Ecology: Populations, Communities & Energy Transfer

IB HL Study Guide

Contents

Complete Study Guide

Topics Covered

1. Populations and Communities (C4.1)
2. Transfers of Energy and Matter (C4.2)
3. HL Extension — Diversity Indices & Statistical Tests
4. Exam Strategy & Common Mistakes
5. Mixed Practice — Exam Style

Aligned to IB Biology HL 2025 syllabus — C4.1, C4.2

Watch: Energy Flow Through Ecosystems VIDEO

Section 1: Populations and Communities (C4.1)

Ecology is the study of relationships between living organisms and their environment. Understanding how populations grow, interact, and form communities is central to IB Biology HL and appears heavily on both Paper 1 and Paper 2.

MEMORISE THIS

Core definitions to memorise:

Term	Definition
Species	A group of organisms that can interbreed and produce fertile offspring
Population	A group of organisms of the same species living in the same area at the same time
Community	All the populations of different species living and interacting in the same area
Ecosystem	A community of organisms and its abiotic (non-living) environment
Biome	A large geographical region with a distinctive climate and community of organisms (e.g. tropical rainforest, tundra)
Habitat	The environment in which a species normally lives
Niche	The role of a species in its ecosystem, including its habitat, feeding relationships, and interactions
Carrying capacity (K)	The maximum population size that an environment can sustain indefinitely

1.1 Sampling Techniques

Ecologists cannot count every individual in a population, so they use **sampling techniques** to estimate population size.

Quadrats are square frames (typically $0.25\ \mathrm{m}^2$ or $1\ \mathrm{m}^2$) placed randomly within a study area. The number or percentage cover of a species is recorded in each quadrat, and the results are used to estimate population density across the whole area.

IB TIP

IB exam tip: Random sampling requires using a random number generator to determine quadrat positions. If you describe "throwing the quadrat over your shoulder," examiners may not award the mark — state that coordinates are generated randomly using a table or calculator.

Transects are lines laid across an area where environmental conditions change (e.g. from shoreline to inland). Organisms are sampled at regular intervals along the line. A **line transect** records species touching the line; a **belt transect** uses quadrats placed along the line for more detailed data.

Capture-Mark-Recapture (Lincoln Index)

For mobile animals, the **capture-mark-recapture** method is used:

1. Capture a sample of individuals, count them, mark them, and release them
2. After a period (allowing marked individuals to mix with the population), capture a second sample
3. Count the total caught and the number of marked individuals in the second sample

The **Lincoln Index** formula estimates population size:

$N = \frac{n_1 \times n_2}{m_2}$

Where:

- N = estimated population size
- n_1 = number captured and marked in the first sample
- n_2 = total number captured in the second sample
- m_2 = number of marked individuals recaptured in the second sample

WORKED EXAMPLE

Worked Example: Lincoln Index

A researcher captures 40 snails in a garden, marks them with non-toxic paint, and releases them. One week later, they capture 50 snails, of which 10 are marked.

$N = \frac{n_1 \times n_2}{m_2} = \frac{40 \times 50}{10} = \frac{2000}{10} = 200$

Estimated population size = 200 snails

⚠ EXAM ALERT

Assumptions of capture-mark-recapture (frequently tested):

- The population is **closed** (no immigration, emigration, births, or deaths between samples)
- Marking does **not** affect survival or behaviour (e.g. does not make individuals more visible to predators)
- Marked individuals mix **randomly** with the rest of the population
- Marks do **not** rub off or become unidentifiable
- Each individual has an **equal chance** of being captured

If any assumption is violated, the estimate will be inaccurate. For example, if marked individuals are more easily predated, fewer will be recaptured, and N will be **overestimated**.

