	
Safety goggles and gloves for the teacher when mixing the fertilizer	1 set	class	

Estimated cost: 12 to 30 per class without a grow light; add about 15 to 25 for a clip-on LED grow light (estimates) (an estimate; A starter portion of duckweed costs about \$5 to \$15 and some aquarium shops give it away; a bottle of liquid houseplant fertilizer is about \$5 and is often already on hand; a sleeve of 50 clear cups is about \$4 and a roll of plastic wrap about \$2. Boxes, toothpicks, hand lenses, thermometers and measuring cups are classroom stock or donated.)

Safety

- Fertilizer concentrate irritates eyes and skin and is harmful if swallowed. Only the teacher handles it, wearing goggles and gloves. The diluted nutrient water is still not for drinking; if it splashes in an eye, rinse with running water for several minutes and tell the teacher.
- Water that stands for two weeks grows bacteria and mold. Wash hands with soap after touching the cups, the water or the fronds. No food or drink at the lab table. Students with mold allergies can count from photographs instead of handling the cups at the end.
- Keep cups and water well away from the lamp, its cord, outlets and power strips. Dry your hands before touching the lamp switch.
- Spilled water is a slip hazard; wipe it up at once.
- Never pour duckweed down a drain or release it into a pond, creek or storm drain. It spreads quickly, and aquarium stock can carry snails, other plants or diseases into local water. Bag it and put it in the trash, or compost it at school.
- Cover each cup with the punched plastic wrap to keep out dust and insects; mosquitoes can breed in uncovered standing water.

Teacher preparation and setup

1. One to two weeks ahead, float the starter duckweed in a shallow tub of nutrient water in the bright spot so it multiplies to about 600 healthy fronds. Remove any brown or white fronds before class.
2. Two days ahead, fill an open jug with tap water and let it stand. If your district treats its water with chloramine, which does not leave standing water, use bottled spring water instead for everything.
3. The day before, mix the nutrient water. Wear goggles and gloves while you handle the concentrate. One quarter of the label's houseplant strength is enough; stronger mixes encourage algae and can burn the fronds.
4. Check the growing spot: small cups in direct afternoon sun can heat well above room temperature. Put a thermometer in a test cup there for an afternoon; if it rises above about 30 °C, move the cups back from

the glass or use the lamp.

5. Plan the top-ups. Water evaporates over two weeks. On each count day, and once midweek if you can, top every cup back to its 200 mL line with plain aged water (never with nutrient water, which would add extra nutrients).
6. Practice the counting rule on the starter culture so you can show it under a document camera: a frond counts once its outline sticks out past the edge of its parent.

Investigation design

Independent variable	Which resource the cup is short of compared with cup B: added nutrients (cup A has none), light (cup C is in the dark), or room and resources per frond (cup D starts four times as crowded).
Dependent variable	Number of fronds on days 0, 7 and 14 and the growth factor; also frond color score and the percent of the water surface covered.
Controlled	Same cup type and the same 200 mL of water, topped up with the same plain water to the same line; Nutrient water from one batch for cups B, C and D; Same temperature (checked with a thermometer in the light and in the box); Same starting health of fronds and the same counting rule; Same count days for every cup and every group
Trials	One cup of each kind per group; the class pools about eight groups and compares medians, so each condition has about eight replicates.
Comparison	Cup B, which gets nutrients, light and an uncrowded start, is the reference. Each other cup differs from B in exactly one way: A against B tests nutrients, C against B tests light, D against B tests crowding.

Student procedure

1. Session 1, day 0. Label four cups A, B, C and D. Measure 200 mL into each and draw the waterline with a marker: cup A gets aged tap water only; cups B, C and D get nutrient water.
2. Using a toothpick, lift healthy green fronds from the starter tub and float 10 fronds in cup A, 10 in cup B, 10 in cup C and 40 in cup D. Fronds often come joined in little clusters; count every frond in a cluster using the counting rule.
3. Record the day-0 count, color score and surface covered for each cup and the starting temperature. Then answer q1 and q2: predict how the cups will rank by growth and which resource might run short in each.
4. Cover each cup with punched plastic wrap. Set cups A, B and D side by side in the bright spot. Put cup C inside its box with the lid closed, right next to the others so it stays at the same temperature. Put one thermometer beside the cups and one inside the box.
5. Session 2, day 7. Read and record both thermometers. Count every cup (cup D one quarter at a time on the '+' paper), score color, estimate surface covered, and note roots, algae or anything unusual. Count cup C last and quickly, then return it to its box. Top every cup up to its line with plain aged water. If a camera is allowed, photograph each cup from directly above.

