DP Biology – C4.1

# Populations and communities

- How do interactions between organisms keep population sizes in check?
- Which interactions make the populations in a community depend on one another?

SL statements C4.1.1–18. Textbook pp. 548–577. There is no HL content in C4.1.

Image: lesser flamingos, Lake Nakuru, Kenya. Syllabub, CC BY-SA 3.0.



# Objectives for each class

| Class | Statements | By the end of the class, you can... |
|---|---|---|
| **1** | C4.1.1–4 | Define a population and estimate its size with random quadrats and with the Lincoln index |
| **2** | C4.1.5–8 | Explain carrying capacity, density-dependent control and the sigmoid growth curve, and model it with duckweed |
| **3** | C4.1.9–12 | Describe a community, compare competition and cooperation, and give examples of each interspecific relationship |
| **4** | C4.1.13–15 | Explain how invasive species compete, describe tests for competition, and use the chi-squared test |
| **5** | C4.1.16–18 | Explain predator-prey cycles, control from higher and lower trophic levels, and allelopathy and antibiotics |

# What is a population?

C4.1.1



Lesser flamingos, Lake Nakuru. Syllabub, CC BY-SA 3.0.

- A **population** is a group of individuals of one species that live in the same area at the same time
- Members of a population normally interbreed
- Two populations of a species are separated by **reproductive isolation**, for example by distance, mountains or water
- Individuals interact: they compete, cooperate and mate

## Discussion

The flamingos at one lake form a population. Would flamingos at a lake 300 km away be part of the same population? What would you need to know to decide? Why might the two populations become more different over time? (A4.1)

# Estimating population size by random sampling



- Counting every individual is usually impossible: too many, too spread out, or hidden
- Counting all of them can also disturb or damage the habitat
- So we count a **sample** and scale up to an **estimate**
- The sample must be **random**, so that every individual has an equal chance of being counted

| Organisms | Method |
|---|---|
| **Sessile: plants, barnacles, mussels** | Random quadrats (C4.1.3) |
| **Motile: beetles, voles, turtles** | Capture-mark-release-recapture (C4.1.4) |

### Key idea

An estimate is never exact. A larger number of samples gives a more reliable estimate.

### Why random?

If you choose where to sample, you tend to pick places with more, or fewer, of the organism. This is bias. Random numbers remove your choice, so the sample is more likely to represent the whole area.

# Random quadrat sampling

C4.1.3



A 1 m quadrat on a rocky shore. M.-N. De Casamajor, Ifremer, CC BY 4.0.

1. Lay two tape measures at right angles along two edges of the area
2. Use a random number generator to give two coordinates
3. Place the quadrat at those coordinates and count the individuals inside
4. Repeat for many quadrats, then find the **mean number per quadrat**

## Scaling up

Population size = mean number per quadrat × (total area / area of one quadrat). This works for sessile organisms that can be counted, both plants, such as daisies or plantains, and animals, such as barnacles and limpets. Decide in advance how to count individuals on the edge of the quadrat.

# Worked example: daisies in a school field

C4.1.3

| Quadrat | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Daisies | 3 | 5 | 0 | 4 | 2 | 6 | 1 | 4 | 3 | 2 |

- Field: 20 m × 30 m = 600 $m^2$; quadrat = 1 $m^2$
- Mean = 30 / 10 = 3.0 daisies per $m^2$
- Estimate = 3.0 × 600 = 1800 daisies
- Standard deviation = 1.8 (from a calculator)

### Standard deviation

It shows how much the counts vary around the mean. A large SD means the daisies are patchy, and a small SD means they are spread evenly. You do not need to learn the formula: use a calculator or spreadsheet.

### Activity

Invented values, for practice. A second student finds a mean of 2.4 per $m^2$ in the same field. Give two reasons why the estimates differ, and suggest how to make the estimate more reliable.

