

Counting Dune Plants: Richness, Evenness and a Diversity Index

Learning target: I can calculate species richness, proportions and Simpson's index of diversity from sample counts, graph the results, and use them to describe how an invasive plant changes a dune community.

Data and graphing

About 45 min

Individual

MS-LS2-4 · practice

MS-LS2-5 · supports

data analysis

independent practice

Standards connections

MS-LS2-4 (practice): Students analyze sample data to describe how a change to a biological component of an ecosystem (an invasive plant spreading) goes with changes in native plant populations, and they identify what the data cannot yet prove, practicing the empirical reasoning the PE asks for.

MS-LS2-5 (supports): A diversity index is one of the measurements used to judge whether a design solution, such as removing an invasive plant, is maintaining biodiversity; students also use their numbers to argue which site to restore first.

Purpose: practice · **Time:** about 45 minutes · **Format:** individual

Answers with reasoning

The scenario

Highway iceplant is a succulent from South Africa that people planted along California roads and coasts to hold soil in place. It spreads into thick mats that cover the sand. A park science team sampled plants at three dune sites on the same stretch of coast. At each site they laid five quadrats (square frames 1 meter on a side) and counted every rooted plant inside them. Site A is a dune where volunteers removed iceplant ten years ago. At Site B iceplant is spreading. Site C has been covered by iceplant for decades.

Rooted plants counted in five 1 m × 1 m quadrats at each site (teaching dataset)

Simulated teaching dataset: the numbers are invented to be realistic, not measured.

Plant	Native or invasive?	Site A	Site B	Site C
Beach bur	native	14	8	2
Yellow sand verbena	native	12	4	0
Beach primrose	native	10	6	2
Silver beach lupine	native	8	2	0
Beach morning glory	native	6	0	0
Highway iceplant	invasive	0	30	36

Simulated data for teaching. The plants are real California dune species, but the counts were invented. Real surveys of mat-forming plants often measure the percent of ground covered instead of counting plants.

How to calculate Simpson's index of diversity — 1. Add the counts to find the total number of plants at the site. 2. For each species, find its **proportion**: its count $\div$ the total. 3. Multiply each proportion by itself (square it). 4. Add all the squared proportions. 5. Subtract that sum from 1. The result is Simpson's index of diversity. It is close to 0 when nearly every plant belongs to one species and gets closer to 1 when there are many species in similar numbers. It also has a meaning you can picture: it is the chance that two plants picked at random (putting the first one back before picking again) are **different** species.

Part A: Richness and proportions

1. Complete the summary table for each site.

Answer: Site A: total $14 + 12 + 10 + 8 + 6 + 0 = 50$; richness 5; native richness 5; iceplant $0 \div 50 = 0$ percent. Site B: total $8 + 4 + 6 + 2 + 0 + 30 = 50$; richness 5; native richness 4; iceplant $30 \div 50 \times 100 = 60$ percent. Site C: total $2 + 0 + 2 + 0 + 0 + 36 = 40$; richness 3; native richness 2; iceplant $36 \div 40 \times 100 = 90$ percent.

Why: Richness counts species with at least one plant; a zero count does not add a species.

Also acceptable: None.

2. Calculate Simpson's index of diversity for Site A and Site B. Fill in the proportion and the squared proportion for every plant, then the sum and the index. Show one proportion calculation below the table.

Answer: Site A: beach bur $14 \div 50 = 0.28$, squared 0.0784; sand verbena 0.24, 0.0576; primrose 0.20, 0.0400; lupine 0.16, 0.0256; morning glory 0.12, 0.0144; iceplant 0, 0. Sum = 0.2160. Index = $1 - 0.2160 = 0.784$. Site B: beach bur $8 \div 50 = 0.16$, 0.0256; sand verbena 0.08, 0.0064; primrose 0.12, 0.0144; lupine 0.04, 0.0016; morning glory 0, 0; iceplant 0.60, 0.3600. Sum = 0.4080. Index = $1 - 0.4080 = 0.592$.

