

Who Is Doing What to Whom? Case Files from Four Ecosystems

Investigation question: Field notes from four ecosystems that share no species describe sixteen pairs of organisms but never name the relationship. Can your group decode who gains and who loses from the evidence, find the pattern the four ecosystems share, and predict the four missing interactions before they are revealed?

Evidence-based mystery

Groups of 4

1 session

Setup 5 · Activity 45 · Cleanup 3 min

MS-LS2-2 · assesses

Scientific purpose

Students work as ecologists handed a box of unlabeled field notes. Each card describes a real pair of species from a California kelp forest, the Mojave Desert, a California city park or a Central American rainforest, with one with-versus-without measurement for each partner. Groups rate every partner plus, minus or zero from the numbers, name the interaction, and place the card in a grid of four ecosystems by five interaction types. The finished grid has exactly one empty cell in each ecosystem, a different type each time, so groups must predict what kind of interaction will fill each gap, and which organisms might be involved, before a sealed envelope reveals four more cards.

Why this helps students with this chapter

A list of five definitions is easy to memorize and hard to use. Decoding the signs from numbers forces students to look at the effect on each partner instead of at appearances or at where an organism lives, which is exactly where the common errors come from (every hitchhiker is a parasite, a grazed plant that survives is not prey). The empty cells turn the lesson's big claim, that the same patterns recur in every ecosystem, into a prediction students make on paper and then check against sealed evidence.

Standards connections

MS-LS2-2 (assesses, constructing an explanation that predicts patterns of interaction among organisms across multiple ecosystems): Students classify sixteen interactions from evidence in four ecosystems that share no species, explain why all five interaction types recur (q8), predict the missing interaction in each ecosystem before the reveal (q3), and predict interactions in a Sierra Nevada ecosystem none of the cards describe (q10). That is evidence toward the PE as written; the competitive, predatory and mutually beneficial examples named in the clarification statement all appear.

Roles (rotate each session)

- **Card reader:** Reads each card aloud in full, names partner A (the first organism in the title) and partner B, and keeps the deck moving so no card is placed on a guess.
- **Calculator:** Says aloud which two numbers are being compared for each partner and runs the one-tenth test whenever the two numbers are close.

- **Recorder:** Writes the ratings and evidence in the q1 table, places the card in the grid, and writes the group's gap predictions.
- **Challenger:** Before any rating is written, asks 'What number shows that?' and, for every plus-minus card, 'Does it eat the other one, or live on or in it?'; leads the argument over the gap predictions.

Materials

Item	Quantity	Per	Note
Interaction case-file cards (16), printed on card stock and cut apart	1 set	group	Card text is in the recording sheet. Shuffle each set so the ecosystems are mixed.
Sealed reveal envelope with cards K5, D5, C5 and R5	1	group	Reveal card text is in the prep list. Mark the envelope 'Open only after all four gap predictions are written.'
Large sheet of paper (or a desk marked with masking tape) ruled as a 4 by 5 grid	1	group	Rows: kelp forest, Mojave Desert, city park, rainforest. Columns: predation, parasitism, competition, mutualism, commensalism.
Sticky notes for gap predictions	4	group	
Calculator	1	group	
Recording sheet	1	student	
Picture cards of the organisms (printed or projected)	1 set	class	Optional; helps multilingual learners and anyone who has never seen a peccary or a cholla.

Estimated cost: 3 to 6 per class (an estimate; Estimate. About three sheets of card stock per group (two of case files, one of reveal cards), so roughly 25 sheets for eight groups, about \$3 from a 50-sheet pack; envelopes, sticky notes and grid paper are classroom stock. Laminated sets can be reused every year.)

Safety

- Paper only: no live organisms, specimens or chemicals are used. The teacher cuts card stock with a paper cutter or scissors during prep; keep fingers clear of the blade.
- If you extend the lab by looking for lichens on schoolyard trees, students stay on paths, observe without scraping or picking, and wash hands afterward; no one picks or tastes mistletoe berries, which can make people sick.

Teacher preparation and setup

1. Print the 16 case-file cards from the recording sheet onto card stock, cut them apart and shuffle each set so the four ecosystems are mixed. Keep each set in its own bag.
2. Print the four reveal cards below for each group, cut them apart (leave off the bracketed key), and seal them in an envelope marked 'Open only after all four gap predictions are written.'
3. Reveal card K5 · Kelp forest · Blacksmith and skin copepods. Copepods are tiny relatives of shrimp. Some kinds clamp onto a fish's skin or gills and feed on its mucus, skin and blood. Blacksmith: in a seawater tank, blacksmith carrying 8 or more copepods grew 4 mm in a month; blacksmith carrying

none grew 7 mm. Very few died. Copepods: these copepods grow up and make eggs only while attached to a living fish. (Key: blacksmith –, copepod +, parasitism.)

