

Productivity and ecosystems

Revision notes · Productivity and energy transfer, ecological terms, biotic and abiotic factors, niche, the ecology core practical, and succession.

For Pearson Edexcel International AS Biology XBI11 and International A Level Biology YBI11. **A Level only** is IA2 content (Units 4 to 6), not needed for the International AS.

Productivity and ecosystems Spec 5.9-5.15 A Level only

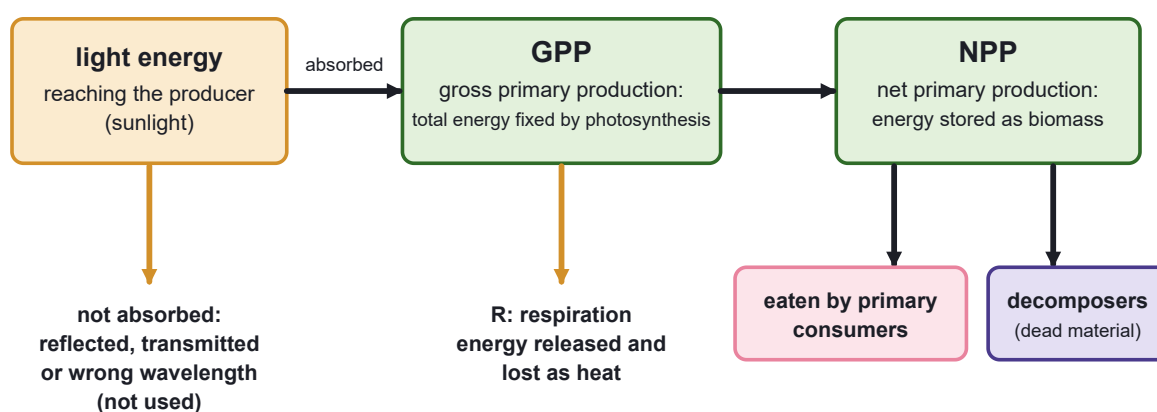
Gross and net primary productivity Spec 5.9

Gross primary productivity (GPP) The total chemical energy fixed by photosynthesis in a given area in a given time (for example $\text{kJ m}^{-2} \text{year}^{-1}$).

Net primary productivity (NPP) The chemical energy remaining in plant biomass after the energy lost in respiration has been taken away. It is the energy available to the next trophic level.

$$\text{NPP} = \text{GPP} - \text{R} \text{ (R = energy lost in plant respiration)}$$

Plants use some of the sugars they make in respiration, to release energy for growth, active transport and other processes. This energy is eventually lost as heat. Only the remainder is stored in new plant material (growth), which is the biomass that can be eaten by herbivores or decomposed. Productivity is measured as a **rate**, for example $\text{kJ m}^{-2} \text{year}^{-1}$ for energy or $\text{g m}^{-2} \text{year}^{-1}$ for dry mass of biomass.



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

all measured in $\text{kJ m}^{-2} \text{year}^{-1}$ (energy) or $\text{g m}^{-2} \text{year}^{-1}$ (dry mass)

From sunlight to biomass: **$\text{NPP} = \text{GPP} - \text{R}$** .

Calculating NPP

A field of grass fixes $12\,500\text{ kJ m}^{-2}\text{ year}^{-1}$ of energy by photosynthesis. The grass loses $4\,100\text{ kJ m}^{-2}\text{ year}^{-1}$ in respiration. Calculate the net primary productivity and express it as a percentage of GPP.

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

2. $\text{NPP} = 12\,500 - 4\,100 = 8\,400\text{ kJ m}^{-2}\text{ year}^{-1}$

3. $\text{Percentage} = 8\,400 \div 12\,500 \times 100$

Answer: $\text{NPP} = 8\,400\text{ kJ m}^{-2}\text{ year}^{-1}$ (67.2 % of GPP)

Maths skill: You may be given any two of GPP, R and NPP and asked for the third. Rearrange the equation first and give the unit ($\text{kJ m}^{-2}\text{ year}^{-1}$ or $\text{g m}^{-2}\text{ year}^{-1}$).

Common mistake: Do not say that GPP is the energy absorbed from the Sun. Most light is not absorbed, and only a small percentage of the light energy that reaches the leaf is fixed.

Efficiency of biomass and energy transfers Spec 5.10

efficiency of transfer (%) = (energy or biomass in the next trophic level $\div$ energy or biomass in the previous trophic level) $\times 100$

Use the same units for both trophic levels. Energy transfer is usually measured in $\text{kJ m}^{-2}\text{ year}^{-1}$, and biomass transfer as dry mass in $\text{g m}^{-2}\text{ year}^{-1}$. Dry mass is used because water content varies and water holds no chemical energy.