1.2 Population Growth

Populations can grow in two characteristic patterns:

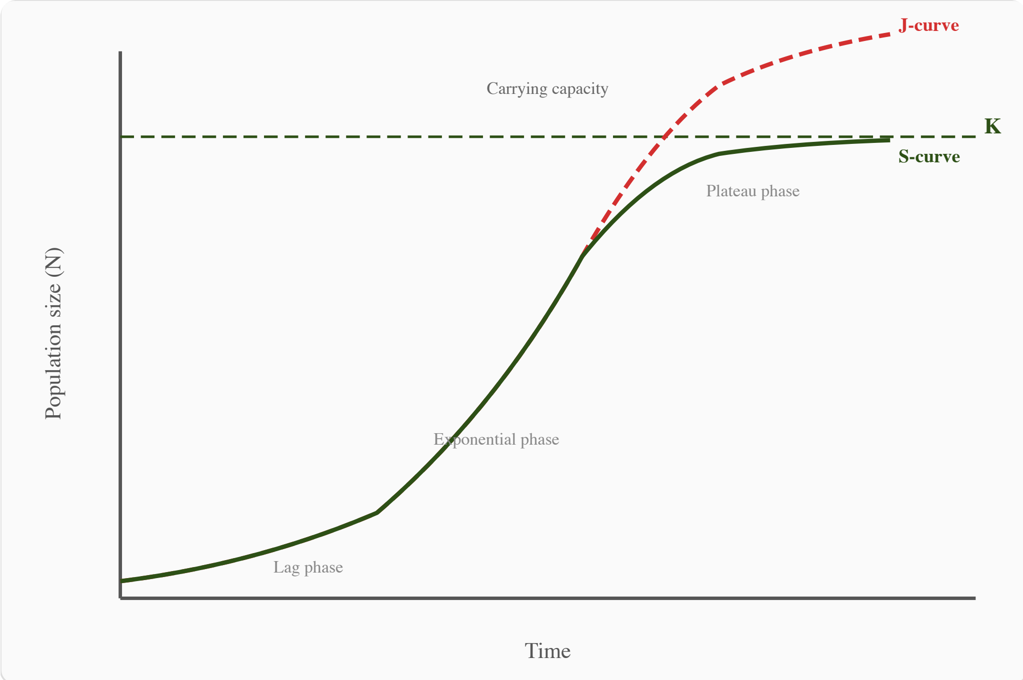
Exponential (J-curve) growth occurs when resources are unlimited. The population grows at an ever-increasing rate with no upper limit. This is rare in nature but can occur temporarily when a species colonises a new habitat or when a limiting factor is removed.

$\frac{dN}{dt} = rN$

Where r is the intrinsic rate of natural increase and N is the population size.

Logistic (S-curve) growth is the more realistic model. Growth starts exponentially but slows as the population approaches the **carrying capacity** (K) of the environment. Environmental resistance (limited food, space, predation, disease) acts as a brake on growth.

$\frac{dN}{dt} = rN\left(\frac{K-N}{K}\right)$



MEMORISE THIS

Phases of logistic growth:

Phase	Description
Lag phase	Population is small; growth is slow as individuals establish and reproduce
Exponential phase	Resources abundant; population grows rapidly as birth rate exceeds death rate
Transitional phase	Growth rate slows as environmental resistance increases
Plateau phase	Population fluctuates around K; birth rate approximately equals death rate

1.3 Factors Affecting Population Size

Population size changes according to four factors:

$$\text{Population change} = (B + I) - (D + E)$$

Where B = births (natality), I = immigration, D = deaths (mortality), E = emigration.

Density-dependent factors become more intense as population density increases:

- Competition for food, water, space, mates
- Predation (more prey attracts more predators)
- Disease (spreads more easily in dense populations)
- Parasitism

Density-independent factors affect populations regardless of density:

- Natural disasters (floods, fires, volcanic eruptions)

- Climate change / extreme weather
- Human activities (habitat destruction, pollution)

1.4 Community Interactions

MEMORISE THIS

Types of species interactions:

Interaction	Effect on Species A	Effect on Species B	Example
Competition	−	−	Two plant species competing for light
Predation	+ (predator)	− (prey)	Lion hunting zebra
Mutualism	+	+	Mycorrhizae (fungi and plant roots)
Parasitism	+ (parasite)	− (host)	Tapeworm in human intestine

Interspecific competition occurs between individuals of *different* species that share a resource. **Intraspecific competition** occurs between individuals of the *same* species — this is often more intense because individuals require exactly the same resources.

EXAM ALERT

The Competitive Exclusion Principle (Gause's Principle): Two species cannot occupy the same ecological niche in the same habitat at the same time. One species will outcompete the other, leading to local extinction of the inferior competitor. In practice, species may coexist through **resource partitioning** — they divide the niche by exploiting slightly different resources or foraging at different times.