4. Reveal card D5 · Mojave Desert · Cactus wren and cholla cactus. Cactus wrens build football-shaped nests of grass among cactus spines. Cactus wrens: nests built inside spiny cholla raised chicks to flying age 7 times in 10; nests in spineless shrubs nearby succeeded 3 times in 10, because snakes and ground squirrels reached them. Cholla: cactuses holding wren nests grew 12.0 new stem joints in a year, on average; cactuses without nests grew 12.5. (Key: wren +, cholla 0 because 0.5 is less than 1.25, commensalism.)
5. Reveal card C5 · City park · California fuchsia and Anna's hummingbird. California fuchsia is a low plant with red, tube-shaped flowers that blooms in late summer, when few other park flowers do. California fuchsia: of 100 flowers hummingbirds could reach, 64 set seed; of 100 flowers bagged in fine mesh, 6 did. Anna's hummingbirds: birds feeding in fuchsia beds found a full meal in about 6 minutes of searching; birds in beds without fuchsia took about 15 minutes. (Key: fuchsia +, hummingbird +, mutualism.)
6. Reveal card R5 · Rainforest · Long-billed hermit and rufous-tailed hummingbird. Both hummingbirds drink nectar from many of the same flowers along forest edges. Some flower patches are visited by both, some by only one. Long-billed hermits: each visit to a patch with no rufous-tails gave a hermit 6 units of nectar; in patches shared with rufous-tails, 4 units. Rufous-tailed hummingbirds: in patches with no hermits, a rufous-tail needed 30 minutes of feeding a day; in shared patches, 40 minutes. (Key: hermit –, rufous-tail – because more feeding time for the same food is worse, competition.)
7. Rule a 4 by 5 grid on large paper for each group (or tape one onto each desk). Do not label which cells will be empty; the gaps appear only when the cards are placed.
8. For students who need a shorter task, make a reduced set of eight cards, two per ecosystem (for example K1, K3, D2, D4, C1, C4, R3 and R4). Each row then has three empty cells; ask those students to predict one gap per row.
9. Remove phones and devices from the tables during the sort and prediction; every fact needed is on the cards.

Investigation design

Independent variable	The pair of species and the ecosystem on each card (four ecosystems, five interaction types)
Dependent variable	The rating given to each partner (+, – or 0), the interaction named, and whether each gap prediction matches the type on the reveal card
Controlled	Every card gives one with-versus-without comparison for each partner; One rating rule for every card: the one-tenth test for close numbers; The same five interaction codes for every ecosystem; No devices or outside sources during the sort and the predictions
Trials	Sixteen case files plus four reveal cards per group; a second group member checks every close call, and the class compares grids at the end.
Comparison	Each group's gap predictions against the sealed reveal cards, and each group's grid against the other groups' grids.

Student procedure

1. Lay out the grid. The card reader reads the two callouts on the recording sheet aloud, and the calculator works the one-tenth example so everyone agrees on the rule.
2. Deal the 16 cards face up. Take one card at a time. The reader reads it aloud and names partner A (the first organism in the title) and partner B, and the group finds the one comparison given for each partner.
3. Rate partner A, then partner B. Decide what 'doing better' means for that measurement (more young, more seeds or more food is better; more parasites or more searching time is worse), compare the two numbers, and run the one-tenth test whenever they are close. The challenger asks for the number before anything is written.
4. Name the interaction from the pair of ratings. For every plus-minus card, decide from the evidence whether one partner eats all or part of the other (predation) or lives on or inside a living host and feeds from it over time (parasitism). The recorder fills in the card's row in q1 and places the card in the grid.
5. When all 16 cards are placed, look along each row of the grid and write GAP in every empty cell (q2). Each row should have exactly one gap; if a row has none or two, recheck the cards in that row.
6. For each gap, write a prediction on a sticky note and in q3: two partners that could fill it in that ecosystem (named species or a general description), the rating you predict for each with a reason, and one measurement a field biologist could make to test it.
7. When all four predictions are written, show them to the teacher and collect the sealed envelope. Rate the four reveal cards exactly as before, place them in the gaps, and record in q3 whether each one matched the type you predicted. Matching the type matters; your species may differ.
8. Answer q4 as a group. Answer q5 to q12 on your own; q8 to q12 may be finished as homework. Return all 20 cards to the bag and envelope.

Expected observations

- Most groups rate 13 to 16 of the 16 cards correctly on the first pass. The common first-pass errors are calling K2, C1 or R2 parasitism or mutualism because one organism lives on or among the other, calling D4 parasitism because the dandelion survives, rating the starlings on C4 as 0 because they usually win, and reading the blacksmith's drop in parasites on K1 as a minus.
- Once every card is placed, each row has exactly one gap: kelp forest, parasitism; Mojave Desert, commensalism; city park, mutualism; rainforest, competition.
- Nearly every group predicts the right type for all four gaps, because the grid forces it. The predicted species vary widely: for the kelp-forest parasite students often suggest a worm or louse on a fish; for desert commensalism, a bird nesting in a cactus or an animal sheltering in a burrow; for the city mutualism, bees or hummingbirds and flowers; for rainforest competition, two monkeys or birds after the same fruit.
- The reveal usually produces a short burst of satisfaction followed by the better question of whether a different pair would have counted. It would: the type is the prediction, not the species.

