DP IB Biology: HL

Your notes

4.1 Species, Communities, Ecosystems & Energy Flow

Contents

4.1.1 Species & Population

Your notes

Species

- A species can be defined as:
  A group of organisms that can interbreed to produce fertile offspring
- The ability to breed and produce fertile offspring is a useful method of distinguishing species for organisms that reproduce sexually but **can be difficult to apply** in some situations
  - Organisms that reproduce by asexual reproduction, such as bacteria, cannot be classified using this method
  - On rare occasions, **animals of different species breed together and produce fertile offspring**, such as the so-called 'wholphin'; the fertile offspring from a cross between a melon-headed whale and a common bottlenose dolphin
    - According to the species rule above the wholphin would be a new species, but while scientists do believe that hybridisation can lead to new species it needs to be a frequent event for this to occur, and wholphins are rare
    - Note that the melon-headed whale is actually a species of dolphin, so the name 'wholphin' is a bit inaccurate!
- The imperfect nature of this method of classifying species means that other characteristics are often used at the same time
  - Organisms of the same species share **similar** morphology
  - **DNA sequences** can be compared, with a certain level of similarity indicating that organisms are the same species

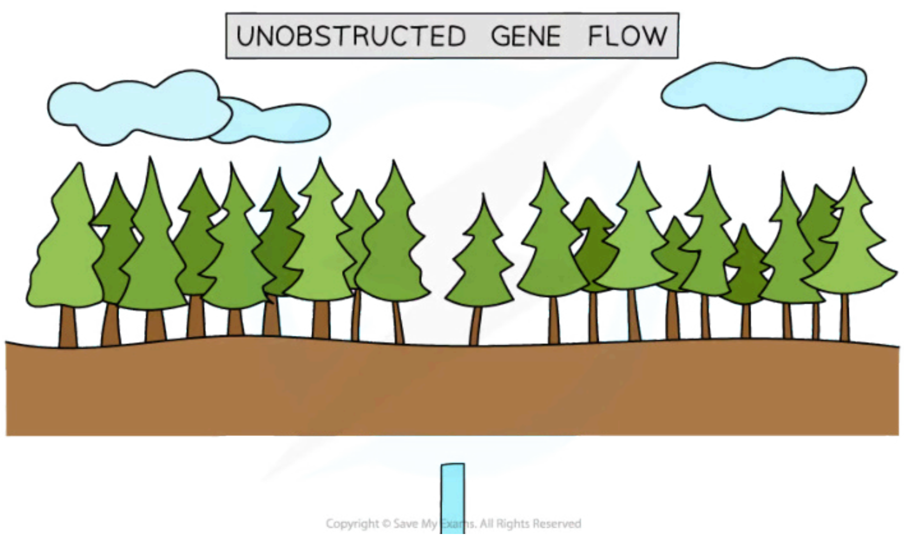
Populations

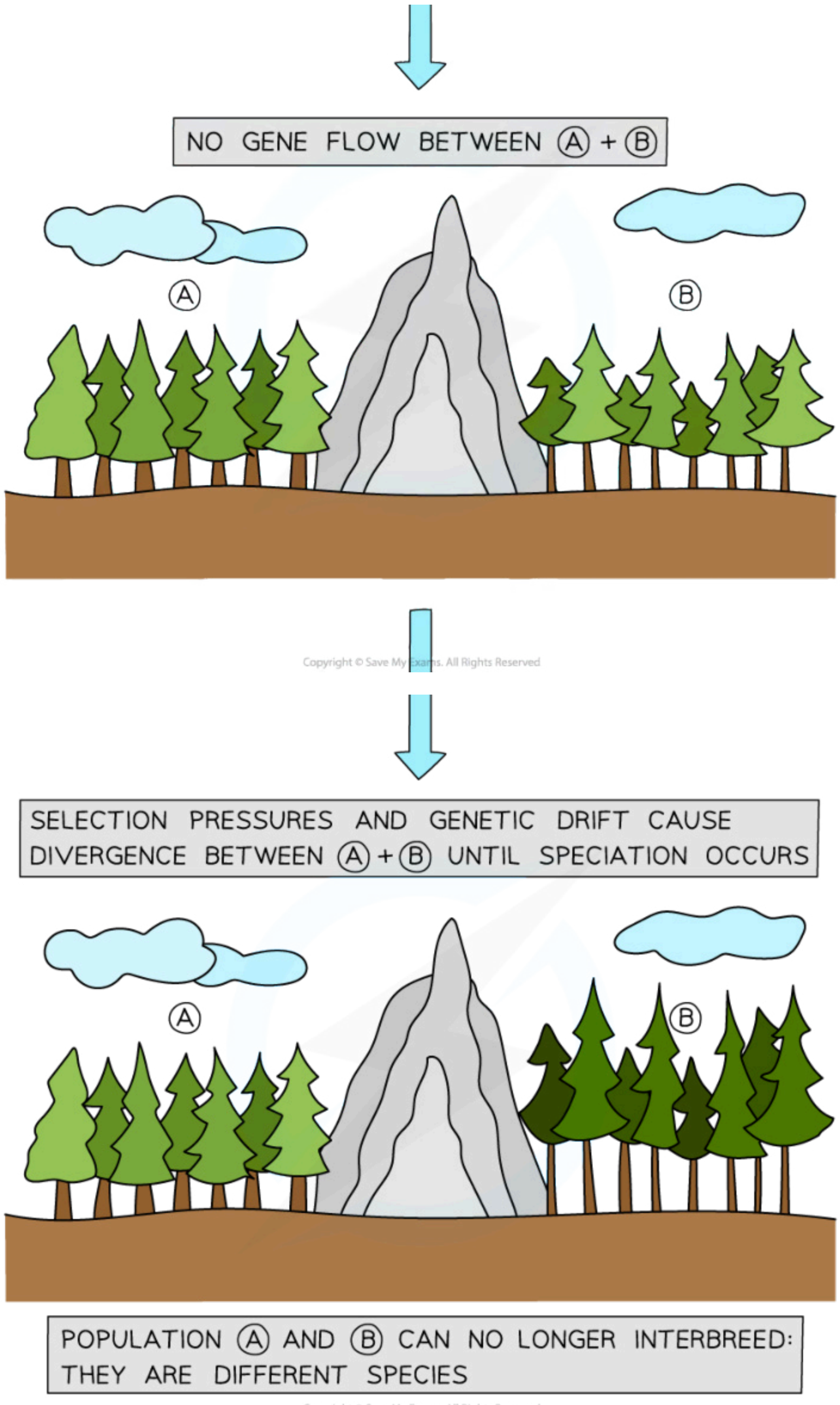
Your notes

- A population can be defined as:

  A group of organisms of the same species living in an area at one time

- A **population** can be isolated from other populations of the same species due to living in a different area
- This isolation means that members of the separate populations **cannot breed together** and **gene exchange** or **gene flow** cannot take place between them
- As long as these isolated populations could, in theory, interbreed to produce fertile offspring, they are the **same species**
- If the environmental conditions affecting each population are different, then **natural selection could act differently** on each population and eventually lead to speciation
  - Genetic drift can also lead to speciation
- Once speciation has taken place, the **two species** can no longer produce fertile offspring; they are **reproductively isolated**

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Reproductive isolation of two populations of trees can occur when the populations are separated for a long period of time

Your notes

Examiner Tip

Make sure that you can state the definition for a species - organisms belong to the same species if they can interbreed to produce **fertile** offspring

4.1.2 Methods of Nutrition

Your notes

Autotroph vs Heterotroph

- Organisms need **energy in the form of** ATP to survive
- The energy stored in ATP comes from other **organic molecules, such as carbohydrates,** and is transferred during the process of **respiration**
- The method by which an organism gains organic molecules to fuel respiration is known as its **mode of nutrition**
- There are two main modes of nutrition; **autotrophy** and **heterotrophy**

Autotrophs

- An **autotroph synthesises**, or produces, **its own organic molecules** from simple inorganic substances in its environment
- **Photosynthetic organisms use light energy** to **convert carbon dioxide from the air into organic molecules** such as carbohydrates
  - Some autotrophs use energy from the oxidation of inorganic compounds instead of light energy
  - Autotrophs that use light energy are known as photoautotrophs, while those that use energy from oxidation of chemicals are known as chemoautotrophs
- Because autotrophs make their own organic molecules without relying on other organisms, they are known as **producers**
- Most green plants are autotrophs, along with algae such as seaweeds, and photosynthetic bacteria such as cyanobacteria