1.5 Ecological Niches

The **fundamental niche** is the full range of environmental conditions and resources a species *could* potentially occupy in the absence of competition and predation.

The **realized niche** is the actual niche a species occupies in practice, which is narrower than the fundamental niche due to interspecific competition, predation, and other biotic interactions.

IB TIP

IB exam tip: If asked to distinguish fundamental and realized niches, always explain *why* the realized niche is smaller — it is competition and predation that restrict it, not simply preference.

1.6 Ecological Succession

Succession is the gradual change in species composition and community structure over time in a given area.

Primary succession starts on bare, lifeless substrates (e.g. bare rock after volcanic eruption, newly formed sand dunes). There is no pre-existing soil.

1. **Pioneer species** (lichens, mosses) colonise bare rock
2. They weather the rock and add organic matter when they die, forming a thin soil layer
3. Small plants (grasses, ferns) can now grow in the thin soil
4. Soil deepens over time, supporting shrubs and then trees
5. A **climax community** is eventually reached — a stable, self-sustaining community in equilibrium with the climate

Secondary succession occurs in areas where a community has been disturbed but soil remains (e.g. after a forest fire, abandoned farmland). It proceeds faster because soil, seeds, and root systems are already present.

MEMORISE THIS

Key succession terms:

Term	Definition
Pioneer species	First organisms to colonise a bare or disturbed area; they are hardy, fast-reproducing, and tolerant of extreme conditions
Seral stage (sere)	Each intermediate community in the succession sequence
Climax community	The final, stable community; species composition remains relatively unchanged unless disturbed
Deflected climax (plagioclimax)	A community held below the climax by human activity (e.g. grazing, mowing)

Section 2: Transfers of Energy and Matter (C4.2)

2.1 Food Chains and Food Webs

A **food chain** shows a single pathway of energy transfer from one organism to the next. A **food web** is a network of interconnected food chains showing the feeding relationships in a community.

MEMORISE THIS

Trophic levels:

Trophic Level	Organisms	Example
Producer (autotroph)	Photosynthetic organisms that convert light energy to chemical energy	Grass, phytoplankton
Primary consumer	Herbivores that feed on producers	Rabbit, zooplankton
Secondary consumer	Carnivores that feed on primary consumers	Fox, small fish
Tertiary consumer	Top predators that feed on secondary consumers	Eagle, shark
Decomposer (saprotroph)	Organisms that break down dead organic matter	Fungi, bacteria

2.2 Energy Flow Through Ecosystems

Energy enters most ecosystems as **sunlight** and is converted to chemical energy by producers through photosynthesis. Energy flows through trophic levels but is **not recycled** — it is lost at each transfer.

⚠ EXAM ALERT

The 10% Rule: On average, only about **10%** of the energy at one trophic level is transferred to the next. The remaining ~90% is lost as:

- **Heat** from cellular respiration (the largest loss)
- **Uneaten material** (roots, bones, tough plant fibres)
- **Excretory products** (urine, faeces)
- **Dead organisms** not consumed before decomposition

This is why food chains rarely exceed 4-5 trophic levels — there is insufficient energy to support another level.

2.3 Pyramids of Ecology

Pyramids of energy show the rate of energy flow (in $\mathrm{kJ\ m^{-2} yr^{-1}}$) at each trophic level. They are **always upright** because energy is lost at each transfer.

Pyramids of biomass show the total mass of organisms at each trophic level. They are usually upright but can be **inverted** (e.g. in ocean ecosystems where phytoplankton biomass at any one time is less than zooplankton biomass because phytoplankton reproduce extremely rapidly).

Pyramids of numbers show the number of individuals at each trophic level. These are often irregular (e.g. one oak tree supports millions of caterpillars).

IB TIP

IB exam tip: If asked “which type of pyramid is always upright?”, the answer is **pyramid of energy**. Pyramids of biomass and numbers can both be inverted in certain ecosystems. Be prepared to explain *why* with a specific example.

2.4 Productivity

Gross primary productivity (GPP) is the total rate of energy fixation (photosynthesis) by producers in an ecosystem.

Net primary productivity (NPP) is the rate of energy storage in plant biomass after accounting for respiratory losses:

$$\text{NPP} = \text{GPP} - R$$

Where R is the energy lost through cellular respiration by the producers.

NPP represents the energy available to the next trophic level (primary consumers).