# Capture-mark-release-recapture

C4.1.4

1. Capture a sample, count them (**M**) and mark them harmlessly
2. Release them and allow time to mix back into the population
3. Capture a second sample (**N**) and count how many are marked (**R**)
4. Population size = (M × N) / R. This is the **Lincoln index**

### Worked example

Invented values. 40 woodlice are caught and marked. A week later, 50 are caught, and 10 of these are marked. Population = (40 × 50) / 10 = 200 woodlice.

| Assumption | Why it matters |
|---|---|
| **Marks are not lost and do not harm the animal** | Lost marks make R too small, so N is overestimated |
| **Marked animals mix fully with the rest** | Otherwise the second sample is not random |
| **No births, deaths or migration between samples** | The population must be the same at both samples |

# Practice: a sea turtle population

C4.1.4



Green turtle grazing on seagrass. P. Lindgren, CC BY-SA 3.0.

| Year | Tagged, M | Second catch, N | Tagged in it, R |
|---|---|---|---|
| 1 | 30 | 36 | 12 |
| 2 | 28 | 40 | 14 |
| 3 | 25 | 30 | 15 |

Invented values, for practice.

## Activity

Turtles are tagged on a front flipper and released. 1. Use the Lincoln index to estimate the population in each year. 2. Describe the trend. 3. Turtles live for decades and swim long distances. Which assumption of the method is most likely to be broken? Explain your answer.

# Carrying capacity



- **Carrying capacity** is the maximum population size that an environment can support
- As a population grows, each individual gets a smaller share of resources, so there is more competition
- Births fall or deaths rise, so growth stops at the carrying capacity

| Organisms | Limited resources |
|---|---|
| **Animals** | Food, water, territory, nesting sites, mates |
| **Plants** | Light, water, mineral nutrients, space for roots |

## Activity

Choose one local animal and one local plant. For each, name the resource you think most limits the population, and suggest an observation that would test your idea.

# Density-dependent control by negative feedback

C4.1.6

| Density-dependent factor | Why its effect increases in a dense population |
|---|---|
| **Competition** | Less food, water or space per individual, so fewer offspring survive |
| **Predation** | Prey are easier to find, and predators increase in number |
| **Pathogens and pests** | They pass more easily between individuals that are close together |

### Negative feedback

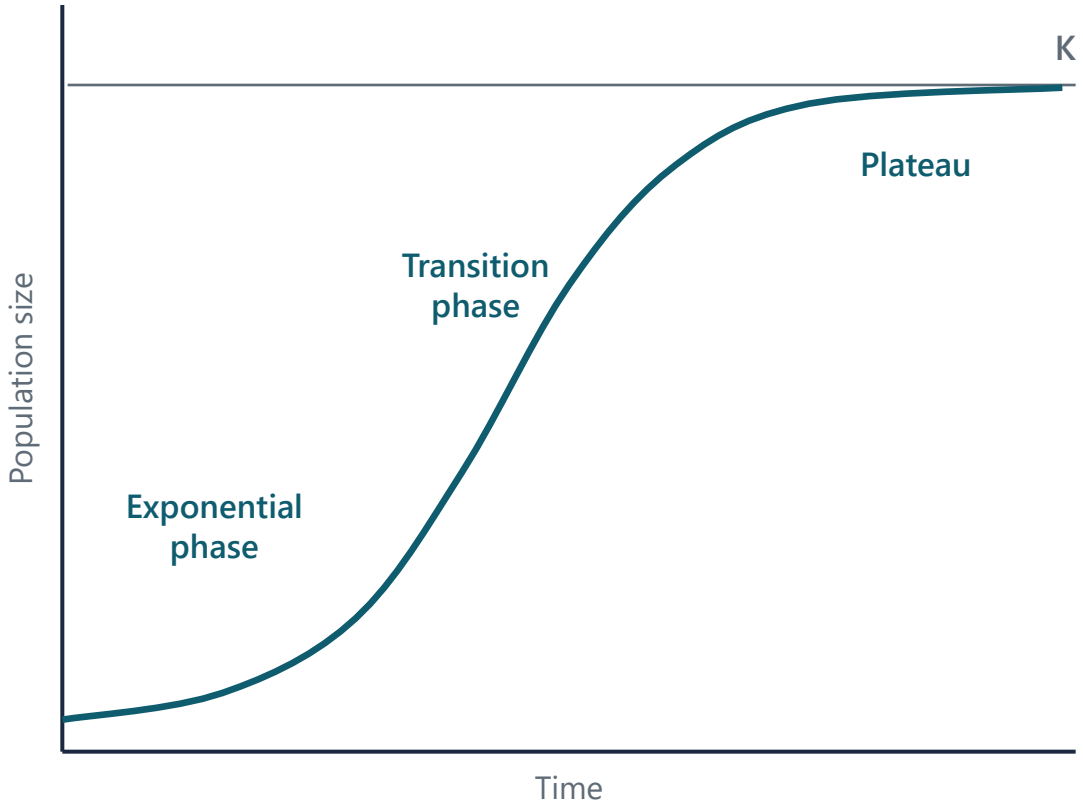
Above the carrying capacity, these factors increase deaths and reduce births, so the population falls. Below it, they relax, and the population rises again. The population fluctuates around the carrying capacity.