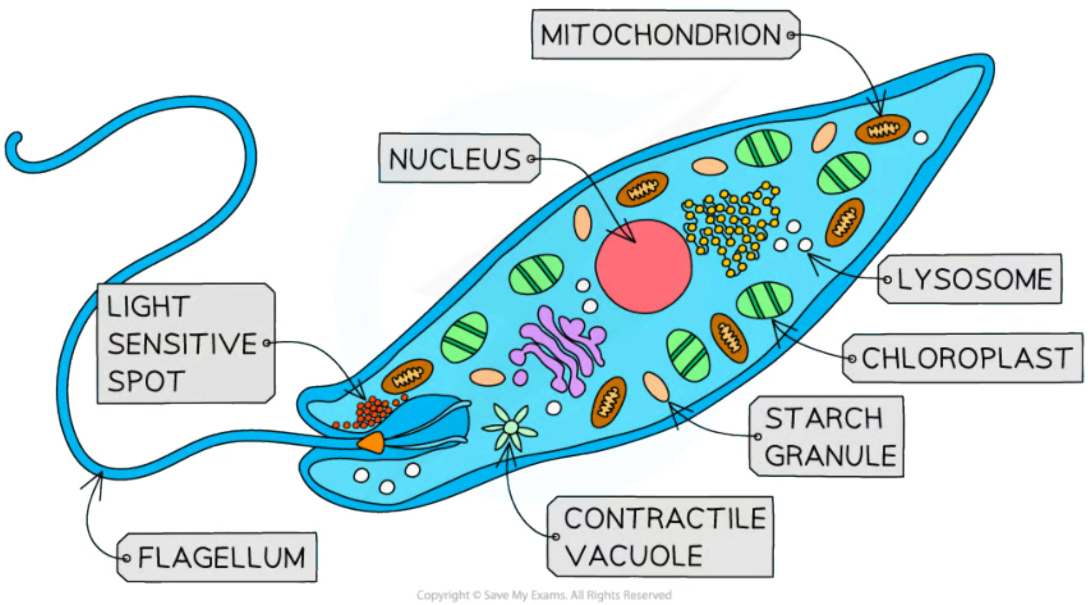
Heterotrophs

- **Heterotrophic organisms** gain their organic molecules by ingesting the tissues of **other organisms**
- There are several types of heterotroph, including **consumers, detritivores**, and **saprotrophs**

Mixing modes of nutrition

- Some organisms are able to make use of **more than one mode of nutrition**, such as **auto-** and **heterotrophy**
  - These organisms are referred to as mixotrophs
- **Euglena** is a **single-celled eukaryotic organism** that makes use of both autotrophy and heterotrophy
  - Euglena cells can **take in bacterial cells** by endocytosis, and then digest them using **digestive enzymes stored in** lysosomes
  - Euglena cells also contain a **light-sensitive spot** that enables them to position themselves so that **maximum light reaches their chloroplasts**

Your notes



Euglena is a single-celled eukaryote that makes use of autotrophic and heterotrophic nutrition

Plant & Algal Nutrition

Your notes

NOS: Looking for patterns, trends and discrepancies; plants and algae are mostly autotrophic but some are not

- The majority of plants and algae are **photosynthetic,** meaning that they are **autotrophs** that rely on energy from the sun to convert carbon dioxide in the air into organic molecules in their tissues
- Their photosynthetic cells contain **pigments which absorb light energy**
  - The main pigment in green plants is chlorophyll, which primarily absorbs light at the red and blue ends of the visible spectrum, reflecting green light
  - Green plants also have carotenoid pigments, known as accessory pigments, which extend the range of light wavelengths that can be absorbed; these pigments appear to be red, yellow, or purple and remain in mature leaves after chlorophyll degrades
  - Brown algae, such as the seaweed kelp, contain a brown pigment called fucoxanthin
  - Red algae and green algae have pigments called phycobilins

- There are some **unusual exceptions** to the autotrophic mode of nutrition used by most plants and algae
  - Some plants parasitise **the roots of other plants**, tapping into the roots of these plants to gain their organic molecules
    - E.g. groundcone plants look like upright pine cones sitting on the ground, but are in fact parasitic plants, having no photosynthetic pigments of their own, and gaining their organic molecules from the roots of surrounding trees

  - Some plants **parasitise fungi**, a feeding mode known as mycoheterotrophy, gaining their organic molecules from the network of fungal cells in the soil
    - The rare plant *Epipogium aphyllum*, also known as the ghost orchid, has no leaves and no chlorophyll, gaining its organic molecules from the fungi that form associations with tree roots

- When exceptions to accepted trends are observed in the natural world, it can sometimes mean that established modes of thinking are incorrect, so it is important to consider discrepancies carefully
  - In the case of non-photosynthetic plants and algae:
    - They are rare
    - They appear to have evolved on multiple occasions from autotrophic ancestors

  - There is not enough evidence to disprove the mode of thinking that says that plants and algae are autotrophs, but we can say that there are a few exceptions to this rule

Types of Heterotrophic Nutrition

Your notes

- There are several ways in which heterotrophs gain organic molecules from other organisms

Consumers

- **Consumers** gain their organic molecules by **ingesting the tissues of other living organisms or recently dead organisms**
- The consumers that eat plants are known as **herbivores**, and the consumers that eat other animals are known as **carnivores**

Detritivores

- **Detritivores** gain organic molecules by **ingesting the tissues of dead organisms** or **ingesting animal waste**
- Detritivores carry out **internal digestion**, meaning that they digest their food **inside** their bodies
- Examples of detritivores include **earthworms, woodlice** and **dung beetles**

Saprotrophs

- Saprotrophs also ingest the tissues of **dead organisms** and **waste material**, but they **secrete enzymes** onto their food, and **digest it externally**
- The **products** of this external digestion are then **absorbed**
- Examples of saprotrophs include **fungi** and **bacteria**
- Saprotrophs secrete a wide range of digestive enzymes that allow them to hydrolyse (break down) a large variety of biological molecules, releasing a large range of products as a result
  - Examples of these products include mineral ions, such as **ammonium ions** and **phosphate ions**

- Importantly, **not all** of the products of external digestion get absorbed by saprotrophs
- Instead, some of the products **remain in the surrounding soil** and become available to **other organisms** such as **plants**
  - This is why saprotrophs are such an **essential component** of ecosystems and food webs
  - Without them, the nutrients **locked up** in dead and waste matter would never be made available again and **producers** such as **plants** would not have access to **sufficient nutrients**

4.1.3 Community

Your notes

Community

- Species do not exist by themselves in their own isolated environment; they **interact** with **other species**, forming **communities**
- A community can be defined as:

  Multiple populations of different species living and interacting in the same area

- For example, a garden pond **community** is made up of populations of fish, frogs, newts, pond snails, damselflies and dragonflies and their larvae, pondweed, water lilies, and all other populations living in the pond

Ecosystems

Your notes

- Communities interact with the **non-living components** of the **environment** they live in, forming **ecosystems**
- An ecosystem can be defined as:

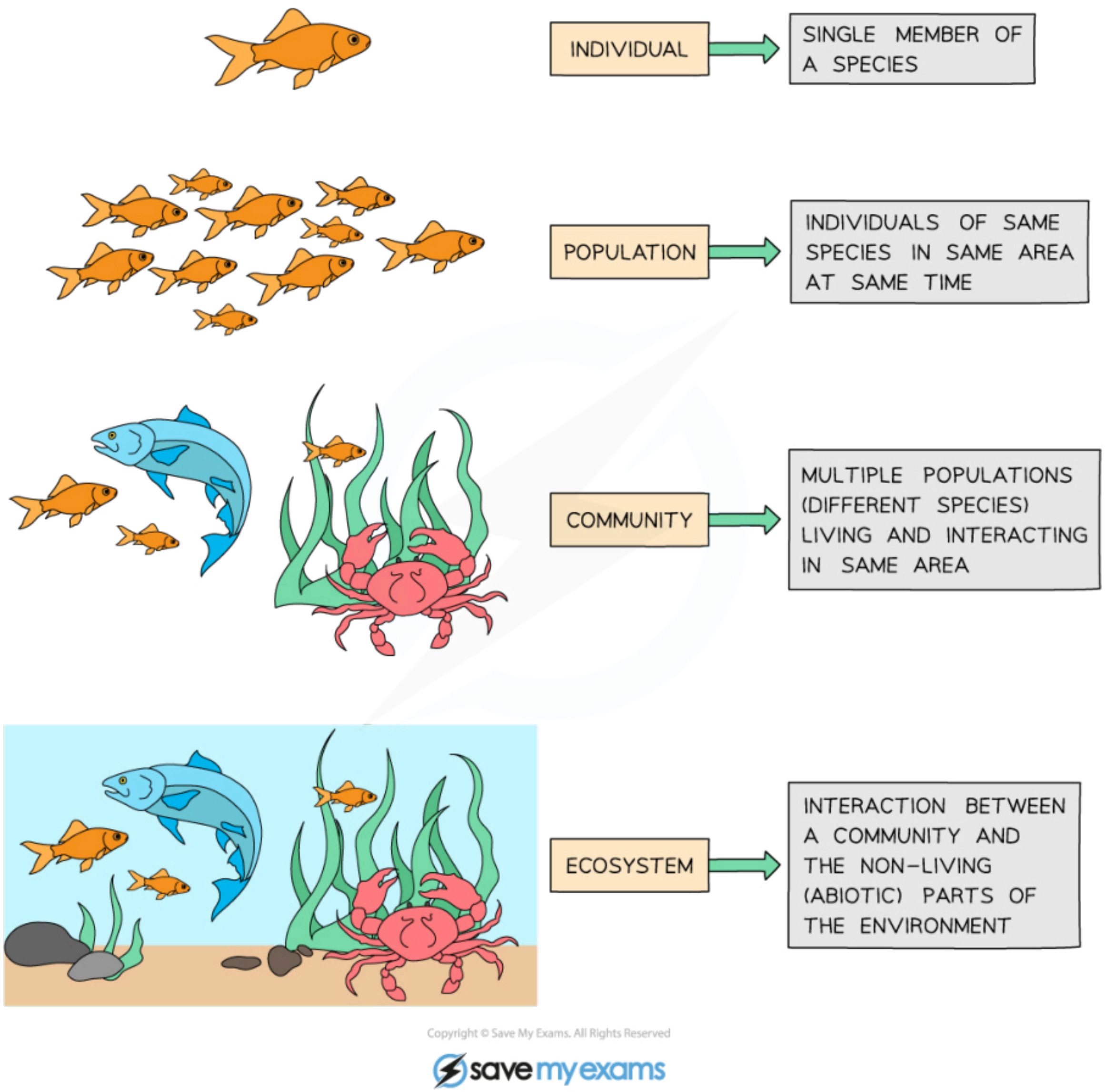
A community and its interactions with the non-living parts of its environment