6. Session 3, day 14. Repeat every count and observation. Compute each cup's growth factor (day-14 count $\div$ day-0 count), and for cups B and D the two weekly factors (day 7 $\div$ day 0 and day 14 $\div$ day 7).
7. Graph the number of fronds against day for all four cups on one set of axes, one color per cup, and draw a top view of each cup in the drawing box.
8. Add your four growth factors to the class table. When every group has reported, find the class median for each cup (list the values in order and take the middle one, or the average of the two middle ones).
9. Answer the analysis questions on your own.
10. Clean up: lift the fronds out with a spoon or pour each cup through a paper towel so no fronds reach the drain, bag the fronds for the trash or compost, pour the water into a sink, rinse the cups and wash your hands.

Expected observations

- These are expected ranges, not tested results, and depend on light and temperature. Cup B usually grows the most: about 4 to 10 times in two weeks (10 fronds to roughly 40 to 100), with deep green fronds.
- Cup A grows less, often 1.5 to 3 times (10 fronds to roughly 15 to 30), because fronds use nutrients they stored before the lab; by day 14 its fronds are often smaller and paler, and their roots are often longer than in cup B.
- Cup C, in the dark, barely changes or shrinks (roughly 8 to 13 fronds) and turns yellow or white over the two weeks.
- Cup D gains the most fronds but usually has a smaller growth factor than cup B (40 fronds to roughly 100 to 250, a factor of about 2.5 to 6), and its week-2 factor is often lower than its week-1 factor as the surface fills. In a cool or dim room, B and D may grow at nearly the same rate.
- Some green algae may cloud cups B and D, which share the nutrients and light with the duckweed; note it as another competitor rather than ignoring it.

Likely difficulties

- Counting is the biggest source of error. Fronds hide under each other and tiny daughter fronds are easy to miss. Insist on the counting rule, have the checker recount any number that seems wrong, and count crowded cups by quarters or from a photo.
- Groups top up with nutrient water by mistake, which adds extra nutrients. Keep the plain water jug and the nutrient jug in different places with large labels.
- Cup C gets left on a windowsill 'for a minute' and is forgotten. Count it last, quickly, and return it to the box before writing the numbers down.
- Students compare raw counts instead of growth factors and conclude that cup D 'grew best' because it has the most fronds. Ask what cup D started with and why the growth factor is the fair comparison.
- If the room is cold over a weekend, all cups grow slowly and differences are small. Compare with the class medians and discuss temperature as a condition that affects growth without being a resource.

Structured debrief

1. Put the class medians on the board in a single row: A, B, C, D. Ask which comparison each pair of cups is (A against B is nutrients, C against B is light, D against B is crowding) and have students say the limiting resource for each before anyone looks at their answers.
2. Look at the spread in the class table. Ask why eight cups that were set up the same way did not give eight identical numbers (different starting fronds, counting differences, position in the window) and why the median is a fairer summary than the highest or lowest cup.
3. Hold up cup C beside cup B. The dark cup had more nutrients than cup A and still did worst: a plant cannot use nutrients without the energy from light to build new tissue. Link it to the lake-layers slide: the bottom of a lake has nutrients but no light.
4. Discuss cup D. If its weekly factor fell in week 2 while cup B's did not, the fronds were starting to compete with each other for surface, light and nutrients, the same shape as the leveling-off part of the deer graph. If D and B grew at the same rate, the cup's carrying capacity had not been reached yet, which is also a real result.
5. Close with the frogs: pale, weak fronds in the dark cup and pale fronds in the unfed cup show that a resource changes what an individual organism is like, which is exactly what the missing alkaloid prey does to a captive dart frog.