### Density-independent factors

Floods, fires, droughts and cold winters affect a population whatever its size. They can cause sudden changes in numbers, but they do not push it back towards the carrying capacity.

# The sigmoid population growth curve

C4.1.7




- **Exponential**: plenty of resources and few predators or diseases, so numbers increase by a constant proportion each generation
- **Transition**: resources run short and density-dependent factors increase, so growth slows
- **Plateau**: births and deaths balance at the carrying capacity, K

**Note**

A lag phase at the start is not expected here. Growth curves for real populations rarely have the smooth shape of this model.

# Case study: the return of the bearded vulture

C4.1.7

- Bearded vultures were hunted to extinction in the Alps by the early 1900s
- Captive-bred birds have been released in the Alps since 1986, and in Switzerland since 1991. The first chick hatched in the wild in Switzerland in 2007
- With protection and plentiful food, the population is now growing

### Why exponential at first?

A few individuals in a large area with plenty of resources face little competition. Each breeding pair adds young, and those young breed in turn, so growth speeds up. Some density-dependent factors, such as predators or competitors, may be missing.

### Activity

Look up the breeding bird index of a Swiss species at vogelwarte.ch. Sketch its curve. Which phase of the sigmoid curve is it in? Suggest which resource will set its carrying capacity.

# Modelling sigmoid growth with duckweed

C4.1.8



Lemna minor. Karelj, CC BY-SA 3.0.

1. Put a few duckweed plants in a beaker of pond water or nutrient solution in light
2. Count the fronds every day or two until the surface is covered
3. Plot number of fronds against time

## Testing the model

Plot the number of fronds on a log scale and time on a normal scale. Exponential growth gives a straight line. Where the line curves away and levels off, growth is no longer exponential.

## Extension

Change one variable, such as nutrient concentration or the surface area of the container. Predict how it will change the carrying capacity, then test your prediction.

# A community: all the interacting organisms

C4.1.9

- A **community** is all the populations of different species living and interacting in an area
- It includes plants, animals, fungi and bacteria
- Together with the abiotic environment, it forms an **ecosystem** (C4.2)



A coral reef community. Jim Maragos, USFWS, public domain.

## Activity

List ten organisms in a community near you, such as a forest, a pond or a meadow. Include at least one fungus and one bacterium. Draw lines between organisms that interact, and label each line with the type of interaction.

# Competition and cooperation within a species

C4.1.10



Spotted hyenas. S. Jurvetson, CC BY 2.0.



Leafcutter ants. Kathy and Sam, CC BY 2.0.

| Interaction | Examples |
| --- | --- |
| **Competition** | Members of a species share the same needs, so they compete for food, light, territory or mates: wildebeest males fight for territory; tree seedlings compete for light |

## Discussion

Competition harms both individuals, as each gets less. Cooperation can benefit all. Why then is competition never removed completely, even in a cooperative group? In social insects, why might workers that never breed still pass on their genes?