- Ecosystems are mostly **self-contained**
- There is a **flow of energy** within an ecosystem and the **nutrients** within it are **recycled** (e.g. the carbon, nitrogen and phosphorus cycles)
- There are both biotic components and abiotic components within an ecosystem
- Ecosystems **vary greatly in size and scale**
  - Both a small pond in a back garden and the open ocean could be described as ecosystems
  - A human being could also be described as an ecosystem (there are thousands of species of bacteria living on and in every person)
- Ecosystems **vary in complexity**:
  - A desert is a relatively simple ecosystem
  - A tropical rainforest is a very complex ecosystem
- **No ecosystem is completely self-contained,** as organisms from one ecosystem are often linked with another ecosystem somehow
  - For example, many birds species are able to migrate long distances to find food sources or breeding locations from multiple ecosystems

Example of an ecosystem

- A forest is an example of a complex ecosystem
- There is a large community of organisms including trees, birds, small and large mammals, insects and fungi
- The **abiotic components** of the ecosystem include the soil type, dead leaves, water from the rain and streams, the rocks, and any other physical or chemical factors
- The abiotic components of the ecosystem **influence** the **community** of organisms (e.g. by providing **habitat**, **nutrients** and other resources organisms need in order to survive and reproduce)

Your notes



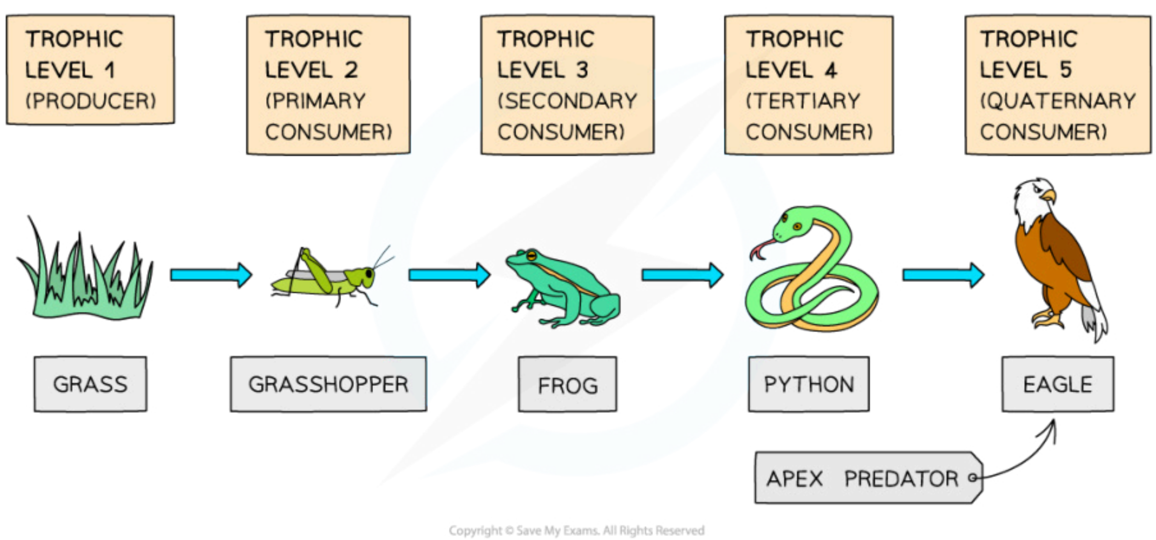
Levels of organisation in an ecosystem

Your notes

4.1.4 Nutrient Cycling

Obtaining Inorganic Nutrients

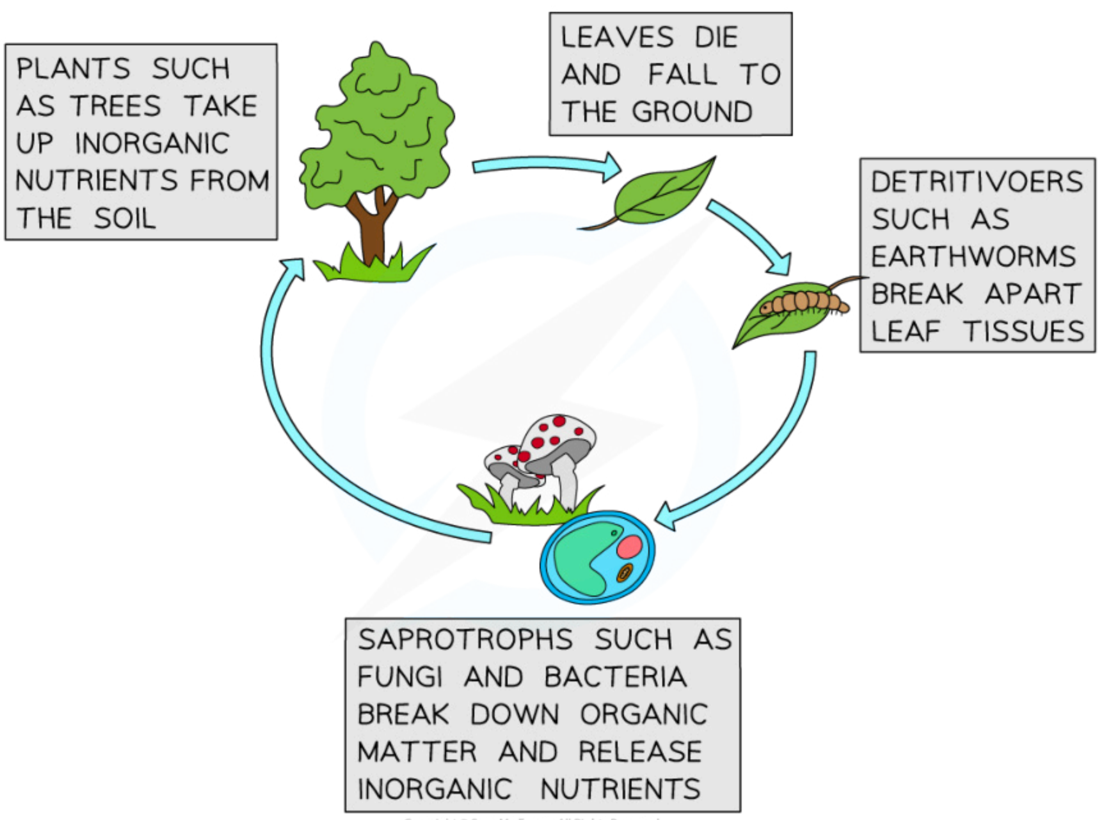
- The individual organisms in an ecosystem need organic molecules to build their cells and tissues
- These molecules contain **carbon, hydrogen, oxygen, nitrogen, and phosphorus,** as well as other elements
- Because these elements are present in the **abiotic environment** (such as the **air** and **soil**) in the form of inorganic compounds or nutrients, ecosystems depend on **producers** to transfer them into the food chain
  - Producers are **autotrophs**, producing organic molecules from inorganic carbon via **photosynthesis**
    - In **terrestrial** (land-based) ecosystems, plants use CO_2 from the **air**
    - In **aquatic** (water-based) ecosystems, plants use CO_2 **dissolved in the water**
  - Plants are also able to **absorb inorganic nutrients such as nitrates and phosphates** from the soil, incorporating them into organic molecules in their tissues as they grow
- The organic molecules in the tissues of producers can then be accessed by other organisms within the community via food chains
  - **Primary consumers** feed on producers, digesting their tissues and absorbing the organic molecules via their digestive system
  - **Secondary consumers** feed on primary consumers, and so on



The inorganic nutrients originally obtained by the producer from the abiotic environment are transferred to other organisms in the community via food chains

Nutrient Cycling

- When inorganic nutrients enter the food chain, they are converted into organic molecules and are **locked up inside the tissues of living plants and animals**
- Because the **supply of inorganic nutrients is finite**, it is essential that when these organisms die the **nutrients locked up in their tissues are released**
  - The organic molecules need to be converted back into inorganic nutrients that can be used by producers
- The process of breaking down the bodies of **dead organisms** and the **waste products** of living organisms is known as **decomposition,** and it enables the **cycling of nutrients**
  - **Detritivores** often begin the process of decomposition by breaking apart tissues
  - **Saprotrophs** release enzymes that break down the organic molecules in the tissues, **releasing inorganic nutrients**
  - While saprotrophs absorb some of these nutrients themselves, what is left in the soil becomes available for producers



The cycling of nutrients in an ecosystem

Your notes

Your notes

Examiner Tip

Remember that while an ecosystem's supply of inorganic nutrients is finite, the supply of energy from sunlight, although it may vary depending on weather conditions, is usually continuous. The concept of nutrient cycling discussed here is separate to the concept of energy flow covered elsewhere; the two ideas should not be confused with each other.