Likely difficulties

- Students compare partner A's number with partner B's number instead of comparing one partner with and without the other species. Have the calculator say 'with ___, without ___' aloud for every rating.
- Students rate whether an organism seems good or bad rather than the effect on it. The question is always 'Does this partner do better or worse because of the other one?'
- The direction of 'better' trips students when a smaller number is good (fewer parasites on K1, less searching time on C5, less feeding time on R5). Ask what the organism would want.
- Groups run the one-tenth test on every card and run out of time. It is only needed when the two numbers are close (K2, C1, C4 starlings, D1 kangaroo rats, R2 and the reveal card D5).
- Some students want to argue that the young rockfish help the kelp or that the orchids hurt the tree. Welcome it: the card's numbers decide the label, and q11 asks what new measurement could change it.

Structured debrief

1. Post the grids. Every group should find the same structure: one gap per ecosystem, a different type each time (kelp forest, parasitism; Mojave Desert, commensalism; city park, mutualism; rainforest, competition). Ask how they knew what the gap had to be before seeing the reveal: the other four ecosystems all had that type, and nothing about the place suggested it could be missing. That is the MS-LS2-2 move, predicting an interaction from a pattern.
2. Work the close calls together: the three zeros (K2, C1, R2) and the starlings on C4. Make the point that competition is – – even when one competitor wins most fights, because the winner still ends up with fewer nest holes than it would have alone.
3. Return to the 'lives on it' trap with q6. Five cards describe one organism on or inside another, and they split into two labels. Then note that the lichen on card C1 is itself a partnership: inside it a fungus and an alga or cyanobacterium are mutualists. Interactions are labels for pairs, so one organism can be in several at once (a señorita is a mutualist with blacksmith and is sometimes prey for kelp bass).
4. Ask which evidence was weakest (q12). R1 compares two different years and C2 compares two different parks, so weather, food or other differences could explain part of the result; the mesh-bag and fenced-plot cards (D3, D4, C5) are experiments and are stronger. Ecologists trust a label more when the comparison changes only the partner.
5. Close with the Sierra Nevada prediction (q10) and a preview of Lab 3: to use these patterns to manage a real population, people need trustworthy counts of it, which is the monitoring problem the frog-sensor shield addresses.

Recording sheet: what students fill in

Lab 2 recording sheet: Who is doing what to whom?

How to rate each partner — Each card gives one comparison for each partner: how it does when the other species is present or common, and how it does when the other species is absent or scarce. First decide what 'doing better' means for that measurement. Rate the partner **+** if it does better with the other species, **–** if it does worse, and **0** if the two numbers differ by less than one-tenth of the larger number. Example: 50 and 47 differ by 3, and one-tenth of 50 is 5; 3 is less than 5, so the rating is 0.

The five codes — **+** **+** mutualism. **+** **0** commensalism. **–** **–** competition. **+** **–** is **predation** when one partner eats all or part of the other (in this lesson, plant eaters count as predators) and **parasitism** when one partner lives on or inside a living host and feeds from it over time.

Teaching data — Every organism and every relationship on these cards is real. The numbers are invented to show the kind of evidence ecologists collect; they are not measurements from any single real study.

Case-file cards (teacher prints and cuts apart; 16 cards)

1 K1 • Kelp forest • Señorita and blacksmith

The señorita is a slim, cigar-shaped fish. Blacksmith are dark, plankton-eating fish that hover in groups and sometimes hold still, head tipped down, beside a señorita. **Señoritas:** at midday, señoritas on reefs crowded with blacksmith had 30 food items in their stomachs, several of them tiny parasites picked off other fish; señoritas on reefs with few blacksmith had 21. **Blacksmith:** fish near señoritas carried 1 skin parasite each, on average; blacksmith on a reef with no señoritas carried 7.

2 K2 • Kelp forest • Giant kelp and young rockfish

Each spring, young rockfish of several kinds drift in from the open ocean and settle into kelp forests. They eat tiny drifting animals, not kelp. **Giant kelp:** stalk tips with many young rockfish around them grew 21 cm per day; stalk tips with few grew 20 cm per day. **Young rockfish:** divers counted 26 per 100 meters of swim path under the kelp and 3 per 100 meters over bare sand nearby at the same depth, where diving birds and bigger fish could spot them.

3 K3 • Kelp forest • Purple sea urchin and sea otter

Divers surveyed 12 rocky reefs where sea otters feed and 12 similar reefs with no otters. **Purple sea urchins:** 3 per square meter on otter reefs; 40 per square meter on reefs without otters. The urchins left on otter reefs hid deep in cracks in the rock. **Sea otters:** watchers on shore timed otter dives. On reefs where urchins were still common, an otter came up with food on 8 of every 10 dives; on reefs where urchins were scarce, on 5 of every 10.

