Populations and communities

C4.1 · SL and HL

A crowded field edge can bias a whole-field conclusion

Connect sampling evidence with population mechanisms

Full shared C4.1: sampling/spread, mark–recapture, carrying capacity, growth, intraspecific and community interactions, mutualism, invasion, association tests, predator/resource control and chemical interference.

Common SL and HL content. Prerequisites: arithmetic, percentages, graphs, cell division and ecological niches.

Teaching data and figures are invented unless a published study is named. Use approved organisms and methods, supplied data or safe simulations.

Define the target before selecting locations

1. **Population.** An interacting same-species group in a defined area; sexually reproducing members normally breed.
2. **Boundary.** Name the species, area and period. Reproductive separation can distinguish populations, while movement can connect them.
3. **Counting unit.** Separate individuals, shoots or other defined units. All plants near school mixes species and leaves the target uncertain.

Random selection is a procedure, not a convenient-looking scatter

Avoid choosing the patches that support the preferred answer

Define the accessible target area before generating random coordinates; include empty and sparse locations.

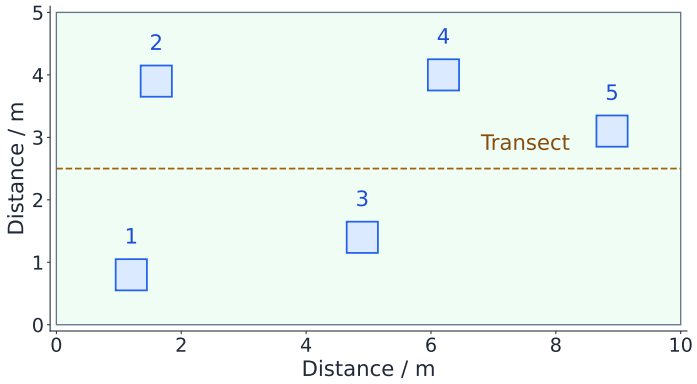
Keep counting rules fixed and record inaccessible locations. Do not move an awkward coordinate into a rich patch.

Different habitat strata can be sampled separately and combined with their actual area weights; equal samples from unequal areas do not automatically give the whole-area mean.

Separate systematic bias from random sampling variation

Issue	Meaning and response
Sampling error	Estimate differs from the true whole-population value even with fair selection
Bias	Method systematically favours a particular result; more biased repeats do not remove it
Precision	More independent representative samples generally improve precision
Spatial pattern	Nearby samples may share one patch; mapped locations help assess independence

Place random quadrats before inspecting the plants



Known **quadrat** area connects counts with population density.

Convert count per quadrat before scaling to the habitat

1. **Invented data.** Five quadrats, each 0.25 square metres: counts three, four, six, five and two. Total 20; mean four per **quadrat**.
2. **Density.** Mean count / quadrat area $= 4 / 0.25 = 16$ plants per square metre.
3. **Total estimate.** Density $\times$ habitat area $= 16 \times 100 = 1{,}600$ plants. Equivalently, 20 / 1.25 gives the same density.

Choose a method that matches the ecological question

Method	Use and limit
Quadrat	Sessile organisms; fixed boundary rule and defined count unit
Line transect	Organisms touching a line or point samples along a defined gradient
Belt transect	A strip or repeated quadrats along the gradient
Interpretation	Measure an abiotic variable and use independent transects; one convenient edge line is not the whole habitat

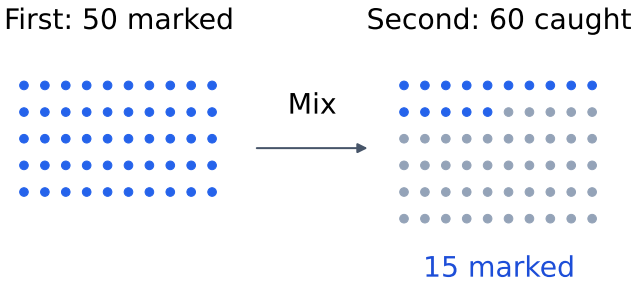
Standard deviation and standard error answer different questions