Sustainability of Ecosystems

- In a functioning ecosystem, the elements that living organisms need are **constantly recycled**
  - **Producers** access **inorganic nutrients** from the abiotic environment and convert them into **organic molecules**
  - **Consumers** gain organic nutrients from **ingesting the tissues** of producers and other consumers
  - **Detritivores** and **saprotrophs break down the organic molecules** in dead tissues and waste matter, making them **available again to producers**
- Provided that the conditions are right and this cycling process continues, ecosystems can be sustainable **over long periods of time**
- If nutrient cycling stops then an ecosystem can only be productive until the **finite supply of inorganic nutrients runs out**
  - Without the process of decomposition, nutrients **remain locked up** in dead tissues and cannot re-enter the food chain
- Nutrient cycling might stop if environmental conditions become **unsuitable for decomposition**
  - **Climate change** might cause an ecosystem to become too dry for saprotrophs to survive
  - **Harvesting** or **deforestation** removes organic matter from the environment and leaves nothing for saprotrophs to digest, meaning that the nutrients contained within this organic matter are not recycled back into the ecosystem and are instead completely removed from the ecosystem

4.1.5 Energy Flow

Your notes

Initial Source of Energy

- **The sun is the initial (first) source of energy for most food chains**
  - **Light energy** from the sun **is converted by producers into chemical energy** stored in the tissues of plants during the process of photosynthesis
  - Chemical energy stored in the tissues of plants **passes to primary consumers** when they ingest plants, and **on to secondary consumers** when the primary consumers are themselves ingested
- There are a few unusual exceptions, such as food chains located in deep sea volcanic vents that rely on bacteria gaining energy from chemical processes; these are chemoautotrophic bacteria

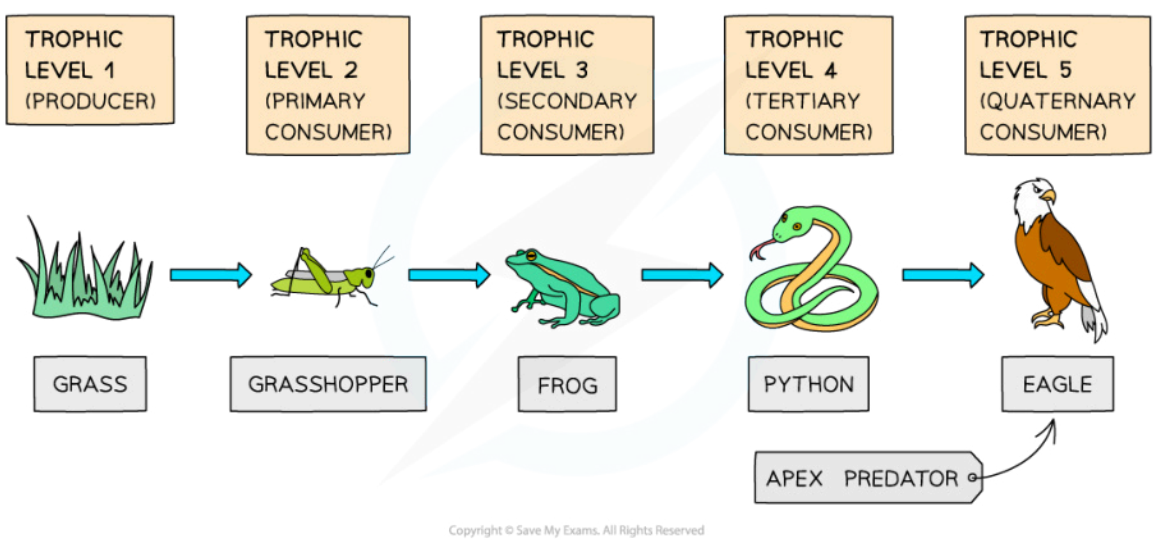
Light Energy Conversion

- **Photosynthesis** is the process of converting light energy into chemical energy
- The photosynthetic pigment chlorophyll **absorbs light energy** when sunlight lands on photosynthesising parts of a plant
- This light energy is used to power several processes which result in the **production of organic molecules,** or **carbon compounds**, including:
  - **Glucose**, which is used in respiration or stored in plant cells in the form of **starch**
  - **Lipids**
  - **Amino acids**
- Hydrolysing these carbon compounds releases energy, so they can be said to contain **stored chemical energy**
- These carbon compounds are used by the plant to build plant tissues, meaning that the energy stored in them is **stored within the tissues of the plant**

Your notes

Energy Flow Through Food Chains

- Chemical energy, stored in **carbon compounds** in plant tissues, is **passed to the primary consumer** when the plant is **ingested**
  - The primary consumer **digests** the plant tissues and **absorbs** the carbon compounds containing **stored chemical energy**
  - These carbon compounds can either be used to fuel **respiration** or to build up animal tissue, meaning that the **stored chemical energy is transferred** to the tissues of the primary consumer
- When the primary consumer is ingested, the **carbon compounds in its tissues,** along with their **stored chemical energy**, pass to the **secondary consumer**, and so on up the food chain
- When an organism dies, the chemical energy stored in carbon compounds in its tissues passes to **detritivores** and **saprotrophs**
- In a food chain, the arrows represent the **transfer of energy**, in the form of stored chemical energy in carbon compounds, from one trophic level to the next, by the process of **feeding**



A simple food chain – the blue arrows show how the chemical energy originally stored by the producer is transferred to other organisms in the food chain

Examiner Tip

Don't forget that the arrows in a food chain or food web represent the transfer of chemical energy from one trophic level to the next through feeding.

Energy Lost by Respiration

Your notes

- The chemical energy stored in ingested carbon compounds can be **released by the process of** respiration
  - The carbon compound **glucose** is the fuel for respiration
  - Other carbon compounds such as lipids **can be converted into glucose** before being respired
- The energy released during respiration can be used by organisms to carry out the **functions of life**
  - **M**etabolism - the enzyme-catalysed reactions taking place inside cells
  - **R**eproduction - the sexual or asexual production of offspring
  - **H**omeostasis - the maintenance of internal conditions within tolerable limits
  - **G**rowth - increasing in size
    - Note that during growth some of the chemical energy in the **carbon compounds** ingested by an organism is **incorporated into the tissues** of the organism as it grows; this **stored chemical energy can be passed to the next trophic level** in the food chain
  - **R**esponse - sensing and responding to the environment
  - **E**xcretion - disposal of metabolic waste
  - **N**utrition - gaining energy and nutrients
- The process of respiration also **releases heat as a by-product**

Energy Conversions

- The process of **respiration** in living organisms **releases heat as a by-product**
  - This applies in **producers, consumers, detritivores**, and **saprotrophs**
- Living organisms **cannot convert the heat energy that is released as a by-product of respiration into any other form of energy**
- This means that **heat energy is lost** from food chains at every trophic level, as well as during decomposition
- This **heat energy** is ultimately **lost to the environment**
- Ecosystems have enough energy to be sustainable because energy is always entering food chains via producers as **they capture light energy from the sun**

Examiner Tip

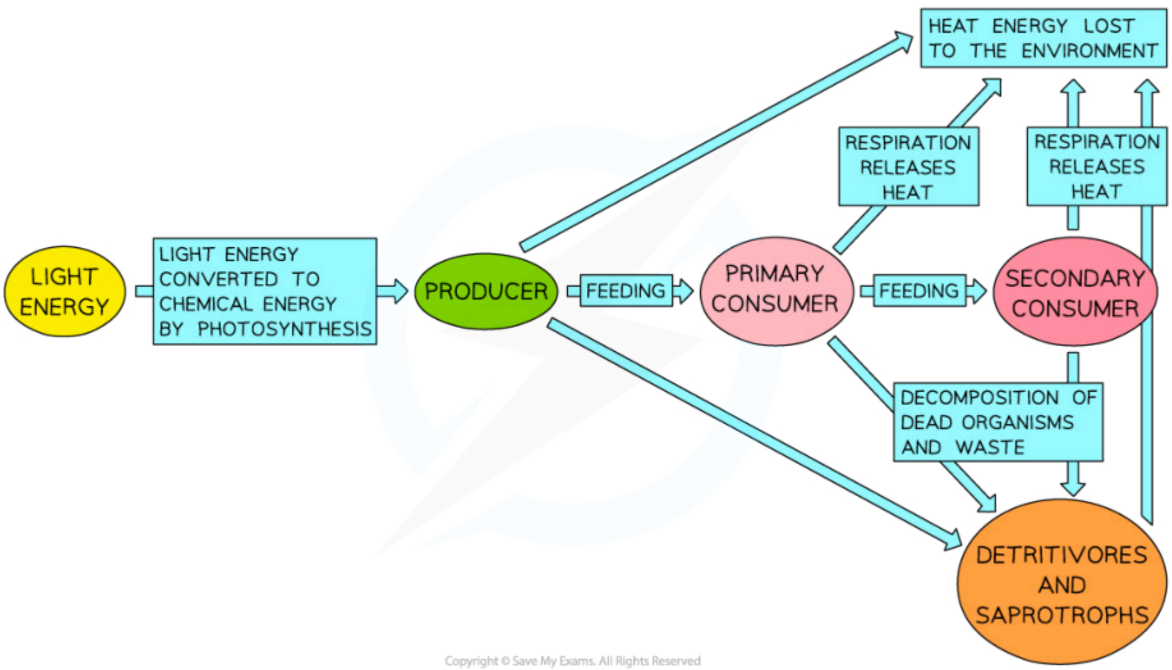
Be careful with your language when discussing energy. You should always describe energy as being released, stored, converted (from one form to another), or transferred (e.g. lost to the environment), never as being produced, made, or destroyed.