Calculating efficiency of energy transfer

Grass in a meadow has an NPP of $8\,400\text{ kJ m}^{-2}\text{ year}^{-1}$. Rabbits feeding on the grass gain $840\text{ kJ m}^{-2}\text{ year}^{-1}$ of energy in their biomass. Calculate the efficiency of transfer from grass to rabbits.

1. $\text{efficiency} = \text{energy in rabbits} \div \text{energy in grass} \times 100$

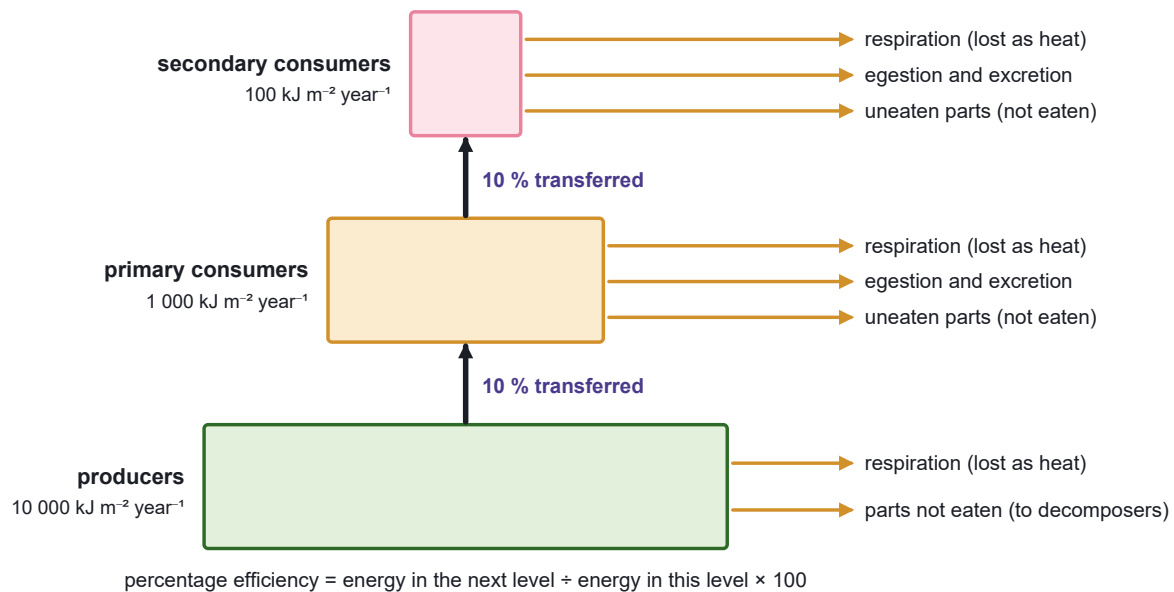
2. $= 840 \div 8\,400 \times 100$

Answer: 10 %

Why transfers are inefficient

- Not all of the organism is eaten: bones, roots, shells, hair and other parts are left uneaten.
- Some of what is eaten is not digested and is lost in faeces (**egestion**).
- Some absorbed material is lost as excretory products such as urea (**excretion**), which contains energy.
- Energy is lost as heat from **respiration** in the consumer, to power movement, active transport and other processes (and, in birds and mammals, to maintain body temperature). This energy is not available to the next trophic level.
- Not all individuals are eaten: some die of disease or old age and pass to decomposers.

Because of these losses, the biomass and energy at each trophic level are lower than in the level before it. This is why food chains rarely have more than four or five trophic levels, and why pyramids of energy are always pyramid-shaped. Transfers are often less efficient from producer to primary consumer (plants contain indigestible cellulose and lignin) and are higher for carnivores (whose food is easier to digest).



A **pyramid of energy**: each level holds less energy because of losses at every transfer.

Exam tip: When explaining energy loss, name the process (respiration, egestion, excretion) and say what happens to the energy (lost as heat; held in material that passes to decomposers). Marks are rarely given for 'energy is lost' on its own.

Population, community, habitat and ecosystem; biotic and abiotic factors Spec 5.11, 5.12

Population	All the organisms of one species living in a habitat at the same time.
Community	All the populations of different species living and interacting in a habitat.
Habitat	The place where an organism, population or community lives, with its own set of environmental conditions.
Ecosystem	A community of organisms together with the non-living (abiotic) components of their environment, and the interactions between them.