# Relationships between species

C4.1.11

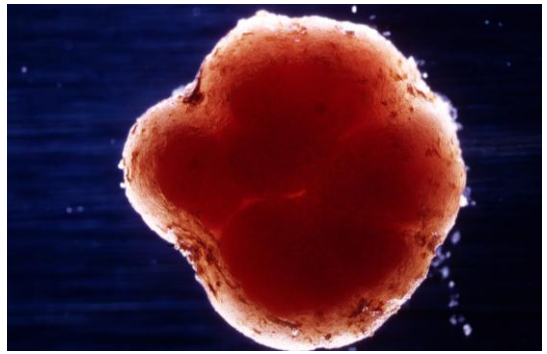
| Relationship | What happens | Example |
|---|---|---|
| **Herbivory** | A primary consumer feeds on a producer | Bison grazing on grass |
| **Predation** | A predator kills and eats its prey | Lynx eating snowshoe hares |
| **Interspecific competition** | Two species use the same limited resource | Lions and leopards hunting the same prey |
| **Mutualism** | Both species benefit | Rhizobium in clover root nodules |
| **Parasitism** | A parasite lives on or in a host and harms it | Ticks feeding on deer |
| **Pathogenicity** | A pathogen lives in a host and causes disease | Chytrid fungus in the evergreen robber frog |

### Activity

Find a local example of each relationship. Which relationship is hardest to tell apart from another, and why?

# Mutualism: both species benefit

C4.1.12







| Partners | Benefit to the plant or coral | Benefit to the partner |
|---|---|---|
| **Legume and Rhizobium** | Rhizobium fixes nitrogen into ammonium, used to make amino acids | Sugars from photosynthesis, and a low-oxygen home in the nodule |
| **Orchid and mycorrhizal fungus** | Seeds have no food store, so the fungus supplies sugars, minerals and water | Adult orchids later supply carbon compounds |
| **Hard coral and zooxanthellae** | Algae supply sugars, amino acids and oxygen from photosynthesis | Shelter in shallow sunlit water, plus carbon dioxide and nutrients |

Images: a cut root nodule, red from leghaemoglobin (CSIRO, CC BY 3.0); lady's slipper orchid (Johan N, public domain); coral reef (J. Maragos, public domain).

# Endemic and invasive species

C4.1.13



Red squirrel. Jojo, CC BY-SA 3.0.

- **Endemic** species occur naturally in an area. **Invasive** species were introduced by humans and spread
- Many invasive species thrive because the predators, pathogens and competitors of their native range are missing
- If an invasive species is better at taking a shared resource, the endemic species declines



Grey squirrel. PierreSelim, CC BY 3.0.

### Example

Grey squirrels were brought to Britain from North America in the late 1800s. They eat seeds more efficiently than red squirrels, including acorns, which red squirrels digest poorly, and they can store more fat for winter. They also carry squirrel pox, which kills reds. Red squirrels have disappeared from most of England and Wales.

# Invasive species in Switzerland

C4.1.13



Nutria. G. Chernilevsky, public domain.



Himalayan balsam. R. Flogaus-Faust, CC BY 4.0.

| Species | Competitive advantage |
|---|---|
| **Nutria (coypu)** | Escaped from fur farms; burrows into river banks and eats large amounts of waterside vegetation, taking food and space from native species |
| **Himalayan balsam** | Grows up to 2 m in a single season and shades out native plants along rivers; its exploding seed pods spread seeds several metres |
| **Japanese knotweed** | Spreads by rhizomes and outgrows native plants on river banks |

## Activity

Choose one invasive species near you. Explain how it outcompetes an endemic species for one named resource.

# Testing for interspecific competition

C4.1.14

| Approach | Method | Example |
|---|---|---|
| **Laboratory experiment** | Grow two species alone and together under the same conditions | Two Paramecium species: one excluded the other when grown together |
| **Field observation** | Random sampling to see whether two species occur together less often than expected | Chi-squared test on quadrat data (C4.1.15) |

**Common mistake**

If one species does better when the other is absent, competition is indicated but not proven. The two species might simply need different conditions. Connell found that Chthamalus survived much better on the middle and lower shore when Semibalanus was removed, but on the upper shore removing Semibalanus made little difference.

# Chi-squared: are two species associated?

C4.1.15



Ling heather. jensu, CC0.



Bracken. L. A. Ratledge, CC BY 4.0.