4.1.6 Energy Losses

Your notes

Wasted Energy – Heat

- The process of **respiration** in living organisms **releases heat as a by-product**
  - This applies in **producers, consumers, detritivores**, and **saprotrophs**
- This **heat energy is lost from ecosystems to the environment** at every trophic level, and during decomposition

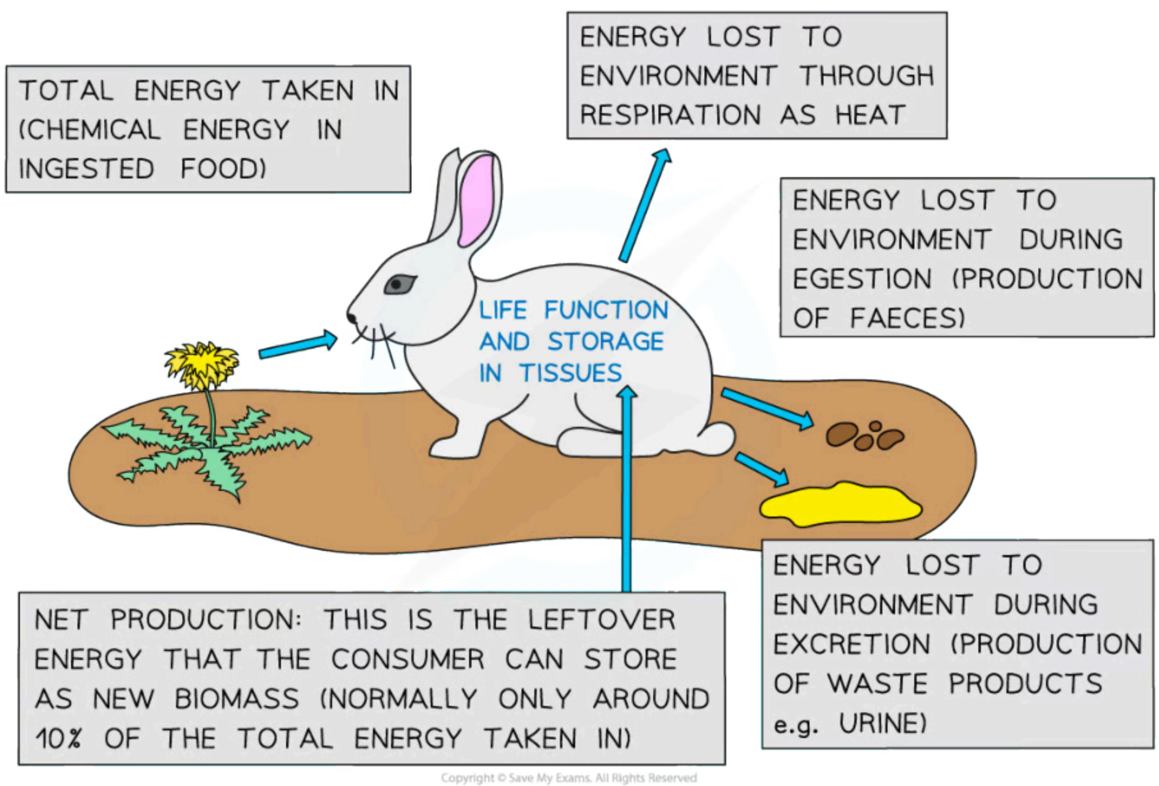


Heat energy released during respiration is lost to the environment at every stage of the food chain

Your notes

Energy Losses between Trophic Levels

- When a consumer ingests another organism **not all the chemical energy in the consumer's food is transferred to the consumer's tissues**
  - **Only around 10%** of the energy is available to the consumer to store in their tissues
  - This is because **around 90%** of the energy is **lost to the environment**
- Around 90% of the energy is lost to the environment because
  - **Not every part of the food organism is eaten,** e.g. the roots and woody parts of plants or the bones of animals, meaning that the chemical energy these uneaten tissues contain is **lost** to the **environment**
  - Consumers are **not able to digest** all of the food they ingest, e.g. cellulose in plants, or the fur of animals, so some is **egested** as **faeces**; the chemical energy in this undigested food is also lost to the environment
  - Energy is lost to the environment in the form of **heat** when consumers **respire**
  - Energy is lost to the environment when organisms **excrete** the waste products of metabolism e.g. urea in urine
- The energy that is left after these losses **is available to the consumer** to fuel their **life functions,** including being stored in **carbon compounds in their tissues during growth**



Energy is lost from the food chain as heat during respiration, due to incomplete digestion, and through excretion of the waste products of metabolism. Remaining energy fuels the organism's life processes or is stored in carbon compounds in the tissues.

Your notes

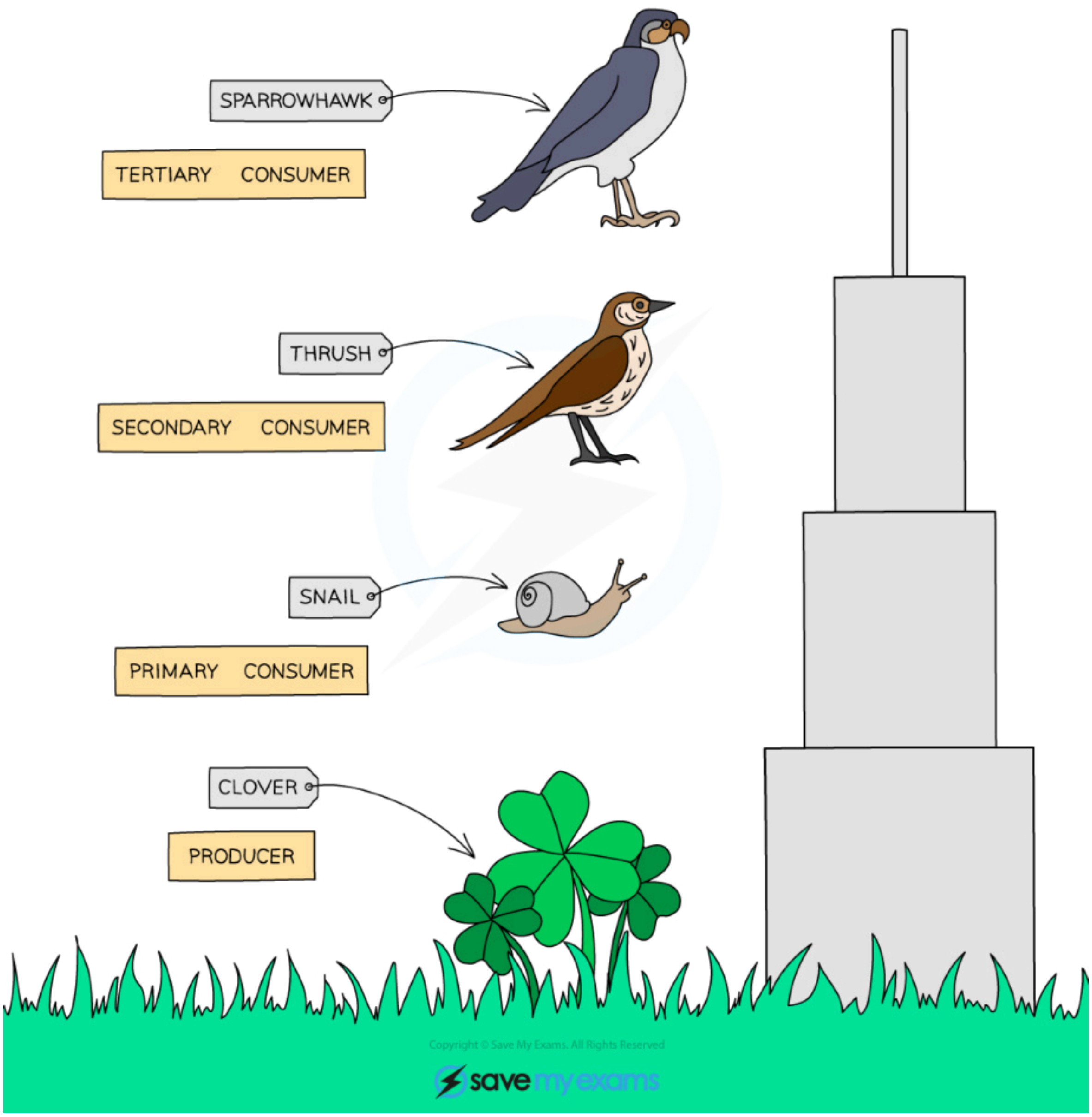
NOS: Use theories to explain natural phenomena; the concept of energy flow explains the limited length of food chains