For example, in a pond the population of frogs, the population of pondweed and the populations of all the other species make up the community. The pond water, sediment, light, dissolved oxygen and temperature are abiotic parts of the ecosystem.

Biotic and abiotic factors

The **numbers** and **distribution** of organisms in a habitat are controlled by both kinds of factor. Distribution describes where organisms are found, and abundance how many there are.

Biotic and abiotic factors		
	Biotic factors	Abiotic factors
Meaning	Factors caused by living organisms	Non-living physical and chemical factors
Examples	Competition (for food, light, space, mates), predation, parasitism and disease, grazing, availability of food	Temperature, light intensity, water availability, pH, salinity, oxygen concentration, mineral ions, wind speed, humidity
Effects	Intraspecific competition limits population size; interspecific competition and predation can exclude a species from part of a habitat	Set the range of conditions in which a species can survive and reproduce, for example plants that are not tolerant to salt are limited to areas of low salinity

Biotic factors are often **density-dependent**: their effect increases as the population gets larger, for example disease and competition. Abiotic factors such as a severe frost affect a population regardless of its size.

Exam tip: In a data question, say whether the factor is biotic or abiotic, and then link it to the effect on numbers or distribution, for example 'an increase in predators lowers prey numbers' rather than just 'predation'.

The concept of niche Spec 5.13

Niche	The role of a species within its habitat, including its interactions with the biotic and abiotic components of the environment (for example its food, its habitat, its time of activity and its position in the food web).
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Each species has a unique niche. Within a habitat, the niche of a species is shaped by its adaptations: where it feeds, what it feeds on, the abiotic conditions it tolerates, when it is active and how it reproduces.

How niche accounts for distribution and abundance

- A species is found only where the biotic and abiotic conditions of its niche are met, which explains its **distribution**.
- If two species have very similar niches, they compete for the same resources. This **interspecific competition** reduces the population of both, or one species outcompetes the other and is excluded from the habitat (the competitive exclusion principle).
- Coexisting species usually have slightly different niches, for example feeding at different heights, on different foods or at different times of day. This reduces competition and allows more species to live in the habitat.
- Within a species, **intraspecific competition** for the resources of its niche limits the population size, so the amount of the resources in the habitat sets the abundance of the species.

For example, two species of birds may both eat insects from the same tree. If one feeds mainly on the trunk and the other on the outer twigs, their niches differ enough for both to survive, and the abundance of each reflects the food in its part of the tree.

Common mistake: Habitat and niche are not the same. A habitat is where an organism lives; a niche is what it does there and how it interacts with its environment.

Core practical 11: a study of the ecology of a habitat Spec 5.14

Core practical: Core practical 11: carry out a study of the ecology of a habitat, such as using quadrats and transects to determine the distribution and abundance of organisms, and measuring abiotic factors appropriate to the habitat.

Choosing the sampling method

Quadrats and transects		
Method	Use	How it is done
Random sampling with quadrats	To estimate the abundance (and mean density or percentage cover) of organisms across an area, avoiding bias	Lay out two tape measures at right angles to form a grid. Use random numbers (from a calculator or table) as coordinates for each quadrat. Place the quadrat at each point
Systematic sampling along a transect	To show how the distribution of organisms changes along an environmental gradient (for example from the sea shore or up a slope)	Stretch a tape measure along the gradient. Place a quadrat at regular intervals (an interrupted belt transect) or record species touching the line (a line transect)

A quadrat is a square frame, often 0.25 m² or 1 m². In each quadrat, record the **abundance** of each species. Use percentage cover for plants that are difficult to count as individuals, such as grass, and count individuals for animals and larger plants. A frequency measure counts how many of the squares in a gridded quadrat contain the species.

mean number per m² = total number counted ÷ (number of quadrats × area of one quadrat in m²)