Recording sheet: what students fill in

Lab 2 recording sheet: Four cups of duckweed

The four cups

Cup	Water	Light	Fronds at start	Differs from cup B in
A	Aged tap water, no added nutrients	Bright	10	Nutrients
B	Nutrient water	Bright	10	(reference cup: everything supplied)
C	Nutrient water	Dark box	10	Light
D	Nutrient water	Bright	40	Crowding: room, light and nutrients per frond

Counting rule and scores — A **frond** is one small, flat, oval green body. Count a new frond as soon as its outline sticks out past the edge of the frond it is budding from. Use the same rule every time. **Color score:** 3 = deep green, 2 = light green, 1 = yellow-green or yellow, 0 = white, brown or see-through. **Surface covered:** estimate the percent of the water surface hidden by fronds, to the nearest 10 percent.

1. Prediction on day 0: rank the cups from the one you expect to grow the most (largest growth factor) to the one you expect to grow the least, and give a reason for your top and bottom choices.

Answer: Most likely ranking: B > D > A > C. Reason for B at the top: it has nutrients, light and room. Reason for C at the bottom: without light the fronds cannot make the food they need to build new fronds.

Why: This is a prediction; credit any ranking with reasons tied to resources. D may be ranked above or below A.

Also acceptable: Students who rank D first because it will have the most fronds should be asked in q3 whether that is the same as the largest growth factor.

- A complete ranking of all four cups
- A resource-based reason for the top and the bottom choices

2. For cups A, C and D, name the resource you think will run short first, and say which other cup you must compare it with to find out.

Answer: Cup A: nutrients (compare with B). Cup C: light (compare with B). Cup D: room on the surface, and with it the light and nutrients each frond gets (compare with B).

Why: Each test cup differs from cup B in one way, so B is the comparison in every case.

- A resource for each of A, C and D
- Cup B named as the comparison

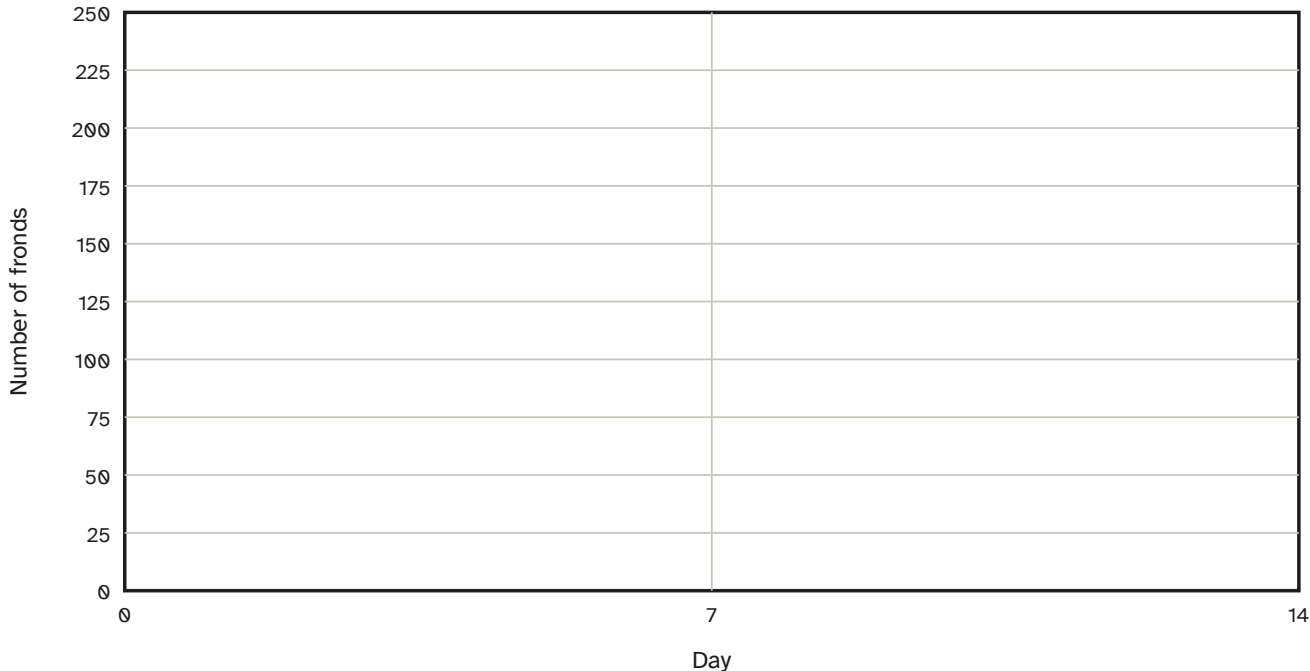
Counts and observations

Cup	Day 0 fronds	Day 7 fronds	Day 14 fronds	Growth factor (day 14 ÷ day 0)	Color score on day 14 (0-3)	Surface covered on day 14 (%)
A						
B						
C						
D						