Quantity	**Interpretation**
Sample standard deviation, s	Spread among sampled **quadrat** counts, in the same count units
Standard error	$s/\sqrt{n}$ estimates uncertainty in the mean under independence assumptions
More samples	Usually reduce standard error; between-quadrat variation can remain large
Interval	Neither quantity alone is automatically a 95% confidence interval

Use the calculator output without changing its units

1. **Five counts.** Three, four, six, five and two: mean four and sample standard deviation about 1.58 plants per **quadrat**.
2. **Mean uncertainty.** Standard error $= 1.58/\sqrt{5} \approx 0.71$ plants per quadrat under independence.
3. **Compare.** The samples 2, 4, 6 and 4, 4, 4 both average four; sample deviations two and zero describe different observed spread, not proof of whole-habitat uniformity.

The marked recaptures are a subset of the second catch



Estimate: 50 × 60 ÷ 15 = 200

A representative marked fraction supports a population estimate.

Derive the Lincoln estimate from a proportion

1. **Relation.** Marked fraction in the second catch approximates the population fraction: $R/C \approx M/P$.
2. **Rearrange.** $\widehat{P} = MC/R$, with M initially marked, C total second catch and R marked recaptures.
3. **Substitute.** $50 \times 60 \,/\, 15 = 200$. 15/60 is one-quarter, so 50 marked animals suggest about 200 in the population.

Predict the direction of a violated assumption

Violation	**Likely effect on this simple estimate**
Lost or missed marks	Observed marked recaptures R falls; estimated population rises
Trap avoidance by marked animals	R can fall; overestimation
Trap attraction by marked animals	R can rise; underestimation
Other assumptions	Little demographic change, adequate mixing, harmless marks and comparable capture probability

Carrying capacity depends on the stated environment

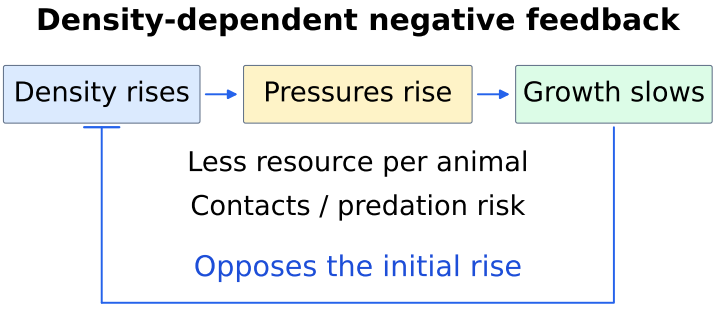
Food, water, light, nutrients and sites can limit different populations

K is the size an environment can sustain over time under stated conditions, not a permanent property independent of seasons or habitat change.

Greater density can reduce resource per individual through intraspecific competition.

Contacts can increase transmission of some pathogens/pests, and dense prey may be easier to find. These effects are not identical for every agent or predator.

Trace the returning influence that opposes further increase



Density-dependent pressures can reduce net population growth.

Count gains and losses while keeping turnover visible

1. **Closed population.** Net change = births − deaths. At 100 individuals, 30 births and ten deaths give an increase of 20.
2. **Balanced state.** At 200, 35 births and 35 deaths give zero net change; reproduction and mortality continue.
3. **Open population.** Add immigration and subtract emigration. Birth/death patterns alone do not identify which resource or interaction caused the change.

A density-independent disturbance can still kill many individuals

Per-individual effect is different from total deaths

A severe frost can affect exposed plants without its per-individual effect being controlled by population density.