- Record only the **presence or absence** of each species in many random quadrats
- H0: the two species are distributed independently
- H1: the two species are associated, positively or negatively

| Observed (100 quadrats) | Bracken present | Bracken absent | Total |
|---|---|---|---|
| **Ling present** | 18 | 42 | 60 |
| **Ling absent** | 32 | 8 | 40 |
| **Total** | 50 | 50 | 100 |

Invented values, for practice.

### Step 1

Put the observed counts and the totals in a contingency table.

# Calculating chi-squared



| Expected | Bracken present | Bracken absent |
|---|---|---|
| **Ling present** | 30 | 30 |
| **Ling absent** | 20 | 20 |

- **Step 2**: expected = (row total × column total) / grand total. For example, 60 × 50 / 100 = 30
- **Step 3**: for each cell, find $(O - E)^2 / E$, then add them: 4.8 + 4.8 + 7.2 + 7.2 = 24.0
- **Step 4**: degrees of freedom = (rows − 1) × (columns − 1) = 1, so the critical value at p = 0.05 is 3.84

### Step 5: conclusion

24.0 is greater than 3.84, so reject H0. The two species are associated. Ling and bracken occur together less often than expected, which is a negative association. This could be caused by competition, or by allelopathy from bracken, but it could also mean that the species need different soils. The test shows an association, not its cause. Remember: degrees of freedom are 1 only for a table with two rows and two columns.

# Practice: two seaweeds on a rocky shore

C4.1.15

| Observed (80 quadrats) | P present | P absent | Total |
|---|---|---|---|
| **Q present** | 24 | 8 | 32 |
| **Q absent** | 16 | 32 | 48 |
| **Total** | 40 | 40 | 80 |

Invented values, for practice.

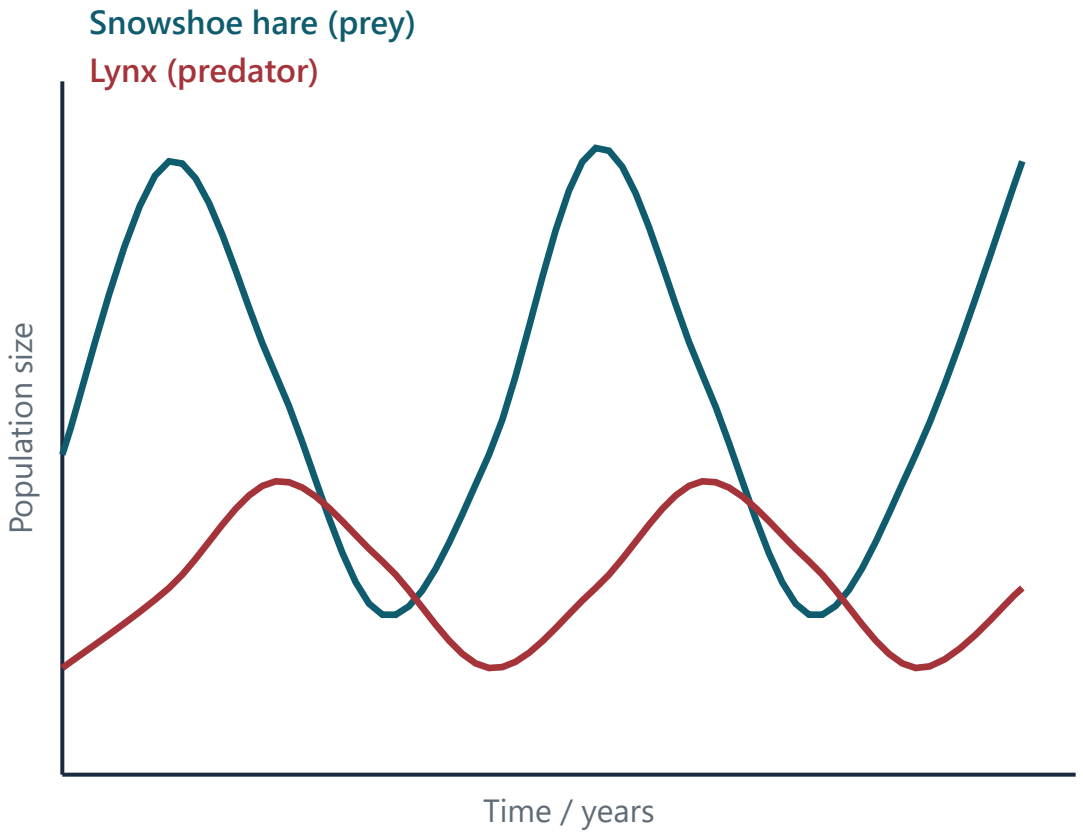
1. State H0 and H1
2. Calculate the four expected values
3. Calculate chi-squared
4. Compare it with 3.84
5. State your conclusion