4 K4 • Kelp forest • Woody-stemmed kelp and giant kelp

Woody-stemmed kelp is a short kelp, about as tall as a person, that grows beneath giant kelp, which reaches the surface. Both need sunlight on the seafloor to grow and to start new young plants. Divers cleared one kind from test plots and checked a year later. **Woody-stemmed kelp:** it covered 60 percent of the seafloor where giant kelp had been cleared and 15 percent under untouched giant kelp. **Giant kelp:** 9 young plants per square meter took hold where woody-stemmed kelp had been cleared; 2 per square meter where it was left.

5 D1 • Mojave Desert • Merriam's kangaroo rat and harvester ants

Kangaroo rats and harvester ants both gather the seeds of the same desert wildflowers and grasses. Biologists fenced kangaroo rats out of some plots, removed ant colonies from others, left some plots alone, and counted three years later. **Kangaroo rats:** 14 per plot where the ants had been removed; 11 per plot where ants were left. **Harvester ants:** 31 colonies per plot where kangaroo rats were fenced out; 20 colonies per plot where rats were present.

6 D2 • Mojave Desert • Catclaw acacia and desert mistletoe

Desert mistletoe is a leafless plant with green, jointed stems that grows in clumps on the branches of desert shrubs and trees. It makes some of its own food from sunlight, but its root-like strands grow into the branch wood and take water and minerals. **Catclaw acacia:** after a dry year, heavily infested shrubs made 35 seed pods each; shrubs with no mistletoe made 90. **Desert mistletoe:** clumps were found only on living branches, and clumps on branches that died also died within a year.

7 D3 • Mojave Desert • Joshua tree and yucca moth

A female yucca moth gathers pollen from Joshua tree flowers, flies to another tree, lays her eggs inside a flower and presses pollen onto it. Her larvae eat some of the developing seeds. **Joshua trees:** of 100 flowers that moths could reach, 28 became seed pods; of 100 flowers wrapped in fine mesh to keep moths out, 0 did. Pods with larvae inside still held most of their seeds. **Yucca moths:** the larvae eat nothing but developing Joshua tree seeds, and no larvae of this moth were found on any other plant at the site.

8 D4 • Mojave Desert • Desert dandelion and desert tortoise

Desert dandelion is a yellow spring wildflower. Biologists fenced some plots so tortoises could not get in and compared them with open plots. **Desert dandelion:** plants inside the fences made 40 seeds each; plants in open plots, where tortoises bit off flowers and leaves, made 22. Few plants were killed outright. **Desert tortoises:** tortoises whose home areas had thick patches of spring wildflowers gained 120 g over the spring; tortoises where wildflowers were sparse gained 30 g.

9 C1 • City park • Lichen and coast live oak

Lichens are crusty, gray-green patches on bark and stone. Each one is a fungus living with an alga or a cyanobacterium that makes food from sunlight. Lichens do not grow into wood or take sap. **Lichen:** patches on oak bark grew 4 mm wider per year; patches on the park's concrete benches grew 1 mm per year. **Coast live oaks:** trunks heavily covered in lichen added 2.0 mm of new wood per year; trunks with almost no lichen added 2.1 mm.

10 C2 • City park • Cooper's hawk and rock pigeon

Cooper's hawks are crow-sized hawks that now nest in many California city parks. **Cooper's hawks:** about 4 of every 10 prey brought to a nest were pigeons or doves. Hawk pairs in parks with many pigeons raised 4 chicks a year; pairs in parks with few pigeons raised 2. **Rock pigeons:** in a park where a pair of Cooper's hawks nested, the pigeon flock fell from 220 to 150 birds over two years; in a similar park with no hawks, it went from 210 to 205.

11 C3 • City park • Rock pigeon and feather louse

Feather lice are flat, wingless insects about 2 mm long. They spend their whole lives on one bird, eating the soft, fluffy parts of its feathers. **Rock pigeons:** over one cold winter, 80 of every 100 pigeons that had been treated to remove lice survived, compared with 60 of every 100 heavily infested pigeons. Pigeons with chewed feathers lose more body heat. **Feather lice:** on a living pigeon, lice lived for weeks and laid eggs on the feathers; lice that fell off a bird died within a few days.

12 C4 • City park • Western bluebird and European starling

Both birds nest in holes, such as old woodpecker holes in park trees, and a park has a limited number of them. Starlings often chase bluebirds away from a hole, but the fights cost them time and sometimes the hole. **Western bluebirds:** where starlings were common, 20 of every 100 bluebird pairs found a nest hole; where starlings were rare, 55 of every 100 did. **European starlings:** where bluebirds were common, 72 of every 100 starling pairs found a nest hole; where bluebirds were rare, 86 of every 100 did.