WORKED EXAMPLE

Worked Example: Calculating NPP

A grassland ecosystem has a GPP of $20{,}000 \text{ kJ m}^{-2}\text{yr}^{-1}$. Producers use $12{,}000 \text{ kJ m}^{-2}\text{yr}^{-1}$ for respiration.

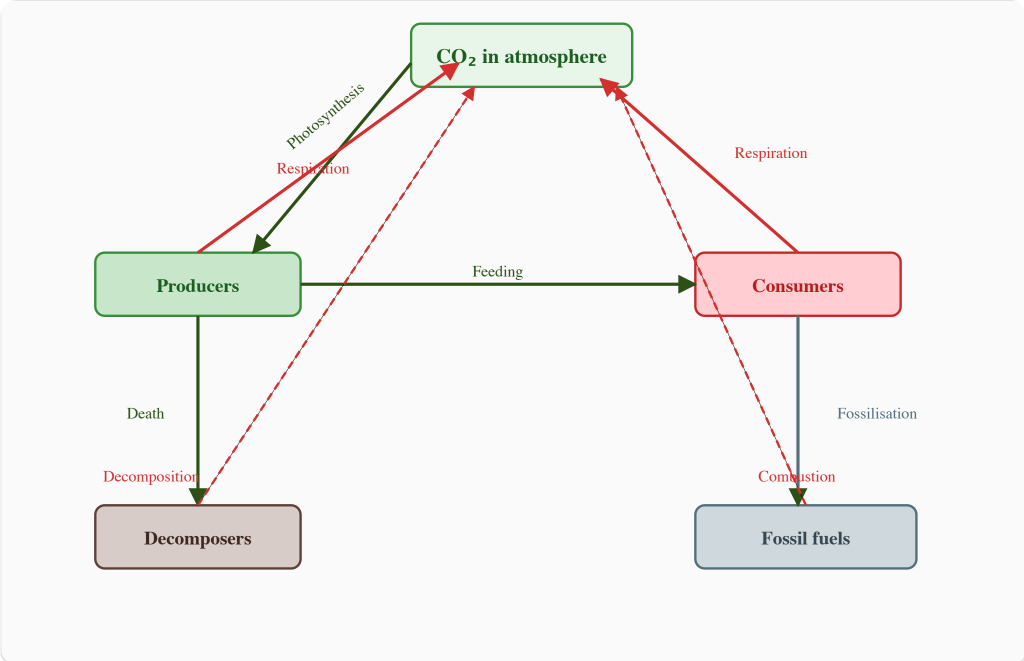
$$\text{NPP} = \text{GPP} - R = 20{,}000 - 12{,}000 = 8{,}000 \text{ kJ m}^{-2}\text{yr}^{-1}$$

Therefore, $8{,}000 \text{ kJ m}^{-2}\text{yr}^{-1}$ of energy is stored in plant biomass and available to herbivores.

If primary consumers assimilate 10% of this: $8{,}000 \times 0.10 = 800 \text{ kJ m}^{-2}\text{yr}^{-1}$ is transferred to the secondary consumer level.

2.5 The Carbon Cycle

Carbon is recycled through ecosystems via biological, geological, and chemical processes.



MEMORISE THIS

Carbon cycle processes:

Process	What happens	Effect on atmospheric CO_2
Photosynthesis	CO_2 fixed into organic molecules by producers	Decreases CO_2
Respiration	Organic molecules broken down, releasing CO_2	Increases CO_2
Combustion	Burning of fossil fuels or biomass releases CO_2	Increases CO_2
Decomposition	Saprotrophs break down dead organic matter, releasing CO_2	Increases CO_2
Fossilisation	Organic carbon trapped in sedimentary rock / fossil fuels over millions of years	Removes CO_2 (long-term)

2.6 The Nitrogen Cycle

Nitrogen is essential for amino acids, proteins, and nucleic acids. Although N_2 makes up 78% of the atmosphere, most organisms cannot use it directly — it must be **fixed** into usable forms.