## Activity

Work in pairs. Then suggest one ecological reason for the result you find. Plan a removal experiment that could test whether the association is caused by an interaction between the two species, and name one variable you would need to control.

# Predator-prey cycles






General shape only. Peaks repeat roughly every 10 years.

1. More hares means more food for lynx, so lynx numbers rise
2. More lynx eat more hares, so hare numbers fall
3. With less food, lynx numbers fall, and hares recover



Lynx. USFWS, public domain.



Snowshoe hare. A. Schmierer, CC0.

# Top-down control and bottom-up control

C4.1.17

| Control | How it works | Example |
|---|---|---|
| **Top-down** | A higher trophic level limits the one below through predation or herbivory | More predatory fish → fewer forage fish → more zooplankton → less phytoplankton |
| **Bottom-up** | The supply of food at a lower level limits the levels above | More nutrients → more phytoplankton → more zooplankton → more fish |



Green turtle. P. Lindgren, CC BY-SA 3.0.

### Key idea

Both kinds of control can act in the same community, but one is usually dominant. Green turtles graze seagrass: the amount of seagrass limits the turtles (bottom-up), and where turtles are protected, their grazing can limit the seagrass (top-down). Removing a top predator, such as wolves, shows top-down control clearly.

# Allelopathy and antibiotics

C4.1.18





Penicillium colonies. Atalyssa, CC BY 4.0.

| | Allelopathy | Antibiotics |
|---|---|---|
| **What** | A plant releases chemicals that stop other plants germinating or growing | A fungus or bacterium releases chemicals that kill or slow the growth of bacteria |
| **Example** | Bracken, walnut trees and sunflowers. A local example: walnut | Penicillium makes penicillin, discovered by Alexander Fleming in 1928 |
| **Effect** | Fewer competitors for light, water and minerals | Fewer competitors for food |

### Similarity

In both, an organism releases a chemical into its environment that deters competitors. Image above left: bracken. L. A. Ratledge, CC BY 4.0.

# Check that you can explain

1. What makes a population, and why we sample
2. Random quadrats and scaling up
3. The Lincoln index and its assumptions
4. Carrying capacity and limited resources
5. Density-dependent negative feedback
6. The sigmoid curve and its phases
7. Testing the model with duckweed
8. Communities, competition and cooperation

- Six types of interspecific relationship
- Three examples of mutualism
- How an invasive species outcompetes an endemic one
- Three ways to test for competition
- Chi-squared tests on two species
- Predator-prey cycles
- Top-down versus bottom-up control
- Allelopathy and antibiotics

# Exit activity: 5 minutes

**On your own and without notes. Hand this in as you leave.**

1. 20 snails are marked and released. Later, 30 are caught, and 6 of them are marked. Estimate the population.

2. Explain why predation is a density-dependent factor.

3. State one benefit to each partner in the mutualism between legumes and Rhizobium.

# Image credits

Large number of flamingos at Lake Nakuru.jpg – Syllabub – CC BY-SA 3.0

Quadrats sur le site Abbadia (Ifremer 00380-49168 – 1942).jpg – Marie-Noelle De Casamajor – CC BY 4.0

Green Sea Turtle grazing seagrass.jpg – P.Lindgren – CC BY-SA 3.0

Lemna minor Prague 2012 1.jpg – Karelj – CC BY-SA 3.0

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SNOWSHOE HARE (Lepus americanus) (5-28-2015) quoddy head, washington co, maine -02 (18988733919).jpg – ALAN SCHMIERER – CC0

P.polonicum.jpg – Atalyssa – CC BY 4.0

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