Conditions log

Day	Temperature beside the cups (°C)	Temperature inside the box (°C)	Water added at top-up (cup A, B, C, D)	Notes: roots, algae, color, anything unusual
0				
7				
14				

Duckweed fronds counted in each cup



 Day 14: draw a top view of each cup as a circle, labeled A to D. Show roughly how much of the surface is covered, and use color or labels to show the frond color. Add one labeled detail you noticed in at least two cups (root length, frond size, algae, crowding).

Answer: Four labeled circles. B nearly or partly covered with green fronds; D the most crowded, often with fronds overlapping; A sparser, with paler fronds; C with only a few yellow or white fronds. At least one labeled detail such as longer roots in A, smaller fronds in A or C, or algae in B or D.

Why: The drawing records the individual-level evidence (color, size, roots) that the counts alone do not show.

- Four circles labeled A to D
- Coverage that matches the recorded percentages
- Color shown or labeled
- At least one labeled detail seen in two or more cups

Weekly growth factors for cups B and D

Cup	Week 1 (day 7 ÷ day 0)	Week 2 (day 14 ÷ day 7)
B		
D		

Class results: growth factors

Group	Cup A	Cup B	Cup C	Cup D
1				
2				
3				
4				
5				
6				
7				
8				
Class median				

3. Using the class medians, rank the cups from largest to smallest growth factor. Which part of your day-0 prediction was right, and which was not?

Answer: Group-specific. The expected order of class medians is B, then D, then A, then C (D and A can swap). The student states which parts of the q1 prediction matched.

Why: Students must read the median row, not their own group's numbers, and compare it honestly with the prediction.

- A ranking taken from the class medians
- A specific statement of what matched and what did not

Analysis questions: answer key

4. Using your group's numbers, calculate the growth factors for cups A and B (show both divisions). Then divide B's growth factor by A's. How many times as much did the cup with added nutrients grow?

Answer: Group-specific. Worked example: A went from 10 to 22 fronds, so $22 \div 10 = 2.2$; B went from 10 to 65, so $65 \div 10 = 6.5$; $6.5 \div 2.2 \approx 3.0$, so the cup with nutrients grew about three times as much.

Why: A growth factor divides the final count by the starting count so cups with different starts can be compared. Expected values: A about 1.5 to 3, B about 4 to 10.

- Both divisions shown with the student's numbers
- The ratio of the two growth factors computed correctly
- A sentence interpreting the ratio

5. For cups A, C and D, name the limiting resource and give the evidence. Each answer must compare the cup with cup B and quote numbers.

Answer: Cup A: limiting resource = nutrients. A and B differ only in added nutrients; A's growth factor (for example 2.2) was far below B's (for example 6.5), and A's fronds were paler. Cup C: limiting resource = light. C had the same nutrient water as B but no light, and it barely grew (for example 10 to 11, a factor of 1.1) and turned yellow. Cup D: the limit was crowding. D had the same water and light as B but four times as many fronds; its growth factor (for example 3.5) was lower than B's even though it gained more fronds, because each frond had less surface, light and nutrients to itself.

Why: This is the core MS-LS2-1 analysis: each cup is compared with the reference cup, and the one difference identifies the resource.

Also acceptable: If D's growth factor matched B's in a group's data or the class medians, credit a conclusion that crowding had not yet become limiting in two weeks.

- Nutrients for A, light for C and crowding (space, light, nutrients per frond) for D
- Each supported by a comparison with cup B
- Numbers quoted for every cup

6. Compare the week 1 and week 2 growth factors for cups B and D. Did either cup slow down in week 2? Explain what a slowdown means using the terms competition and carrying capacity.

Answer: Group-specific. Typical: B week 1 about 2.5, week 2 about 2.5 (no slowdown); D week 1 about 2.5, week 2 about 1.5 (slowdown). A slowdown in D means the fronds had begun to compete with each other: as the surface filled, each new frond got less room, light and nutrients, so fewer new fronds were made per frond. The cup was approaching its carrying capacity, the largest population its resources can support.