MEMORISE THIS

Nitrogen cycle processes:

Process	Description	Organisms involved
Nitrogen fixation	$N_2 \rightarrow NH_3$ (ammonia) / NH_4^+ (ammonium)	*Rhizobium* (in root nodules of legumes), free-living bacteria, lightning
Nitrification	$NH_4^+ \rightarrow NO_2^- \rightarrow NO_3^-$	Nitrifying bacteria (*Nitrosomonas*, *Nitrobacter*)
Assimilation	Plants absorb NO_3^- or NH_4^+ from soil; used to make amino acids and nucleotides	Plants
Ammonification	Decomposition of proteins / urea releases NH_4^+ back to soil	Decomposers (saprotrophic bacteria and fungi)
Denitrification	$NO_3^- \rightarrow N_2$ (returned to atmosphere)	Denitrifying bacteria (anaerobic conditions, e.g. waterlogged soil)

⚠ EXAM ALERT

Common exam mistake: Students confuse nitrogen fixation with nitrification. Nitrogen fixation converts N_2 gas into NH_3/NH_4^+. Nitrification converts NH_4^+ into NO_3^- (nitrate). These are carried out by *different bacteria*. Also note: denitrification is the *reverse* of fixation in terms of outcome and occurs under *anaerobic* conditions.

2.7 Bioaccumulation and Biomagnification

Bioaccumulation is the build-up of a persistent, non-biodegradable substance (e.g. DDT, mercury, PCBs) within an organism over its lifetime. The substance is absorbed faster than it can be metabolised or excreted.

Biomagnification is the increasing concentration of a substance at each successive trophic level in a food chain. Top predators accumulate the highest concentrations.

✎ WORKED EXAMPLE

Classic Example: DDT and Biomagnification

DDT (dichlorodiphenyltrichloroethane) was widely used as a pesticide. It is fat-soluble, persistent, and does not break down easily:

- Water: 0.000003 ppm
- Phytoplankton: 0.04 ppm
- Zooplankton: 0.5 ppm
- Small fish: 2 ppm
- Large fish: 25 ppm
- Fish-eating birds (e.g. osprey): $250+$ ppm

At high concentrations, DDT caused eggshell thinning in birds of prey (e.g. peregrine falcon, bald eagle), leading to population crashes. This led to the ban of DDT in many countries.

IB TIP

IB exam tip: If asked *why* biomagnification occurs, the key points are: (1) the substance is **persistent** (not broken down), (2) it is **fat-soluble** (stored in lipid tissues, not excreted), and (3) organisms at higher trophic levels consume **many organisms** from the level below, accumulating their stored toxins.

Section 3: HL Extensions — Diversity Indices & Statistical Tests

3.1 Simpson's Diversity Index

Biodiversity can be quantified using the **Simpson's Diversity Index**. This measures species richness (number of species) and evenness (how equally individuals are distributed among species).

$D = 1 - \sum \left(\frac{n}{N}\right)^2$

Where:

- D = diversity index (ranges from 0 to 1; higher values = greater diversity)
- n = number of individuals of each species
- N = total number of all individuals

WORKED EXAMPLE

Worked Example: Simpson's Diversity Index

A meadow survey finds the following:

Species	Number of individuals (n)	$\frac{n}{N}$	$\left(\frac{n}{N}\right)^2$
Daisy	30	0.300	0.0900
Buttercup	25	0.250	0.0625
Clover	20	0.200	0.0400
Dandelion	15	0.150	0.0225
Thistle	10	0.100	0.0100

Total (N) = 100

$\sum \left(\frac{n}{N}\right)^2 = 0.0900 + 0.0625 + 0.0400 + 0.0225 + 0.0100 = 0.2250$

$D = 1 - 0.2250 = 0.775$

Interpretation: $D = 0.775$ indicates relatively high diversity. A value close to 1 means high diversity (many species, evenly distributed); a value close to 0 means low diversity (dominated by one species).

For comparison, if one species had 96 individuals and four others had 1 each: $D = 1 - (0.96^2 + 4 \times 0.01^2) = 1 - 0.9220 = 0.078$ — very low diversity.

⚠ EXAM ALERT

Common calculation errors:

1. Forgetting to square each $\frac{n}{N}$ value before summing
2. Forgetting to subtract from 1 at the end
3. Using the wrong version of the formula — IB uses $D = 1 - \sum(n/N)^2$ (not $1/\sum$)

Always show your working clearly in a table format as shown above — it is easy to make arithmetic mistakes and the table allows examiners to award method marks even if the final answer is wrong.