13 R1 • Rainforest • Mantled howler monkey and howler botfly

A botfly larva lives under the skin of a howler monkey, often on the neck, growing inside a small swelling for several weeks before it drops to the ground and becomes an adult fly. **Howler monkeys:** in a year with many botflies, 30 of every 100 young monkeys died; in a year with few botflies, 12 of every 100 died. Most adult monkeys carried a few larvae and survived. **Howler botflies:** larvae of this kind of botfly have been found growing only in howler monkeys.

14 R2 • Rainforest • Canopy tree and orchids

Many rainforest orchids live perched high on tree branches. Their roots grip the bark and soak up rain; they make their own food from sunlight and take nothing out of the tree. **Canopy trees:** trees carrying many orchids added 12.0 mm to their trunk width in a year; trees carrying few added 12.5 mm. **Orchids:** of 100 young orchids tied onto branches 25 m up, 78 were alive a year later; of 100 planted on the dim forest floor, 9 were.

15 R3 • Rainforest • Leafcutter ants and their fungus

Leafcutter ants carry leaf pieces into their underground nest, chew them into mush and spread it on a spongy fungus garden. The ants and their young eat swollen tips that the fungus grows. A young queen carries a pellet of fungus with her to start each new nest.

Leafcutter ants: of 10 lab colonies whose garden was taken away, none survived a month, even with fresh leaves; all 10 colonies that kept their gardens survived.

Fungus: gardens kept without ants were overgrown by molds within a week, and this fungus has never been found growing wild away from leafcutter nests.

16 R4 • Rainforest • Jaguar and collared peccary

Collared peccaries are pig-like animals that travel in small herds. **Jaguars:** about one third of the prey remains in jaguar droppings were peccaries. Female jaguars in areas with many peccaries raised a litter about every 2 years; where peccaries were scarce, about every 3 years. **Collared peccaries:** in forest where jaguars hunt, 45 of every 100 young peccaries lived to their first birthday; in a nearby forest where jaguars had been hunted out, 70 of every 100 did.

1. Rate both partners on every card. Partner A is the first organism in the card's title. Write the two numbers you compared for each partner, then name the interaction.

Answer: K1: señorita +, 30 vs 21 food items; blacksmith +, 1 vs 7 parasites (fewer is better); **mutualism**. K2: giant kelp 0, 21 vs 20 cm per day (difference 1, less than 2.1); young rockfish +, 26 vs 3; **commensalism**. K3: purple urchin –, 3 vs 40 per square meter; sea otter +, food on 8 vs 5 of 10 dives; **predation**. K4: woody-stemmed kelp –, 15 vs 60 percent cover; giant kelp –, 2 vs 9 young per square meter; **competition**. D1: kangaroo rat –, 11 vs 14 per plot (difference 3, more than 1.4); harvester ants –, 20 vs 31 colonies; **competition**. D2: catclaw –, 35 vs 90 pods; mistletoe +, lives only on living branches and dies when the branch dies; **parasitism**. D3: Joshua tree +, 28 vs 0 pods per 100 flowers; yucca moth +, larvae can eat only Joshua tree seeds; **mutualism**. D4: desert dandelion –, 22 vs 40 seeds; tortoise +, 120 vs 30 g gained; **predation** (plant eating counts in this lesson). C1: lichen +, 4 vs 1 mm per year; oak 0, 2.0 vs 2.1 mm (difference 0.1, less than 0.21); **commensalism**. C2: Cooper's hawk +, 4 vs 2 chicks; rock pigeon –, flock 150 vs 205 after two years; **predation**. C3: rock pigeon –, 60 vs 80 of 100 survived; feather louse +, lives and breeds only on a living pigeon; **parasitism**. C4: western bluebird –, 20 vs 55 of 100 pairs found holes; starling –, 72 vs 86 of 100 (difference 14, more than 8.6); **competition**. R1: howler monkey –, 30 vs 12 of 100 young died; botfly +, grows only in howler monkeys; **parasitism**. R2: canopy tree 0, 12.0 vs 12.5 mm (difference 0.5, less than 1.25); orchids +, 78 vs 9 of 100 alive; **commensalism**. R3: leafcutter ants +, 10 vs 0 of 10 colonies survived; fungus +, overgrown without ants and never found without them; **mutualism**. R4: jaguar +, a litter every 2 vs every 3 years; collared peccary –, 45 vs 70 of 100 young survived; **predation**.

Why: Each rating compares one partner with and without the other species, and the label follows from the pair of ratings. The five close pairs are the three zeros (K2, C1, R2) and the two small but real minuses (D1 kangaroo rats, C4 starlings), which the one-tenth test settles. For the plus-minus cards the label depends on whether the partner eats the other (K3, D4, C2, R4) or lives on or inside a living host (D2, C3, R1).