Why: Each proportion is the count divided by the site total of 50; squaring and summing gives the chance two random picks match. All values were rechecked by calculator.

Also acceptable: Accept 0.78 and 0.59 if rounded.

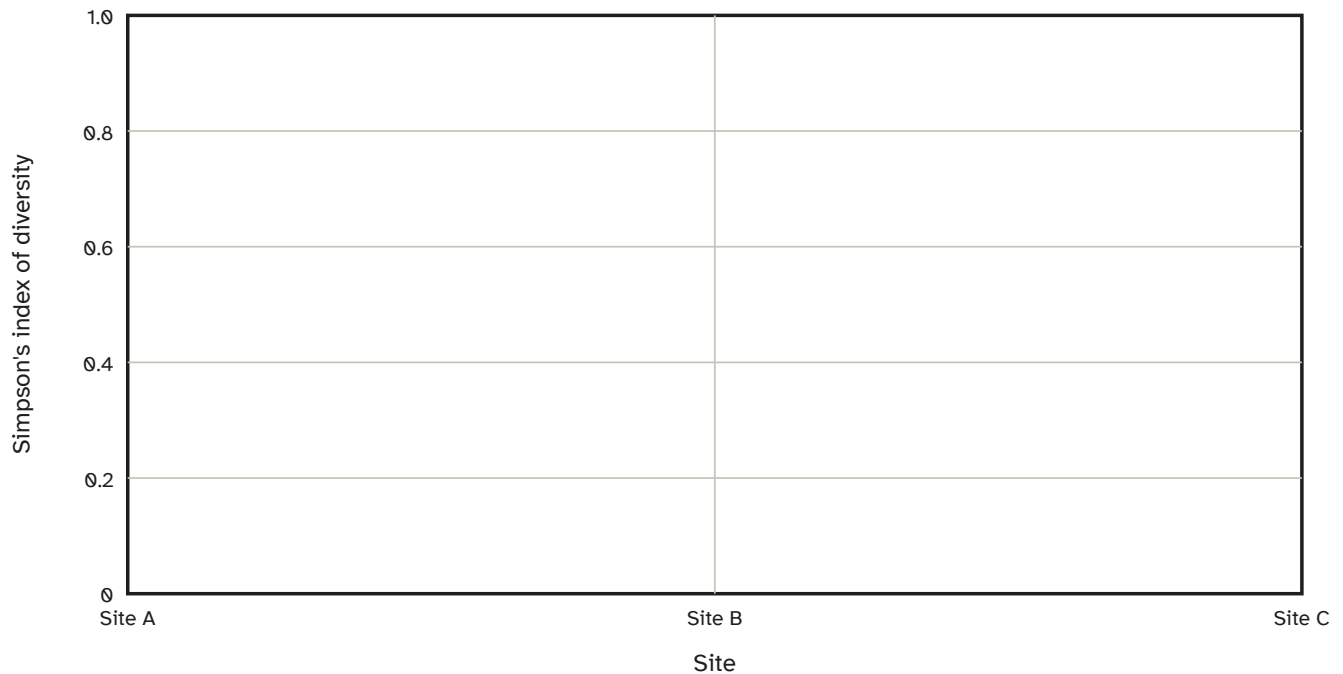
3. Calculate Simpson's index of diversity for Site C. Show each step.

Answer: Total 40. Proportions: beach bur $2 \div 40 = 0.05$; beach primrose $2 \div 40 = 0.05$; iceplant $36 \div 40 = 0.90$. Squares: 0.0025, 0.0025, 0.8100. Sum = 0.8150. Index = $1 - 0.8150 = 0.185$.

Why: Species with a count of 0 contribute 0 to the sum, so only three terms are needed.

Also acceptable: Accept 0.19 if rounded.

Simpson's index of diversity at three dune sites



Part B: Interpret

4. Draw one bar for each site on the graph. Describe the pattern from Site A to Site C in one or two sentences, using your three index values.