- Scientists can gather information about the world by **observing events**, or **phenomena**, before **formulating theories** that seek to explain those events
- In the case of food chains:
  - Scientists **observe** that food chains are short and have a pyramid structure
  - **Theories** of energy flow and energy losses can provide an explanation for these phenomena

- **Food chains are limited in length**
  - Food chains rarely have more than around four or five trophic levels; this is because with energy losses at each trophic level, there is **less and less energy available to the consumer** as you go up the food chain
  - When a food chain gets longer than four or five trophic levels it becomes too difficult for a predator to hunt enough prey to gain the energy to survive

- Biomass **decreases with each trophic level**
  - Because only around 10% of the energy stored in a producer's tissues is available to a primary consumer, **primary consumers needs to consume a large amount of plant biomass to gain enough energy to survive**
  - Again, only around 10% of the energy stored in a primary consumer's tissues is available to a secondary consumer, meaning that **secondary consumers need to consume a large amount of prey biomass to gain enough energy to survive**
  - This leads to a large reduction in biomass at each trophic level and means that when represented in terms of biomass, food chains have a **pyramid** structure

Your notes



The biomass at each trophic level of a food chain can be represented as a pyramid of biomass. The pyramid shape results from the energy losses at each trophic level.

Examiner Tip

Make sure that you know the different ways that energy can be lost from a food chain and that you can explain the effects that these losses have on food chain structure.Be careful not to mix up pyramids of biomass with pyramids of energy.

Your notes

4.1.7 Skills: Species, Communities, Ecosystems & Energy Flow

Identification of Trophic Level

Classifying species as autotrophs, consumers, detritivores, or saprotrophs

- A species can be classified as an autotroph, consumer, detritivore, or saprotroph on the basis of its mode of nutrition

Autotrophs

- An **autotroph** synthesises, or produces, its own organic molecules from simple inorganic substances in its environment
  - **Photosynthetic organisms** use **light energy** to convert **carbon dioxide from the air** into organic molecules such as **carbohydrates**
  - Some autotrophs use energy from the oxidation of inorganic compounds instead of light energy
  - Autotrophs that use light energy are known as **photoautotrophs**, while those that use energy from oxidation of chemicals are known as **chemoautotrophs**
- Because autotrophs make their own organic molecules without relying on other organisms, they are known as **producers**
- Most **green plants** are autotrophs, with few exceptions
  - Some unusual plants are parasitic, gaining their nutrients from the roots of host plants, or via networks of fungi in the soil

Heterotrophs

- **Heterotrophic organisms** gain their organic molecules from **other organisms**
- There are several types of heterotroph, including **consumers, detritivores,** and **saprotrophs**

Consumers

- **Consumers** gain their organic molecules by ingesting the tissues of other living or recently dead organisms
- The consumers that eat plants are known as herbivores, and are the **primary consumers** in a food chain
- The consumers that eat other animals are carnivores, and those that eat the primary consumers are **secondary consumers**
- Carnivores that eat secondary consumers are **tertiary consumers**

Detritivores

- **Detritivores** gain organic molecules by **ingesting the tissues of dead organisms** or ingesting **animal waste**
- Detritivores digest their food inside their bodies
- Examples of detritivores include earthworms, woodlice and dung beetles

Saprotrophs

- **Saprotrophs** also gain their organic molecules from **dead matter**, but they **digest their food externally**
- Saprotrophic organisms **secrete enzymes** onto dead matter, and these enzymes **break down the food before nutrients are absorbed**
- Saprotrophs include fungi and bacteria

Your notes

Classifying Species as Autotrophs, Consumers, Detritivores, or Saprotroph Table

Species	Method of gaining organic molecules	Mode of nutrition
Common pin mould	Secretion of multiple enzymes onto dead plant material	Saprotrophic
Common nettle	Conversion of carbon dioxide from the air into carbon compounds using light energy	Autotrophic
Barn owl	Hunts and eats small rodents	Consumer (secondary)
White legged snake millipede	Ingests dead plant matter	Detritivore
Roe deer	Feeds on grass, leaves, and berries	Consumer (primary)

Examiner Tip

The two main modes of nutrition are autotrophism and heterotrophism, and within those modes are different types e.g. a heterotroph can be a consumer, a detritivore, or a saprotroph depending on its food source and its method of digestion

Practical 5: Mesocosm – Sustainable Ecosystem

Reasons for building mesocosms

- A **mesocosm** is an experimental container in which a **naturally occurring** ecosystem **is simulated**
- Mesocosms can be used to **study the response of an ecosystem to changes in specific factors** such as nutrient and light levels
- Unlike a real ecosystem, it is possible in a mesocosm to **control all of the factors other than the variable being studied**
- Mesocosms can be set up in many different ways for many purposes
  - Water tanks can be set up on land to study the effect of sewage pollution on ponds or lakes
  - Underwater enclosures can be built in coastal waters or lakes to study the effect of temperature change or dissolved carbon dioxide on ocean ecosystems
  - Trees can be planted in large greenhouse-like buildings to replicate a rainforest to investigate the passage of carbon through this ecosystem
- Mesocosm experiments can be **considered unrealistic** due to their enclosed nature and the level of control that can be achieved
  - **Realism can be improved** by designing large mesocosms that share more of the features of a real ecosystem e.g. enabling mixing of layers of water in a large ocean mesocosm

Building a mesocosm in the lab

- It is possible to build small mesocosms in the laboratory
- Factors to consider:
  - The container should be **transparent** to **enable sunlight to reach producers** inside the mesocosm
  - **Autotrophs** should be included so that **light energy** can be converted into **chemical energy** inside the mesocosm
  - Small primary consumers such as zooplankton or other small invertebrates could be included, but it is important to consider whether the mesocosm is likely to be large enough to support them
  - Do not include secondary consumers in a mesocosm because there will not be enough energy in the food chain to sustain them for long, and it could be considered **unethical** to allow the primary consumers to be eaten in this way
- Mesocosms can be set up as open systems, i.e. without a lid, but sealed systems are **more controlled**, and therefore more useful for experimental purposes
  - Sealed systems prevent organisms and substances from entering or leaving
- In the lab, a mesocosm can be set up and then a **known factor can be altered** to assess its effect
  - E.g. different **light** levels, different **temperatures** etc.
- In order to assess the impact of changing one factor, a **control** mesocosm must be set up at the same time
  - A control mesocosm will be **exactly the same** as the experimental mesocosm, **but the altered variable will not be changed**
  - The purpose of this is to demonstrate that any change in the mesocosm is **due to the altered factor and not another factor**