Also acceptable: Accept 'herbivory, counted as predation in this lesson' for D4. Accept evidence written as a change (for example 'pigeons fell by 70 instead of 5') for C2. A student who rates the starlings 0 without running the test loses that row; one who runs the test and then misreads it should be shown the arithmetic.

- Both partners rated on every card with the numbers compared
- One-tenth test shown for the close pairs
- Interaction named correctly from the ratings, with predation and parasitism distinguished

2. Write each card code in the correct cell of the grid. Write GAP in every empty cell.

Answer: Kelp forest: predation K3; parasitism GAP; competition K4; mutualism K1; commensalism K2. Mojave Desert: predation D4; parasitism D2; competition D1; mutualism D3; commensalism GAP. City park: predation C2; parasitism C3; competition C4; mutualism GAP; commensalism C1. Rainforest: predation R4; parasitism R1; competition GAP; mutualism R3; commensalism R2.

Why: With every q1 rating correct, each row has one gap and the four gaps are four different types. A row with no gap or two gaps means a card in that row was misclassified, which is the self-check built into step 5.

- All sixteen codes in the correct cells
- Exactly one GAP in each row, in the cells listed

3. Predict each gap before you open the envelope. Fill in the last column after the reveal.

Answer: Types: kelp forest, parasitism; Mojave Desert, commensalism; city park, mutualism; rainforest, competition. Example predictions: a parasitic worm or crustacean on a kelp-forest fish (fish –, parasite +; measure the growth or survival of fish with and without the parasite); a bird or lizard sheltering in a cactus or a burrow (sheltering animal +, cactus or burrow owner 0; measure the host's growth with and without the lodger); bees or hummingbirds and park flowers (both +; compare seed set in bagged and open flowers and the feeding success of the animal); two monkeys or two birds feeding on the same fruit or nectar (both –; compare each one's food intake where the other is present and absent). The reveal cards are K5 (blacksmith and skin copepods, parasitism), D5 (cactus wren and cholla, commensalism), C5 (California fuchsia and Anna's hummingbird, mutualism) and R5 (long-billed hermit and rufous-tailed hummingbird, competition).

Why: The grid forces the type of each gap, so the real test is whether the predicted pair is plausible for that ecosystem and whether the predicted ratings and measurement fit the type. Different species from the reveal card are fully acceptable.

Also acceptable: Any real or realistic pair from the right ecosystem with ratings that match the type, for example sea lice on a fish, a pack rat nesting under a creosote bush, honeybees and lavender, or two kinds of fruit-eating birds at one fig tree.

- Correct missing type for each ecosystem
- A plausible pair of partners for that ecosystem
- Ratings that fit the type, with a reason
- A with-versus-without measurement that could test it
- Reveal column completed honestly

4. Which card caused the biggest argument in your group? Write its code, the two ratings or labels people argued for, and the evidence that settled it.

Answer: Answers vary. Common choices: D4, argued as parasitism because the dandelion survives, settled because the tortoise eats parts of the plant and moves on rather than living on it; C4, argued as + – because starlings win the fights, settled by the one-tenth test (72 vs 86 is a real drop); K2, argued as mutualism because fish 'look after' the kelp, settled because kelp growth did not change.

Why: The point is that the group used a number or a definition, not volume, to settle the dispute.

- Names a card and the two competing ratings or labels
- States the specific evidence or rule that settled it

Analysis questions: answer key

5. Show the one-tenth test for (a) the starlings on card C4 and (b) the canopy trees on card R2. Give the rating for each.

Answer: (a) Starlings on C4: $86 - 72 = 14$; one-tenth of 86 is 8.6; 14 is more than 8.6, so the rating is $-$. (b) Canopy trees on R2: $12.5 - 12.0 = 0.5$ mm; one-tenth of 12.5 is 1.25; 0.5 is less than 1.25, so the rating is 0 .

Why: The test uses one-tenth of the larger number. The starlings' drop is smaller than the bluebirds' but still real, so competition stays $-$; the trees' difference is too small to count.

Also acceptable: Accept percentage reasoning ($14 \div 86$ is about 16 percent, more than 10 percent; $0.5 \div 12.5$ is 4 percent, less than 10 percent).

- Correct difference and one-tenth value for each
- Correct rating for each

6. Five cards describe one organism living on or inside another: C1, C3, D2, R1 and R2. Sort them by interaction and explain why where an organism lives cannot decide the label. Use two cards with different labels as your evidence.

Answer: Commensalism: C1 (lichen on oak) and R2 (orchids on a canopy tree). Parasitism: C3 (lice on a pigeon), D2 (mistletoe in catclaw) and R1 (botfly larvae in a howler monkey). All five live on or in another organism, yet they fall under two labels, so location cannot decide. What decides is the effect on the host: the oak added 2.0 vs 2.1 mm of wood, no measurable change, so it is 0 ; the pigeons survived winter 60 vs 80 of 100, a clear loss, so they are $-$.