3.2 Chi-Squared Test (χ^2)

The **chi-squared test** is used to determine whether there is a **statistically significant association** between two categorical variables (e.g. species distribution and an abiotic factor like soil type).

$\chi^2 = \sum \frac{(O-E)^2}{E}$

Where:

- O = observed frequency
- E = expected frequency (calculated assuming no association)

WORKED EXAMPLE

Worked Example: Chi-Squared Test

A student investigates whether the distribution of a moss species is associated with the direction a wall faces (north vs south). They sample 100 quadrats:

	Moss present	Moss absent	Row total
North-facing	35	15	50
South-facing	20	30	50
Column total	55	45	100

Step 1: Calculate expected values

$E = \frac{\text{row total} \times \text{column total}}{\text{grand total}}$

	Moss present (E)	Moss absent (E)
North-facing	$\frac{50 \times 55}{100} = 27.5$	$\frac{50 \times 45}{100} = 22.5$
South-facing	$\frac{50 \times 55}{100} = 27.5$	$\frac{50 \times 45}{100} = 22.5$

Step 2: Calculate χ^2

$\chi^2 = \frac{(35-27.5)^2}{27.5} + \frac{(15-22.5)^2}{22.5} + \frac{(20-27.5)^2}{27.5} + \frac{(30-22.5)^2}{22.5}$

$= \frac{56.25}{27.5} + \frac{56.25}{22.5} + \frac{56.25}{27.5} + \frac{56.25}{22.5}$

$= 2.045 + 2.500 + 2.045 + 2.500 = 9.09$

Step 3: Determine significance

Degrees of freedom = $(r-1)(c-1) = (2-1)(2-1) = 1$

Critical value at $p = 0.05$ with 1 degree of freedom = 3.841

Since $\chi^2 = 9.09 > 3.841$, we **reject the null hypothesis**. There is a statistically significant association between wall direction and moss distribution at the 5% significance level.

IB TIP

IB exam tip: Always state the null hypothesis before calculating. For example: “There is no significant association between wall direction and moss distribution.” You must compare the calculated χ^2 to the critical value from the table and state whether you reject or fail to reject the null hypothesis at $p = 0.05$.

3.3 Mark-Recapture Assumptions and Limitations

⚠ EXAM ALERT

HL extension — evaluating mark-recapture:

The Lincoln Index provides an estimate only. Its reliability depends on the validity of the assumptions:

Assumption	If violated	Effect on estimate
Closed population (no births, deaths, immigration, emigration)	Individuals leave or enter	Overestimate (if emigration) or underestimate (if immigration)
Marking does not affect survival	Marked individuals predated more easily	Fewer recaptured, so N is overestimated
Marks do not rub off	Marks lost between samples	Fewer marked recaptured, so N is overestimated
Random mixing	Marked individuals remain clustered	If second sample is from the cluster, N is underestimated; if from elsewhere, N is overestimated
Equal probability of capture	Some individuals are trap-shy or trap-happy	Trap-shy: overestimate; trap-happy: underestimate

To improve reliability: increase sample sizes, allow adequate mixing time, use durable non-toxic marking methods, and verify assumptions where possible.

Section 4: Exam Strategy & Common Mistakes

⚠ **EXAM ALERT**

Top mistakes in ecology exams:

1. **Confusing biomass and energy pyramids** — only energy pyramids are always upright
2. **Saying "energy is recycled"** — energy flows through ecosystems; only matter (carbon, nitrogen) is recycled
3. **Forgetting units** — productivity must be in $\mathrm{kJ\ m^{-2} yr^{-1}}$; diversity index is unitless
4. **Using "adapted" loosely** — say "the species has adaptations that are suited to…" not "the species adapted to its environment" (which implies Lamarckian evolution)
5. **Confusing food chains and food webs** — a food chain is a single linear pathway; a food web shows multiple interconnected chains
6. **Saying "top predators have the most energy"** — they have the *least* energy; they have the highest concentration of persistent toxins via biomagnification
7. **Simpson's Index errors** — forgetting to square, forgetting to subtract from 1, or using the reciprocal formula instead of the complement formula

IB Exam-Style Questions

Question 1 *(3 marks)*

Explain why food chains rarely have more than four or five trophic levels.

▶ Markscheme

Question 2 *(4 marks)*

A population of rabbits is introduced to an island with abundant vegetation and no predators. Describe and explain the expected changes in population size over time.