Why: Comparing weekly factors shows whether per-frond growth is falling, which is the signature of competition within a species as a population nears its carrying capacity.

Also acceptable: If neither cup slowed, credit: 'neither population was close to its carrying capacity yet, so competition was not yet limiting growth'.

- Weekly factors compared for both cups
- Slowdown (or its absence) described correctly from the data
- Uses competition and carrying capacity correctly

7. Estimate how many fronds cup D could hold if its whole surface were covered: day-14 count ÷ (percent covered ÷ 100). Show the calculation, then name one reason the real carrying capacity of the cup could be lower than your estimate.

Answer: Group-specific. Worked example: 180 fronds covering 60 percent: $180 \div (60 \div 100) = 180 \div 0.6 = 300$ fronds. Reasons the real carrying capacity could be lower: nutrients or light could run out before the surface fills; fronds overlap and shade each other near full cover; the estimate of percent covered is rough.

Why: Scaling a partial count to full coverage is a reasonable estimate of the space limit only, and assumes fronds stay the same size and do not stack.

- The division shown correctly with the student's numbers
- A result in fronds
- One valid reason the true carrying capacity could be lower

8. Resources affect individual organisms, not only how many there are. Describe how the fronds in cups A and C looked on day 14 compared with cup B, and explain what each resource was doing for the individual plants. Then connect this to the poison dart frogs: how can a missing resource change what an organism is like?

Answer: Cup C's fronds turned yellow or white and often looked thin, and cup A's fronds were paler and often smaller with longer roots than cup B's deep green fronds. Light supplies the energy a plant uses to make sugar and keep its green chlorophyll; without it, individual fronds used up stored food and lost their color. Nutrients such as nitrogen are the raw material for building new plant tissue and chlorophyll; without enough, each frond stayed small and pale. Dart frogs show the same idea: the alkaloids that make a wild frog poisonous come from the ants and mites it eats, so a frog raised without that resource looks normal but is not poisonous. A missing resource can change what an individual is like, not just how many individuals there are.

Why: This connects the population data to the individual-growth idea of MS-LS1-5 and back to the chapter phenomenon.

- Describes the appearance of A and C compared with B
- Explains what light and nutrients each do for an individual plant
- Connects to the dart frog's diet-derived poison

9. Why did the class pool its results, and why use the median instead of a single group's numbers? Suppose one group's cup C grew a lot. What are two possible explanations, and how would you check?

Answer: One cup can be unusual for reasons that have nothing to do with the resource being tested, so pooling eight groups shows whether an effect is real and repeatable. The median is the middle value, so one very high or very low cup cannot pull it far. A cup C that grew a lot could mean the box let light in (or the cup was left out of the box), or that the group miscounted or started with more than 10 fronds. Check by inspecting the box for gaps, asking whether it stayed closed, and recounting from day-7 and day-14 photos.

Why: Students should distinguish a real effect from a one-off result and propose concrete checks.

- Explains why pooled data are more trustworthy
- Explains why the median resists one extreme value
- Gives two plausible explanations and a way to check

10. Name one thing that was supposed to stay the same for all four cups but might not have (look at your conditions log). Explain how it could have changed the results and how you would control it better next time.

Answer: Examples: the box may have been warmer or cooler than the light spot (compare the two thermometers); cup C got some light during counting; algae grew in B and D and competed with the duckweed; evaporation was greater in the brightest spot so water levels differed between top-ups; one cup sat closer to the window. The student explains the effect (for example, a warmer box would let cup C use stored food faster) and a fix (for example, a thermometer check every day, a light-safe counting routine, or rotating cup positions daily).

Why: Any specific, plausible uncontrolled variable with an effect and a fix earns credit; the conditions log is the evidence.

- Names a specific variable that may not have stayed the same
- Explains how it could change the results
- Proposes a concrete improvement

11. Write a claim, supported by the class data, about how the availability of light, nutrients and space affected the duckweed population. Include at least three numbers and explain the mechanism (what each resource does for a duckweed plant).