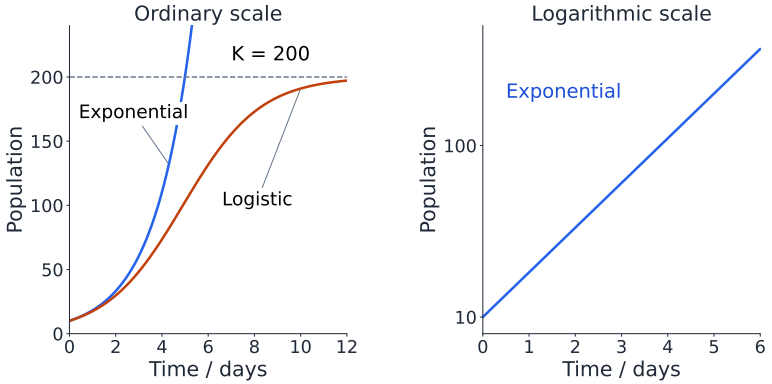
More organisms exposed can still mean more deaths in total; that fact alone does not establish density dependence.

Weather, resource depletion and response delays can interact, producing fluctuations or collapse instead of smooth regulation.

Constant proportional growth gives increasing absolute additions

1. **Doubling model.** $P_t = P_0\,2^{t/T_d}$, where the doubling time is T_d.
2. **Invented daily sequence.** Ten individuals doubling daily give ten, 20, 40, 80 and 160 at days zero to four.
3. **Interpretation.** The additions are ten, 20, 40 and 80. The same proportional increase is not a fixed addition of ten each day.

Contrast ordinary and logarithmic population axes



An exponential phase is straight on a logarithmic size axis.

Use an appropriate graph to test the exponential phase

1. **Axes.** Population size on a logarithmic vertical axis, ordinary time horizontally: equal ratios become equal vertical steps.
2. **Relation.** $\ln P = \ln P_0 + rt$ gives continuous per-capita rate r as the slope.
3. **Limit.** Zero and negative counts have no logarithm. A short approximate straight segment supports a local phase, not indefinite exponential increase.

A sigmoid model does not require an initial flat lag phase

Limitations strengthen as the population approaches K

The middle of an ideal sigmoid is steep and the upper region approaches balanced gains and losses.

The logistic model $dP/dt = rP(1 - P/K)$ gives zero net growth at P = K for the stated positive-r model.

A real culture can have an acclimation period, but a flat lag is not compulsory in every ecological sigmoid. K and actual conditions can change.

Design a duckweed investigation without forcing an S shape

1. **Measure.** Count defined fronds at fixed times in approved cultures; use separate replicate vessels.
2. **Control.** Starting count, light, temperature, nutrient medium, vessel area and counting rule should be comparable.
3. **Test.** Plot observed growth, examine early logarithmic behaviour and later departures; consider nutrients, shading and space. Recounts of one vessel are not independent biological replicates.

A real growth-and-crash case need not follow smooth logistic regulation

1. **Published abstract: St Matthew reindeer.** Twenty-nine introduced in 1944; about 6,000 in 1963; 42 survivors counted in 1966.
2. **Timing.** The crash occurred during winter 1963–64. The later count is not the date the crash began.
3. **Mechanism and limit.** Resource depletion interacted with extreme winter conditions. The population peak is not evidence that a permanent K was exactly 6,000.

Different activities can produce different intraspecific relationships

Example	Mechanism
Male red deer	**Competition** for mating opportunities
Crowded Scots pine	Competition for light, water and nutrients
Wolves hunting large prey	Cooperation can improve food acquisition
Penguin huddles	Shared grouping reduces heat loss; cooperation does not abolish other competition

Competing and cooperating

compete (shared limiting resource)

- male red deer: mating opportunities
- crowded Scots pines: light, water, nutrients

cooperate (gain in another task)

- wolves: hunting large prey together
- penguin huddle: less heat lost per bird

the same individuals can do both, for different resources and tasks

> Members of one population do both

Name the interaction and its effect on the partners

Interaction	Example and consequence
Herbivory	Caterpillar gains food while a plant loses leaf tissue
Predation	Lynx kills/eats a hare; food supply and predation can affect populations
Competition	Different plant species share limiting light, nutrients or space

Do not restrict a community to visible animals

Interaction or level	Example and limit
Mutualism	Compatible legume and nodulating bacteria exchange benefits
Parasitism	A feeding tick benefits while imposing a cost on a living mammal
Pathogenicity	A disease-causing bacterium disrupts host function; disease and parasitism can overlap
Levels	**Community** includes plants, animals, fungi and microbes; ecosystem also includes abiotic conditions/exchanges

Legume nodules exchange nitrogen supply and plant carbon

1. **Bacterial contribution.** Compatible nitrogen-fixing bacteria convert atmospheric nitrogen into biologically usable nitrogen compounds.
2. **Plant contribution.** Plant carbon supports bacterial energy and growth; the nodule provides a suitable protected environment.
3. **Limit.** This is not nitrogen gas becoming plant glucose directly, and not every bacterium near a root forms an effective nodule.