Why: This targets the chapter misconception that anything living on another organism is a parasite. The test is the effect, not the address.

- Sorts the five cards correctly
- States that the effect on the host decides the label
- Uses numbers from two cards with different labels

7. Cards D4 (dandelion and tortoise) and D2 (catclaw and mistletoe) both rate $+ -$, and in both the plant usually survives. What evidence on the cards makes one of them predation and the other parasitism?

Answer: The tortoise eats parts of the dandelion (flowers and leaves) and moves on; it does not live on the plant, and its benefit comes from what it eats, so D4 is predation in this lesson's sense. The mistletoe lives attached to the catclaw, its strands grow into the living wood and take water and minerals over time, and it dies when its branch dies, so D2 is parasitism. Both hosts are harmed and usually survive, so survival cannot separate them; the way the benefit is taken does.

Why: Predation and parasitism share the $+ -$ code. The lesson separates them by whether the consumer eats and moves on or lives on or inside a living host.

- Identifies eating-and-moving-on for D4
- Identifies living on or in the living host for D2, with card evidence
- States that the shared code and host survival do not decide it

8. The four ecosystems in your grid share no species at all. Describe the pattern across the four rows after the reveal, and explain why ecologists expect every ecosystem on Earth to contain all five interactions. Use the idea of limited resources in your explanation.

Answer: After the reveal every ecosystem contains all five interactions: something eats something, something lives on a host, two species compete, a pair helps each other, and one species benefits from another without affecting it. The species are completely different from row to row, but the shapes of the relationships are the same. Ecologists expect this everywhere because every ecosystem has living things that need food, water, light, space and shelter, and those resources are limited. Wherever resources are limited, some organisms get them by eating others or by feeding from a living host, organisms that need the same scarce resource reduce each other's share, partnerships that let both partners get more are favored, and some organisms use another's body or structure as a resource without costing it anything measurable. So a new ecosystem can be expected to show the same five patterns, even before anyone has studied its species.

Why: This is the explanation MS-LS2-2 asks for: a prediction of interaction patterns across ecosystems grounded in a cause (limited resources and organisms' needs), using evidence from the grid.

- States that all four ecosystems contain all five types despite sharing no species
- Explains the recurrence using limited resources and what organisms need
- Connects at least two interaction types to resource limits
- Makes or implies a prediction for other ecosystems

9. Card K3 shows that sea otters keep purple urchins scarce, and urchins eat giant kelp. Predict how much giant kelp grows on otter reefs compared with reefs without otters. Then predict what happens to the young rockfish on card K2 if otters disappear from a reef. Name the interaction at each link of your chain.

Answer: Otter reefs should have much more giant kelp than reefs without otters. Otters eat urchins (predation, otter + urchin -), so urchins stay scarce, and fewer urchins eat less kelp (predation by a plant eater, urchin + kelp -). If otters disappear, urchins multiply and chew the kelp down, and the young rockfish lose the canopy they shelter in (commensalism, rockfish + kelp 0), so fewer young rockfish survive birds and bigger fish. The rockfish decline even though otters never interact with them directly.

Why: Three linked interactions carry the effect: otter to urchin, urchin to kelp, kelp to young rockfish. It matches the otter-urchin-kelp story on slide 13 and is the same shape as wolves, elk and willows in Yellowstone.

- Predicts more kelp with otters
- Predicts fewer young rockfish if otters disappear
- Names the interaction at each link (predation, predation, commensalism)

10. A high meadow and lake in the Sierra Nevada is an ecosystem none of the cards describe. Predict one competition and one mutualism you would expect to find there. For each, describe the two partners (a general description such as 'two kinds of seed-eating birds' is fine), give the rating for each partner, and describe one measurement that would test your prediction.

Answer: Example competition: trout and frog tadpoles or two kinds of insect-eating birds both eating the same aquatic insects (both –); compare each one's food intake or growth in lakes or meadows with and without the other. Example mutualism: bumblebees and meadow wildflowers (bee + gets nectar and pollen, flower + is pollinated), or Clark's nutcrackers and whitebark pines (the bird eats seeds but buries far more than it eats, and forgotten caches grow into new trees); compare seed set in bagged and open flowers, or seedling numbers near caches.

Why: Students should apply the recurring patterns to a place they have not studied, with plausible partners, correct ratings and a test that compares with and without the partner.

Also acceptable: Any plausible pairs: grazers such as deer and ground squirrels sharing meadow plants (competition); mycorrhizal fungi and pine roots, or lichens on rocks (mutualism inside the lichen). In the Sierra Nevada, introduced trout also eat mountain yellow-legged frog tadpoles, which students may correctly call predation as well as competition.

- One competition with two plausible partners and – – ratings
- One mutualism with two plausible partners and + + ratings
- A with-versus-without measurement for each

11. Pick one card you rated 0 (K2, C1 or R2). Describe a new measurement that could change that 0 to a + or a –, and say which way you think it might go and why.