Answer: Claim: the duckweed population grew only as fast as its scarcest resource allowed. Evidence (class medians, example values): with nutrients, light and room (cup B) the population grew about 6 times; without added nutrients (cup A) about 2 times; without light (cup C) about 1 time, so it did not grow; and with a crowded start (cup D) about 3.5 times. Mechanism: light supplies the energy duckweed uses to make the sugars that build new fronds, nutrients supply raw materials such as nitrogen, and space at the surface is where each frond catches its light. When any one of these was short, it limited how many new fronds could be made, even though the others were plentiful.

Why: This is the MS-LS2-1 performance: a claim about resource availability and population size supported by data and a mechanism.

- A claim linking resource availability to population growth
- At least three numbers from the class data
- A mechanism for light, nutrients and space
- Uses the idea that the scarcest resource sets the limit

Individual evidence of learning

Each student hands in their own counts and conditions tables, the four-line graph, the day-14 drawing, the class table with medians, and written answers to q1 to q11. The growth factors with q5 and q11 are the evidence for analyzing data on resource availability and population size; q6 and q7 are the evidence for competition and carrying capacity; q8 is the evidence for effects on individual organisms.

Assessment criteria

Criterion	Proficient looks like
Data collection	Counts for days 0, 7 and 14 in every cup, color scores, surface estimates and temperatures recorded; growth factors computed correctly and entered in the class table.
Fair comparison	Identifies cup B as the reference and states which single difference each other cup tests; uses growth factors, not raw counts, to compare (q4, q5).
Limiting resource reasoning	Names nutrients for A, light for C and crowding (space, light and nutrients per frond) for D, each supported by a comparison with B and numbers from the class medians.
Population and individuals	Explains both the population effect (growth factor) and the individual effect (color, frond size) of a missing resource, and connects the individual effect to the dart frog phenomenon (q8).
Evaluating the investigation	Explains why pooling and medians matter, names a specific uncontrolled variable from the log, and proposes a concrete improvement (q9, q10).

Accessibility adaptations

- Pair a student with low vision or limited fine-motor control with a partner who moves fronds with the toothpick while the student counts from an enlarged phone or tablet photo and records.

- Provide a growth-factor helper: a worked example (10 fronds to 60 fronds is $60 \div 10 = 6$ times) printed at the top of the counts table.
- Offer a sentence frame for q5: 'Cup __ grew __ times while cup B grew __ times. The only difference was __, so the limiting resource was __.'
- Let students who need movement act as the class 'cup keeper team' for the midweek top-up, and accept a labeled photo series in place of the day-14 drawing.

Low-cost alternative

Cut the cost by asking an aquarium shop or a pond-keeping family for spare duckweed (many give it away), using a bright window instead of a grow light, and running cups A, B and C in every group but only one cup D per table. If no duckweed is available at all, run the same four conditions with mustard or radish seeds on damp paper towels in clear zip bags (A: plain water, B: nutrient water, C: nutrient water in a dark box, D: four times as many seeds) and, after 10 to 14 days, count the seedlings whose seed leaves have opened and turned green and score their color. Do not use height as the measure: seedlings in the dark grow tall and pale while they use up the food stored in the seed, which makes the dark bag look like the winner. Seedlings grow as individuals rather than multiplying, so the crowded bag tests individual growth more than population growth.

Model limitations

This investigation has not been physically tested by the authors; the expected numbers are ranges based on published descriptions of how fast duckweed grows, and a classroom's light and temperature can change them a great deal. A cup is a tiny, simplified pond: it has no grazers, no water flow bringing in new nutrients, and only one duckweed species, so it shows competition within a species far more clearly than a real pond would. Cup D changes several things at once (surface per frond, light per frond and nutrients per frond), so it shows that crowding limits growth but cannot say which of those three ran short first. Two weeks is long enough to see differences in growth but usually not long enough for any cup to level off completely.

Teacher notes

All numeric keys are group-specific; the worked examples show the calculation and the expected ranges. The most common reasoning error is comparing raw counts instead of growth factors, which makes cup D look like the winner; push every group back to growth factors. If cup C's thermometer reads several degrees different from the light spot, use it as the q10 discussion rather than discarding the data. Duckweed is a flowering plant, but in this lab it reproduces by budding, so each new frond is a genetic copy of its parent; students do not need that detail but sometimes ask why there are no seeds.