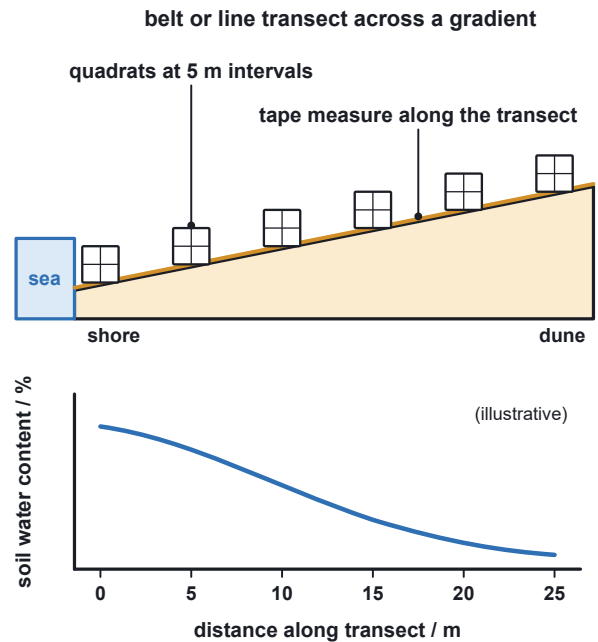
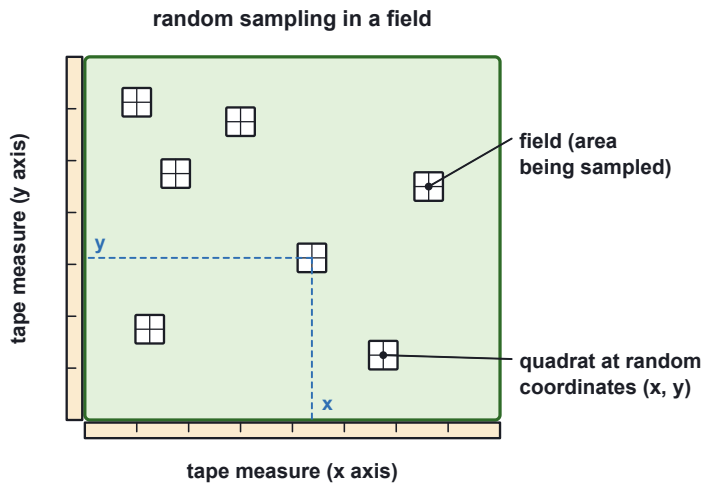
estimated population size = mean number per m² × total area of habitat in m²

Estimating a population

Ten 0.25 m² quadrats were placed randomly in a field of area 2 000 m². A total of 35 daisy plants were counted in the quadrats. Estimate the population size of daisies in the field.

1. Total area sampled = 10 × 0.25 = 2.5 m²
2. Mean per m² = 35 ÷ 2.5 = 14
3. Population = 14 × 2 000

Answer: 28 000 daisy plants



Random sampling with coordinates (left) and a **transect** across a gradient with an abiotic factor measured at each quadrat (right).

Measuring abiotic factors

Measure abiotic factors at each quadrat so that distribution can be linked to environment. The factors chosen depend on the habitat. Examples are light intensity (light meter), soil or water pH (pH meter or probe), soil moisture (moisture meter, or mass lost on drying), temperature (thermometer or probe), wind speed (anemometer), and salinity or dissolved oxygen (probe). Take several readings and calculate a mean.

Reliability, safety and ethics

- Use a large enough sample (for example 10 to 30 quadrats) so that the mean is representative. Sample size is large enough when the running mean stops changing.
- Identify species using a key; use the same sampling effort and the same person where possible, and record the time of day and the season.
- Link the distribution of a species to an abiotic factor by plotting both against distance on a graph, and use a statistical test (for example a correlation test) to find whether the relationship is significant. Correlation does not by itself show cause.
- Risks: slips and trips, sun, ticks, contaminated water, sharp objects. Wear suitable clothing and footwear, check weather and tides, work in pairs and wash hands.
- Cause as little damage as possible to the habitat: take quadrats carefully, do not trample the vegetation more than needed, return any animals, and obtain permission to sample.