Answer: Example for K2: measure whether the young rockfish's waste adds nutrients the kelp can use, by comparing kelp growth with many versus no fish over a whole season; if the kelp grew measurably faster with fish, the 0 would become a + and the pair a mutualism. Example for C1: measure whether thick lichen keeps bark wetter and leads to more fungal rot; if so, the oak's 0 could become a –. Example for R2: weigh orchid loads on branches and count branches that break in storms; a heavy load could make the tree's rating –.

Why: A 0 means no measurable effect so far. Labels follow evidence, so a better or longer measurement can move a pair to another category, as discussed on slide 20.

- Names a specific new measurement on the 0 partner
- Says which way it could change the rating and why
- Recognizes that the label would then change

12. Which card's comparison is weakest as evidence? Explain what else could explain its difference, and how a fairer comparison could be made.

Answer: Best answers: R1 compares a year with many botflies to a year with few, so a difference in weather, fruit and leaf supply or disease between the two years could explain some of the extra deaths; a fairer comparison would follow infected and uninfected young monkeys in the same year, or compare young monkeys with heavy and light loads in the same troop. C2 compares two different parks, which might differ in food or people as well as hawks; a fairer comparison would count pigeons in the same park before and after the hawks arrived, alongside a park without hawks.

Why: A comparison is strongest when only the partner differs. Fenced plots and mesh bags (D1, D3, D4) change only the partner, so they are stronger evidence than comparisons across years or places.

Also acceptable: Accept K3 (otter reefs and non-otter reefs may differ in other ways) or K1 (crowded and quiet reefs may differ in food) with a confound and a fairer design.

- Names a card and a plausible alternative cause for its difference
- Describes a fairer comparison that changes only the partner

Individual evidence of learning

Each student keeps their own copy of the q1 to q3 tables and writes q5 to q12 individually. q8 (the explanation of why all five interactions recur) and q10 (the prediction for an unstudied Sierra Nevada ecosystem) are the main evidence for MS-LS2-2; q3 shows prediction from the grid's pattern; q5 and q11 show the evidence rule; q6 and q7 show the distinctions between look-alike interactions; q12 shows judgment about the quality of evidence.

Assessment criteria

Criterion	Proficient looks like
Ratings from evidence	At least 14 of the 16 cards rated correctly, each rating backed by the two numbers compared for that partner, with the one-tenth test shown for close pairs.
Classification	Each interaction named correctly from its two ratings, with predation and parasitism told apart by eats-versus-lives-on evidence rather than by the code alone.
Pattern and prediction	Finds all four gaps, predicts a plausible pair and ratings for each before the reveal, and explains that every ecosystem has living things competing for limited resources, so the same five interaction types appear everywhere even when the species differ.
Judging evidence	Identifies a card whose comparison could be explained by something other than the partner (different years or different parks) and describes a fairer comparison.

Accessibility adaptations

- Provide a large-print card set with the two partner names in bold and each partner's two numbers on their own line.
- Show a picture of each organism; give multilingual learners a glossary card for gains, loses, no measurable change, host and the five interaction names, plus the frame 'With ___, partner A ___; without ___, it ___, so A is ___.'

- Offer the reduced eight-card set (two per ecosystem) and let students rate one partner at a time on a two-column strip before naming the interaction.
- For students who need movement, build the grid on a wall or the floor with taped columns and let the group walk each card to its cell; accept spoken answers to q8 to q12 recorded on a device.

Low-cost alternative

Print the cards on plain paper four to a page, or project one card at a time and have groups rate it on mini whiteboards while each student keeps the grid in a notebook. Project the four reveal cards at the end instead of sealing envelopes, after every group has shown its predictions.

Model limitations

This activity has not been physically tested by the authors with a class. The organisms and relationships are real, but every number on the cards is invented, and each card shrinks a relationship to one with-versus-without comparison per partner. Real interactions can shift with conditions (in a Kenyan experiment, acacia trees cut back the rewards they give their guard ants after large browsers were fenced out), many pairs have both helpful and harmful effects at once (scrub jays eat many acorns but also plant the ones they forget), and a 0 means only that no difference was measured. The one-tenth rule is a classroom convention, not a statistical test; ecologists decide whether a difference is real from many repeated samples.

Teacher notes

Grade q1 and q2 against the key; grade q3 on plausibility, not on matching the reveal species. The built-in self-check is the grid: if a row does not have exactly one gap, a card in it is misread, and the group can find its own error. Expect the D4 tortoise card and the C4 starlings to cause the best arguments; let the challenger lead them before stepping in. Keep the reveal cards sealed until predictions are written, because the prediction is the evidence for MS-LS2-2. If time runs short, finish q5 to q7 in class and assign q8 to q12; q8 and q10 are the items to look at first. The lichen on C1 is a good closing puzzle: it is a commensal partner of the oak and is itself a mutualism.