Answer: Bars at about 0.78 (A), 0.59 (B) and 0.19 (C). The index falls steadily from Site A to Site C: the more of the dune iceplant covers, the less diverse the plant community is. Site C's index is less than a quarter of Site A's.

Why: The pattern links greater iceplant cover with lower diversity; $0.185 \div 0.784 \approx 0.24$.

Also acceptable: Accept 'drops by about 0.2, then by about 0.4'.

- Bars drawn at the three values
- Describes a decrease from A to C
- Uses all three index values

5. Sites A and B have the **same** species richness. Explain why Site B's index is much lower. Use the word *evenness* and at least one proportion from your table.

Answer: Both sites have 5 species, but at Site B the plants are not shared evenly: iceplant makes up 0.60 of all plants, while the four natives together make up only 0.40. Low **evenness** means that a random pick is usually iceplant, so the sum of squares is larger (0.408 compared with 0.216) and the index is lower. At Site A no species is more than 0.28 of the total.

Why: Simpson's index rewards evenness; one dominant species raises the sum of squares sharply because 0.6 squared is 0.36.

Also acceptable: Accept 'one species dominates' as the description of low evenness.

- Notes equal richness
- Uses the word evenness correctly
- Cites iceplant's 0.60 proportion or the sums of squares

6. The sum of squared proportions is the chance that two plants picked at random (with the first put back) are the **same** species. What is that chance, as a percent, at Site A and at Site C? Explain what the difference means for someone walking across each dune.

Answer: Site A: $0.216 = 21.6$ percent. Site C: $0.815 = 81.5$ percent. At Site A, about one pair in five picked at random is the same species, so a walker sees many kinds side by side. At Site C, about four pairs in five are the same species (nearly always iceplant), so the dune looks and works like a single-species carpet.

Why: The sum of squared proportions is the probability of a match when sampling with replacement; the index is the chance of a mismatch.

Also acceptable: Accept 22 percent and 82 percent.

7. A ranger wants to know how mixed the **native** plants still are at Site B. Leave out the iceplant and calculate the index for Site B's four native plants only (their new total is 20). Compare it with Site A's index, and explain why a high native-only index does not mean Site B's native plants are doing fine.

Answer: Native-only Site B: proportions $8 \div 20 = 0.40$, $4 \div 20 = 0.20$, $6 \div 20 = 0.30$, $2 \div 20 = 0.10$. Squares: 0.16, 0.04, 0.09, 0.01. Sum = 0.30. Index = $1 - 0.30 = 0.70$, a little lower than Site A's 0.784. The natives that remain are still fairly evenly mixed, but there are only 20 native plants at Site B compared with 50 at Site A, and one native species (beach morning glory) is already gone. An index describes the mix, not how many plants there are, so it can hide a population that is shrinking.

Why: This shows why scientists report richness, abundance and an index together rather than any one number.

Also acceptable: Accept 0.7.

- Native-only index of 0.70 with steps
- Comparison with 0.784
- Explains that the index ignores abundance (20 versus 50 native plants) or the lost species

Part C: What the data can and cannot tell you

8. A student concludes, 'The data prove that iceplant caused the loss of native plants.' Name **two** other differences between the sites that could also explain the pattern, and describe an experiment the park could run to test whether iceplant is the cause.

Answer: Other possible differences: the sites may get different amounts of foot traffic or trampling; one may be closer to the waves and get more salt spray or sand burial; soil or moisture may differ; Site A had volunteers who might also have planted natives. Experiment: choose several plots with iceplant at one site, remove the iceplant from half of them (chosen at random) and leave the rest, then count native plants in all plots each year for several years. If natives return mainly where iceplant was removed, iceplant is the likely cause.

Why: The survey shows a pattern (correlation); a removal experiment with comparison plots tests cause.

Also acceptable: Accept a before-and-after comparison at one site if the student also includes plots where nothing is removed.