▶ Markscheme

Question 3 *(3 marks)*

Distinguish between bioaccumulation and biomagnification.

▶ Markscheme

Question 4 *(4 marks)*

Outline the role of bacteria in the nitrogen cycle.

▶ Markscheme

Mixed Practice — Exam Style

IB TIP

How to use this section: Unlike topic-specific practice, these questions are interleaved — they mix all topics from this guide in random order. Before answering, identify *which concept or topic area* the question is testing. This is exactly the skill you need on Paper 1 and Paper 2, where you don't know in advance which topic each question covers.

1. **[Energy Flow]** In a food chain, which trophic level contains the most energy?

   A. Tertiary consumers (top predators)

   B. Secondary consumers

   C. Primary consumers (herbivores)

   D. Producers (autotrophs)

2. **[Population Growth]** A population of bacteria is growing in a flask with limited nutrients. The growth curve is best described as:

   A. Exponential growth only, continuing indefinitely

   B. Logistic growth — initially exponential, then levelling off at carrying capacity

   C. Linear growth at a constant rate

   D. Immediate plateau — growth rate is constant from the start

3. **[Nitrogen Cycle]** Which process converts atmospheric N_2 into a form usable by plants?

   A. Nitrification

   B. Denitrification

   C. Nitrogen fixation

   D. Ammonification

4. **[Ecological Pyramids]** Which type of ecological pyramid is always upright?

   A. Pyramid of numbers

   B. Pyramid of biomass

   C. Pyramid of energy

   D. All three types are always upright

5. **[Simpson's Diversity Index]** A habitat has 4 species with the following numbers: 90, 5, 3, 2. Another habitat has 4 species with: 25, 25, 25, 25. Which statement is correct?

   A. The first habitat has greater diversity because it has more total individuals

   B. The second habitat has greater diversity because individuals are more evenly distributed among species

   C. Both habitats have equal diversity because they have the same number of species

   D. Diversity cannot be compared without knowing the species names

6. **[Succession]** Which of the following best describes primary succession?

   A. Regrowth of a forest after a fire, using existing soil and seed bank

   B. Colonisation of bare rock by pioneer species, leading gradually to a climax community

   C. A farmer abandoning a field, which gradually returns to forest

   D. The replacement of one dominant species by another after a disease outbreak

7. **[Bioaccumulation]** A persistent pesticide is found at highest concentrations in:

   A. Producers (phytoplankton)

   B. Primary consumers (zooplankton)

   C. Secondary consumers (small fish)

   D. Tertiary consumers (fish-eating birds)

8. **[Carbon Cycle]** Which process removes CO_2 from the atmosphere?

   A. Respiration

   B. Combustion of fossil fuels

   C. Photosynthesis

   D. Decomposition

9. **[Community Interactions — Distractor]** Two species of finch on an island both eat medium-sized seeds. Over time, one species evolves a larger beak and shifts to eating larger seeds. This is an example of:

   A. Mutualism — both species benefit

   B. Parasitism — one species exploits the other

C. Resource partitioning driven by interspecific competition — the competitive exclusion principle leads to niche differentiation

D. Predation — one species preys on the other

10. **[Mark-Recapture — Distractor]** In a mark-recapture study, a researcher marks 50 fish and releases them. In the second sample, they catch 60 fish, of which 5 are marked. The estimated population size is:

A. 110

B. 300

C. 600

D. 3000

▶ Show Answers

November 2026 Prediction Questions

⚠ EXAM ALERT

These are NOT official IB questions. These are trend-based practice questions written to reflect the topic areas and question styles most likely to appear on the November 2026 IB Biology HL Paper 2. Based on recent exam patterns (2022—2025), expect heavy weighting on: energy flow and trophic efficiency (including calculations), the nitrogen cycle, and human impacts on ecosystems (pollution, invasive species, habitat fragmentation).

▶ **Question 1 — Energy Flow and Ecological Efficiency [8 marks]**
▶ **Question 2 — Nitrogen Cycle and Human Impact [7 marks]**
▶ **Question 3 — Biodiversity and Invasive Species [6 marks]**

IB Biology HL — Ecology: Populations, Communities & Energy Transfer — Complete Study Guide — 2025 Syllabus — Good luck!