Explain a demonstrated orchid–fungus exchange

1. **Adult green Goodyera repens.** Labelled carbon/nitrogen work demonstrated fungal nitrogen reaching the orchid and photosynthetically fixed plant carbon reaching the fungus.
2. **Life stage.** Tiny orchid seedlings can require fungal carbon before they photosynthesize.
3. **Limit.** Some adult orchids remain dependent on fungal carbon. Every orchid always supplies sugar to its fungus is an incorrect generalization.

A hard-coral photosymbiosis has two material transfers

1. **Coral benefit.** Organic products of photosynthesis reach the host from symbiotic dinoflagellates within its tissues.
2. **Symbiont benefit.** The host supplies a habitat and access to carbon dioxide and inorganic nutrients from metabolism.
3. **Conditions.** Light and suitable conditions matter; stress can disrupt the partnership and produce bleaching. Name the benefit in each direction.

Keep origin, range and ecological impact distinct

Term	Meaning and regional example
Native	Naturally present in the region; Scirpus mariqueter in the estuary example
Endemic	Geographically restricted; not a synonym for any resident of one plot
Introduced	Moved beyond natural range; introduction does not always lead to invasion
Invasive competitor	Introduced Spartina alterniflora can capture resources and harm resident populations in the Yangtze estuary

Test competition with a comparison that controls other changes

1. **Invented pots.** Focal plants average 12 g alone and 8 g with a second species: reduction $4/12 \times 100 \approx 33.3\%$.
2. **Laboratory design.** Randomize replicated pots; match focal density, soil, water, light and pot size. Density designs answer different questions.
3. **Field removal.** Include sham disturbance and replication. Removing a species can also alter soil or light; co-occurrence alone does not identify **competition**.

Record each independent quadrat in one presence/absence category

Invented category	Observed count
A and B present	25
A present, B absent	15
A absent, B present	15
Neither present	25

Generate expected counts under independence

1. **Null hypothesis.** A presence and B presence are independent in the sampled habitat.
2. **Marginal totals.** Each row totals 40; each column totals 40; grand total 80.
3. **Expectation.** Row total $\times$ column total / grand total $= 40 \times 40 / 80 = 20$ in each category. Do not count marginal totals as additional observations.

Compare the statistic with the supplied decision rule

1. **Statistic.** $\chi^2 = \sum \frac{(O-E)^2}{E}$. Each contribution is $5^2/20 = 1.25$; four contributions give 5.00.
2. **Decision.** Degrees of freedom $(2-1)(2-1) = 1$. At the supplied 5% critical value 3.84, five exceeds the threshold: reject independence.
3. **Direction.** The species occur together more often than expected: positive association. This is not proof of **competition** or of mutualism.

An association does not identify the ecological mechanism

Check assumptions and alternative explanations

Shared habitat preference can cause positive association; competition or different abiotic preferences can cause negative association.

Use independent sites, adequate expected counts and a preselected significance level. Adjacent subsamples of one patch are not automatically independent.

Failure to reject does not prove no interaction: detection and sample size affect power. Seek a suitable alternative method when assumptions fail.

Trace the possible delay between prey and predator changes

1. **Prey rise.** More food can support predator feeding, survival and reproduction.
2. **Returning effect.** More effective **predation** can lower prey growth; later prey scarcity can lower predator survival or reproduction.
3. **Recovery and limit.** Reduced encounters at low prey density can permit recovery. Cycles and delays are not perfectly fixed in every **community**.