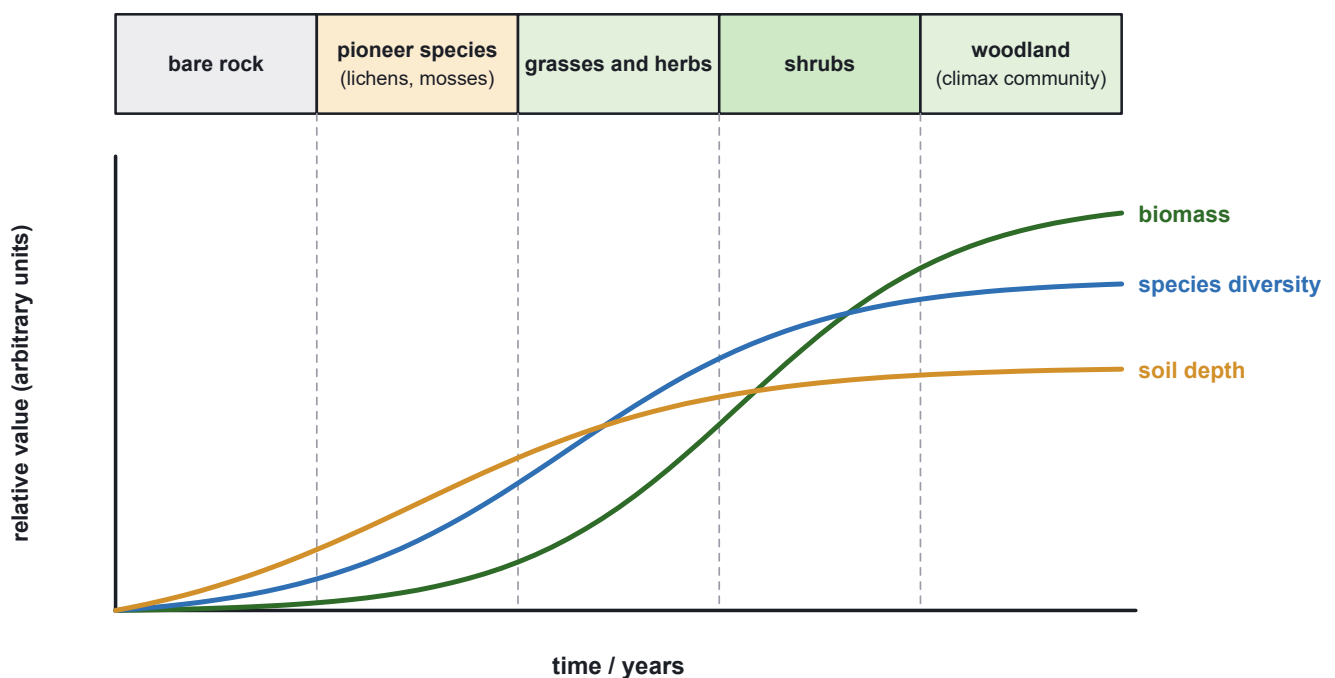
Exam tip: If asked why sampling is random, say it avoids bias in choosing where to place quadrats. If asked why a transect is used, say it samples across a gradient, so changes in distribution can be linked to a change in an abiotic factor.

Succession Spec 5.15

Succession is the process by which an ecosystem changes over time, with one community of species replacing another. **Primary succession** starts on bare, newly formed land such as rock or sand dunes,

where there is no soil. **Secondary succession** happens where soil is already present, for example after a forest fire or when farmland is abandoned.

1. **Colonisation**: pioneer species such as lichens, mosses or algae arrive, often as wind-blown spores or seeds. They are adapted to tolerate harsh abiotic conditions, such as low nutrients and water availability, and can photosynthesise or fix nitrogen.
2. Pioneers change the abiotic environment. They weather rock, trap dead material and, when they die and are decomposed, add organic matter and minerals, which form a thin soil that holds more water.
3. The conditions become less hostile, so new species such as grasses and small herbs can germinate and grow. They outcompete the pioneers, which are replaced. Each community changes the conditions and allows the next to colonise (shrubs, then trees).
4. As succession proceeds, soil depth, nutrients and water retention increase. Species diversity and biomass rise, and food webs become more complex.
5. Eventually a stable **climax community** forms, in which the species are in balance with the abiotic environment (especially the climate) and no further net change in species occurs. The climax community is usually dominated by a few large, long-lived species, such as woodland trees in temperate climates.



Primary succession: biomass, species diversity and soil depth all increase and level off at the **climax community**.

Early and late stages of succession		
Feature	Pioneer stage	Climax community
Species diversity	Low	High (but dominated by a few species)
Soil depth and nutrients	Thin soil or none; few nutrients	Deep, rich soil
Abiotic conditions	Harsh and variable	Stable, less extreme
Biomass	Low	High
Food webs	Simple	Complex
Size of dominant plants	Small	Large

Exam tip: The key idea is that each stage changes the environment, making it more suitable for the next. Say what the species change (the abiotic conditions such as soil) and what that allows.

Quick check

1. Write the equation linking NPP, GPP and R.
2. Give two ways in which energy is lost between trophic levels.
3. What is a niche?
4. Why are quadrats placed at random?
5. What is a climax community?

Quick check answers

Productivity and ecosystems

1. $NPP = GPP - R$.
2. Respiration (heat), egestion, excretion, uneaten parts.
3. The role of a species in its habitat, including its interactions with biotic and abiotic factors.
4. To avoid bias in sampling.
5. The stable community at the end of succession, in balance with the abiotic conditions.