- Two plausible alternative differences
- An experiment that removes iceplant from some plots and keeps comparison plots
- States the result that would support iceplant as the cause

9. Site C's total (40 plants) is smaller than the others. Why can richness depend on how many plants you count? How could the team make the comparison fairer next time?

Answer: The more plants you count, the more likely you are to find rare species, so a smaller sample can miss species that are really there and give a lower richness. The team could count the same number of plants at every site, sample more quadrats at Site C, or keep adding quadrats until new species stop appearing.

Why: Richness rises with sampling effort; fair comparisons control effort.

Also acceptable: Accept 'count until no new species show up' (a species-accumulation approach).

- Explains that small samples can miss rare species
- Suggests a way to equalize or increase sampling

10. The park can pay for iceplant removal at only one site this year. Should it choose Site B or Site C? Make a recommendation that uses at least **two** numbers you calculated, and name one piece of information you would want before deciding.

Answer: Example for Site B: Site B still has 4 native species and 20 native plants, and its native-only index is 0.70, so natives are present to spread back once iceplant is gone; iceplant is 60 percent of the plants, not 90 percent, so removal is likely cheaper and faster than at Site C, and acting now may stop the spread before Site B looks like Site C (index 0.185). I would want to know the cost of removal at each site. Example for Site C: Site C has the lowest index (0.185) and 90 percent iceplant, so it has the most to gain, and it may be a source of iceplant pieces spreading to other dunes. I would want to know whether native seeds can still reach Site C.

Why: Either recommendation is defensible if it uses calculated numbers and weighs a real trade-off; this mirrors evaluating competing solutions.

Also acceptable: A student who recommends a staged plan (B now, C next year) earns full credit if the reasoning uses numbers.

- Clear recommendation of one site
- Uses at least two calculated numbers
- Gives a reason linked to recovery, cost or spread
- Names one further piece of information needed

Teacher notes

All numbers were checked by script: Site A index 0.784, Site B 0.592, Site C 0.185; Site B native-only 0.70. The index used here, $1 - \sum p^2$, is Simpson's index of diversity calculated as if each pick were put back; field ecologists sometimes use a version for small samples, $n(n - 1) \div N(N - 1)$, which gives slightly higher values. This matches the chapter vocabulary and Lab 1. The plants are real native California dune species (beach bur, yellow sand verbena, beach primrose, silver beach lupine, beach morning glory) and highway iceplant (*Carpobrotus edulis*), which the California Invasive Plant Council rates as highly invasive; it was brought from South Africa for erosion control, forms dense mats, and stabilizes sand that many native dune plants need to keep moving. The extension answers: Site C with one morning glory (total 41) gives an index of about 0.224, up from 0.185, because a new species adds richness and slightly evens the mix; Site B with 70 iceplant (total 90) gives about 0.380, down from 0.592, because one species dominates even more. Common errors: adding the proportions instead of their squares (which always gives 1 and an index of 0), dividing by the wrong total, and counting zero-count species in richness.

Scaffold offered to students: A small example to copy

Practice with a made-up sample of 10 plants: 6 of species X and 4 of species Y. Proportions: $6 \div 10 = 0.6$ and $4 \div 10 = 0.4$. Squares: $0.6 \times 0.6 = 0.36$ and $0.4 \times 0.4 = 0.16$. Sum: $0.36 + 0.16 = 0.52$. Index: $1 - 0.52 = 0.48$. Check your work two ways: the proportions at a site must add up to 1, and your index must be between 0 and 1. If you get 0 for every site, you forgot to square.

Extension: Does adding a species always raise the index?

Suppose one beach morning glory plant sprouts at Site C, so the counts become 2, 0, 2, 0, 1 and 36 (total 41). Predict whether the index goes up or down, then calculate it to check. Next, suppose 40 more iceplant plants were counted at Site B instead. Calculate the new index. Write a rule, in your own words, about what raises a Simpson's index and what lowers it, and explain why counting a new invasive species could raise the index even while the dune gets less healthy.