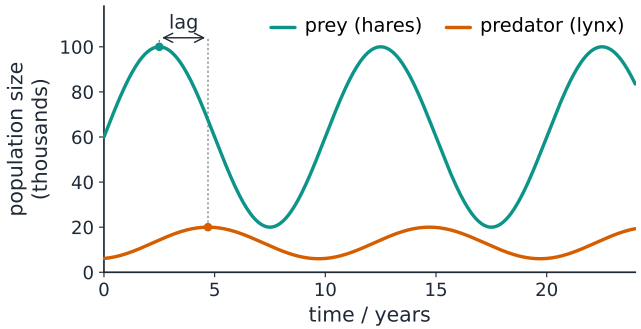
The Yukon hare experiment tested interacting causes

1. **Real system.** Snowshoe hares in boreal forest interact with lynx and other predators and show roughly decadal fluctuations.
2. **Manipulation.** Krebs and colleagues changed food supply and mammalian predator access on large forest blocks.
3. **Evidence.** Each treatment raised hare density, and the combined treatment had a larger effect than either alone. This supports interacting effects, not a lynx-only cause inferred from a graph.

Separate regulation from feeding-arrow direction

Control	**Possible causal chain**
Top-down	More effective predators → fewer herbivores → less plant consumption
Bottom-up	More of a limiting resource → greater plant production → potentially more herbivore support
Combined	Both routes can operate; one can dominate in a particular **community** or period
Experimental caution	Adding food to hares differs from fertilizing soil; responses need not be identical

Predator and prey cycles



Food supply and other consumers also regulate both

Identify the producer, chemical and susceptible target

Example	Mechanism and limit
Sorghum bicolor	Root hairs release sorgoleone; can inhibit competing plants, including photosynthetic effects
Penicillium rubens	Penicillin inhibits wall synthesis in susceptible growing bacteria
Environmental context	Concentration, contact, degradation and soil conditions affect outcomes
Causal test	An extract or inhibition zone alone does not establish the cause of a field pattern

Attempt the complete handout questions before checking

Define the sampling model before using a formula

Estimate abundance from quadrat area; separate spread from mean uncertainty; explain mark–recapture assumptions and bias direction.

Calculate gains/losses and exponential growth, then evaluate model departures, cooperation, community interactions and invasion evidence.

Complete the presence/absence test, identify the association direction and explain why experimental controls are still needed.

Check sampling and recapture practice

1. **Quadrats.** Total 24 across six half-square-metre quadrats; mean four, density eight per square metre, estimated population 2,400.
2. **Spread.** Sample deviations two versus zero do not prove habitat uniformity; first standard error $2/\sqrt{3} \approx 1.15$ per **quadrat**.
3. **Recapture.** $80 \times 50 \,/\, 20 = 200$; observed marked recaptures 15 gives about 267, an overestimate due to lost marks.

Check growth and competition practice

1. **Population balance.** $150 + 40 - 18 + 12 - 9 = 175$ after the interval.
2. **Doubling.** Starting at eight with a two-day doubling time gives 16, 32 and 64 on days two, four and six.
3. **Competition.** Fifteen $\rightarrow$ nine grams: reduction $6/15 \times 100 = 40\%$. Replicate controlled comparisons before inferring the mechanism.

Check the negative-association example

1. **Expected counts.** Rows and columns each total 50; grand total 100; each expectation $50 \times 50 \,/\, 100 = 25$.
2. **Statistic and decision.** Observed 15, 35, 35, 15: each contribution $10^2/25 = 4$; chi-squared $= 16$, one degree of freedom. Sixteen exceeds 3.84: reject independence at the stated level.
3. **Interpretation.** Co-occurrence is lower than expected, so association is negative. **Competition** is possible; habitat differences and detection remain alternatives.

Check yourself

State the method, units, comparison and inference limit

Randomness is a sampling procedure; quadrat count is not automatically count per square metre; standard deviation differs from standard error.

A marked subset belongs within the second catch. A model curve or significant association does not identify its cause by itself.

Name both mutualistic benefits, distinguish native from endemic, and identify the producer, target and conditions for chemical interference.