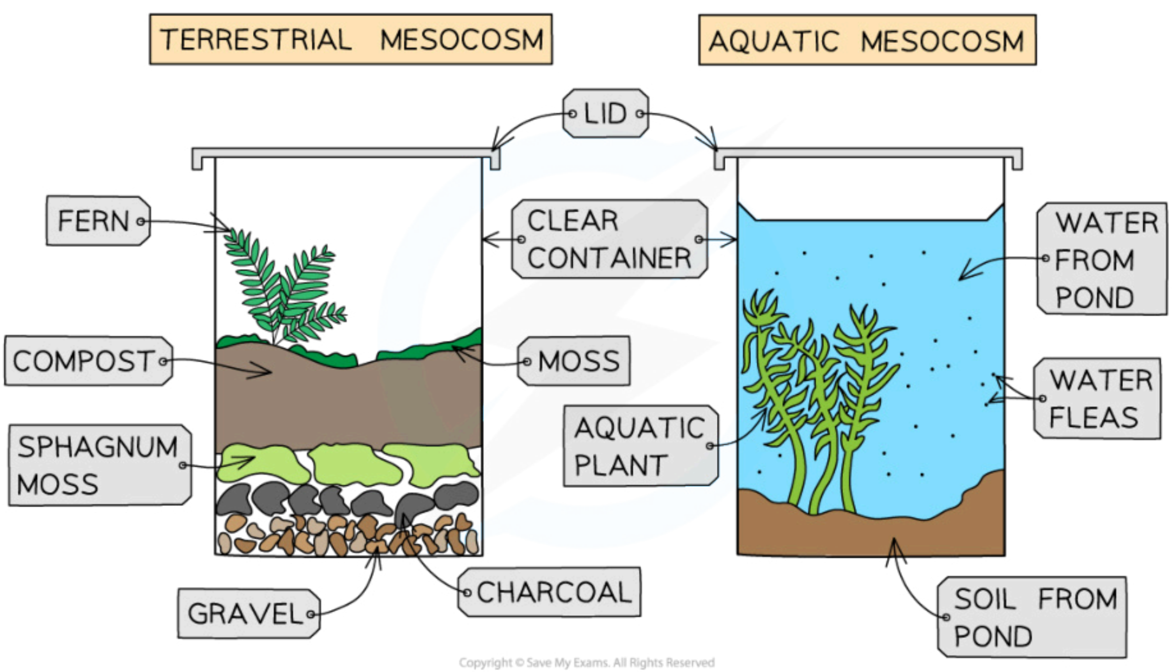
Your notes

Terrestrial mesocosm

- Place **drainage material** such as gravel in the bottom of a clear container
- Add a layer of charcoal on top of the drainage layer; this can help to prevent the growth of mould
- Place a layer of sphagnum moss or filter paper on top of the charcoal to **provide separation** between the base layers and the organic matter above
- Add a layer of soil or compost above the separation layer; this provides **organic material and micro-organisms** to aid with nutrient cycling
- Plant **slow-growing producers** such as healthy mosses and ferns in the growth medium
- Water the growth medium before sealing the container with a lid
  - The mesocosm may need watering while it establishes, but **avoid excessive watering**; once the mesocosm has stabilised, the plants should release enough water vapour during respiration to maintain moisture levels
- Place the container in a **light location**, and ensure that the **temperature is stable**

Aquatic mesocosm

- The base layer of the mesocosm should consist of **organic substrate** from the bottom of a lake or pond; this will provide naturally occurring nutrients and microorganisms
- Add **lake or pond water**; this ensures that it contains the required microscopic organisms and avoids chemicals from tap water
- Add **healthy aquatic plants** to produce carbohydrates and **oxygenate the water**
- Small aquatic organisms such as water fleas or water snails can be added, but not more organisms than the size of mesocosm can support
- Place the container in a **light location**, and ensure that the **temperature is stable**



Building a terrestrial or aquatic mesocosm

Your notes

4.1.8 Skills: Chi-squared test & Statistical Significance

Your notes

Chi-squared Test for Association

Looking for associations between species

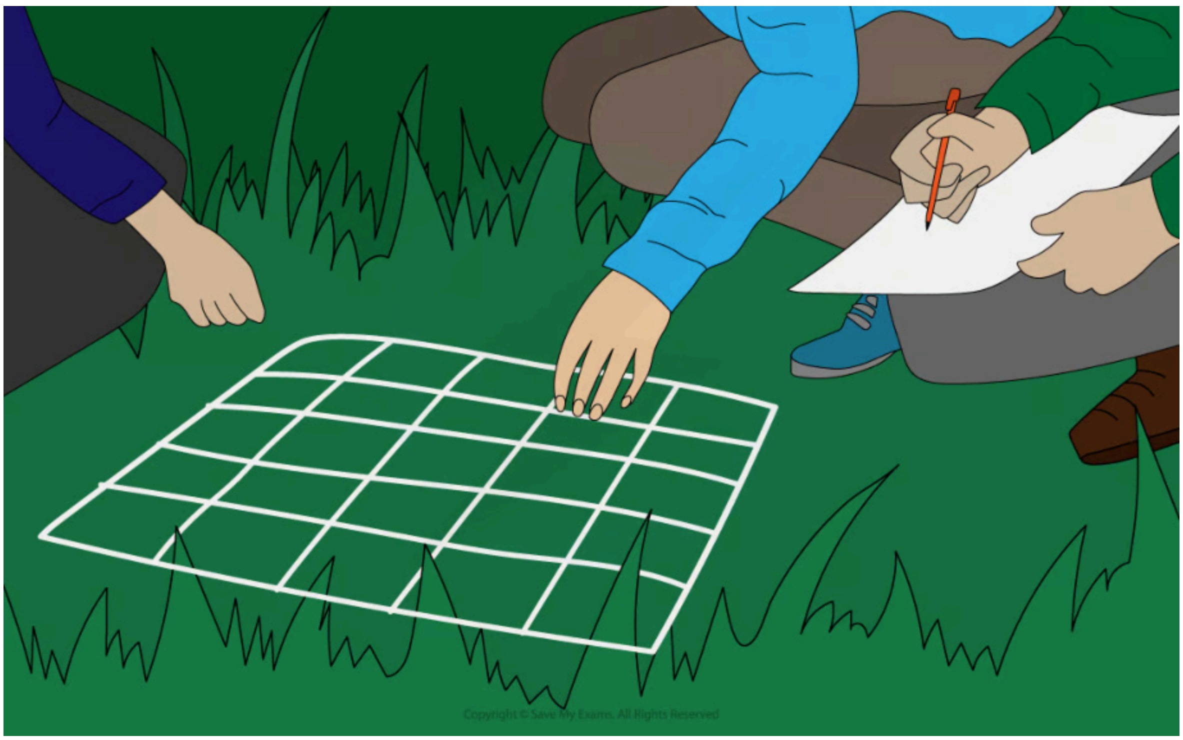
- The distribution of species in a habitat is **rarely random**; it usually depends on factors such as soil type, water availability, and competition
- It is sometimes possible to observe an **association** between the distributions of different species within a habitat, e.g.
  - Species that are in a symbiotic relationship are likely to be **found next to each other**; we would say that there is **a positive association between the distributions of these two species**
  - Species that are in **direct competition** for the same resources will exclude each other from their immediate surroundings, and so are likely to be **found in different parts of a habitat**; there might be a **negative association between the distributions of these two species**
- If species have **no interaction** with each other, then there will be **no association between their distributions**, and any that appears to occur will be **due to chance**
  - We would say that such species have distributions that are **independent** of each other
- **Random sampling** with **quadrats**, along with a statistical test called the **chi-squared test**, can be used to test for an **association between two species**

Using quadrats to study the distribution of species

- A **quadrat** is a **square frame** that is placed within the area to be studied to provide a **sample**
  - Quadrats are used to study the **distribution** of sessile organisms
  - Quadrats can be **different sizes** depending on the species being studied
    - A 1 m^2 quadrat can be used to study small organisms such as herbaceous plants in a grassland or limpets on a rocky shore
    - A 400 m^2 quadrat can be used to study large organisms such as trees (quadrats like this will usually be marked out with string rather than a frame!)
  - Scientists can record **different types of data** from a quadrat depending on the aim of a study and the species involved
    - **Presence or absence** of a species
    - **Species frequency**; how many individuals are in the quadrat
    - **Species abundance**; measured on a scale called the **ACFOR** scale on which species are recorded as being abundant, common, frequent, occasional, rare, or none
    - **Percentage cover**; the percentage of the quadrat covered by a species
  - Quadrats can be divided up into smaller squares to allow percentage cover to be assessed more easily
- The use of quadrats enables researchers to obtain data that is a **representative sample** for the habitat being studied

  - Often an area being studied is very large and it is impractical to record data across an entire habitat, so quadrats provide small **samples** that **represent** the whole habitat
- For a sample to be representative, it needs to be:
  - **Large enough**; the larger and more diverse a habitat, the more quadrats need to be used
  - **Random**; this avoids bias e.g. when a student decides to place their quadrats in a particular place because it looks more interesting

- Randomness can be achieved by dividing a habitat up into **grid squares** and then using a **random number generator** to decide where to place each quadrat



Random sampling with quadrats can be used to study the distribution of organisms

The chi-squared test

- A statistical test called the **chi-squared test** determines whether there is a **significant difference** between the **observed and expected results** in an experiment
  - Its purpose is to assess whether any difference in these results is **due to chance**, or **due to an association** between the variables being tested

- A chi-squared test can be used to analyse data from quadrat sampling to determine whether or not there is a **statistically significant association** between the distributions of two species
  - To the eye there may appear to be an association between the two species, but if it is **not statistically significant** then researchers can conclude that species distributions are independent of each other, and any appearance of association is **due to chance**

Your notes

- If an association **is statistically significant** then it must be due to **an important factor**, such as a symbiotic relationship
- A chi-squared test enables scientists to test hypotheses
  - A **hypothesis** is a **testable statement** about the expected outcome of an experiment
  - There are two types of hypothesis:
    - A **null hypothesis** states that there is **no significant difference, or association,** between data sets e.g. that there is no association between the distributions of two species
    - An **alternative hypothesis** states that there is **a significant difference, or association**, between data sets e.g. that there is an association (either positive or negative) between the distributions of two species
- The result of a chi-squared test enables scientists to either **accept** or **reject** a **null hypothesis**

Using the chi-squared test to test for association

- Step 1: Construct a **contingency table** for your results
  - This allows the number of quadrats that contain one, both, or neither species to be recorded
- Step 2: Calculate the row, column, and overall totals for your contingency table
- Step 3: Calculate the **expected** values (E) for your table
  - The results recorded in the contingency table are the **observed values** (O); to calculate the chi-squared value we need to calculate the **expected values** for each data point.
  - The expected values are what we would expect to see **if the null hypothesis were correct**
  - Note that this is the first step towards calculating the **chi-squared value**, the equation for which is:

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

Σ = sum of   O = observed value   E = expected value

- Step 4: Calculate the **difference** between the observed and expected values
  - Subtract the expected values from the observed values (O - E); some of the resulting values will be negative
- Step 5: Square each difference
    - This eliminates negative values
- Step 6: Divide each squared difference by the expected value
- Step 7: Add all of the results from step 6 together
  - This gives the **chi-squared value**
- Step 8: Calculate the **degrees of freedom**
- Step 9: Establish a **probability** level or **p-value**
  - As biologists, we work with a probability level of **0.05**, or **5%**
  - This means that we can be 95% certain that any significant difference or association is **not due to chance**

Your notes

- Some studies require a higher level of certainty than this e.g. medical researchers may use a smaller p-value
- Step 10: Use a **critical values table** and the results of steps 8–9 to find the critical value
    - In order to understand what the chi-squared value says about the data, a table relating chi-squared values to probability is needed; this **critical values table** displays the probabilities that the differences between expected and observed values are due to chance
- Step 11: Compare the chi-squared value with the critical value to assess **the significance**

Worked example

A researcher decided to test for an association between the distribution of two types of mollusc on a rocky shore; limpets and dog whelks. Their **null hypothesis** was that there was no association between the distributions of limpets and dog whelks.They carried out 50 randomly placed quadrat samples on the rocky shore, recording either the presence or the absence of both limpets and dog whelks in each quadrat.They obtained the following results:

- Quadrats containing limpets only: 14
- Quadrats containing dog whelks only: 21
- Quadrats containing both limpets and dog whelks: 7
- Quadrats containing neither limpets nor dog whelks: 8

Use the chi-squared test to determine whether or not there is a **statistically significant association** between the distributions of limpets and dog whelks.

Step 1: Construct a contingency table

Contingency Table

	Limpets present	Limpets absent
Dog whelks present	7	21
Dog whelks absent	14	8

Step 2: Calculate the row, column, and overall totals for your contingency table

Contingency Table

	Limpets present	Limpets absent	Row total
Dog whelks present	7	21	28
Dog whelks absent	14	8	22
Column total	21	29	50

Step 3: Calculate the expected values

The equation for working out the expected values is:

$$\frac{\text{row total x column total}}{\text{overall total}}$$

E.g. to calculate the expected value for the category in which both dog whelks and limpets are present:

$$\frac{28 \times 21}{50} = 11.76$$

Step 4: Calculate the difference between the observed and expected values

O = 7

E = 11.76

7 - 11.76 = -4.76

Step 5: Square each difference

$-4.76^2 = 22.66$

Step 6: Divide each squared difference by the expected value

22.66 ÷ 11.76 = 1.93

Repeat steps 3–6 for all of the results in the contingency table

Chi-squared Working Out Table

Your notes

	O	E	O–E	$(O-E)^2$	$(O-E)^2/E$
Limpets only	14	9.24	4.76	22.66	2.45
Dog whelks only	21	16.24	4.76	22.66	1.4
Both dog whelks and limpets	7	11.76	−4.76	22.66	1.93
Neither dog whelks nor limpets	8	12.76	−4.76	22.66	1.78

Step 7: Add all of the results from step 6 together to obtain the chi-squared value

2.45 + 1.4 + 1.93 + 1.78 = 7.56 (this is the **chi-squared value**)

Step 8: Calculate the degrees of freedom

Degrees of freedom can be calculated using the following equation:

Degrees of freedom = (number of columns - 1) x (number of rows - 1)

Columns and rows refer to the original contingency table.

In this example, there are 2 columns and 2 rows in the contingency table

Degrees of freedom = (2 - 1) x (2 - 1)

= 1 x 1

= 1

Step 9: Determine the probability level

As biologists, we work at a **probability of 0.05,** or **5%**

Step 10: Use a critical values table and the results of steps 8–9 to find the critical value

Chi-squared Critical Values Table

Degrees of freedom	Probability that the difference between observed and expected results is due to chance			
	0.1	0.05	0.01	0.001
1	2.71	3.84	6.64	10.83
2	4.60	5.99	9.21	13.82
3	6.25	7.82	11.34	16.27
4	7.78	9.49	13.28	18.46

With **degrees of freedom** as **1**, and a **probability level** of **0.05**, the **critical value** can be read from the table as **3.84**

Step 11: Compare the chi-squared value with the critical value to assess significance

The chi-squared value of 7.56 **is larger than** the critical value of 3.84

This means that there **is a significant association** between the two species (see section below on statistical significance)

Examiner Tip

When calculating a chi-squared value it is very helpful to create a table like the one seen in the worked example. This will help you with your calculations and make sure you don't get muddled up!

Your notes

Statistical Significance

Your notes

- The **chi-squared value**, once calculated, can be compared to a **critical value**; this allows **statistical significance** to be **assessed**
- If the chi-squared value is **larger** than the critical value, there is a **statistically significant difference** between observed and expected values, or a **statistically significant association** between two sets of results
  - In this case, the **null hypothesis** can be **rejected**
- If the chi-squared value is **equal to or smaller than** the critical value, there is no **statistically significant difference** between observed and expected values, or no **statistically significant association** between two sets of results
  - In this case, the **null hypothesis** can be **accepted**
- To determine the critical value biologists generally use a **probability level**, or **p-value**, of **0.05**, or **5%**
  - This means that if a difference or association is shown to be statistically significant **at this level**, there is only a **5% probability (i.e. probability = 0.05) that this result might be due to chance**

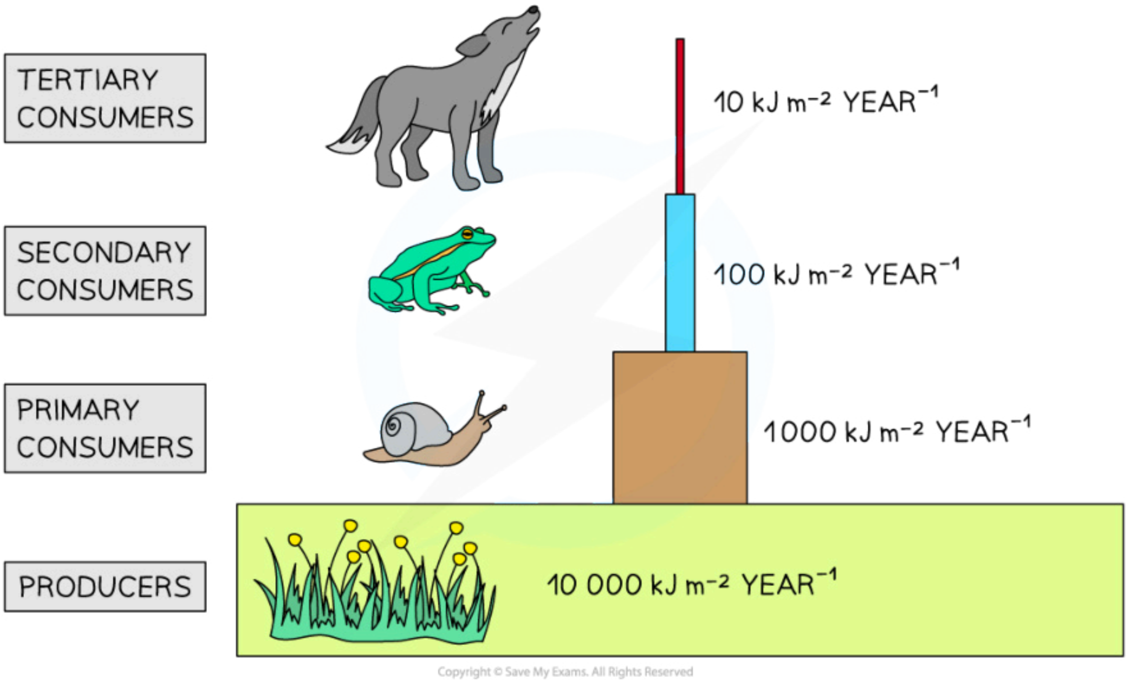
4.1.9 Skills: Pyramids of Energy

Your notes

Pyramids of Energy

- Pyramids of energy illustrate the **amount of energy contained** within the biomass of organisms at each trophic level
- The **length** of each box, or bar, represents the quantity of energy present
  - Pyramids of energy **should be drawn to scale** so that each bar is **proportional** in size to the amount of energy that it represents
  - In some situations, however, a pyramid of energy may be an approximate sketch where each bar is a rough representation of the energy contained
- These pyramids are always **widest at the base** and decrease in size as they go up
  - The base is wide due to the large amount of energy contained within the biomass of producers
- Pyramids of energy show a **stepped decrease** in the energy contained at each level of the food chain rather than appearing as pyramid with smooth sides
- The levels of a pyramid of energy should be labelled **producer**, **first consumer**, **second consumer**, and so on
- The units used should be the amount of **energy, per unit area, per year** e.g. kJ m^{-2} $year^{-1}$
- As you move up the pyramid to higher trophic levels, the quantity of energy decreases as **not all energy is transferred** to the biomass of the next trophic level (roughly 10 % of the energy is passed on)
- Energy is lost at each trophic level due to
  - Incomplete consumption
  - Incomplete digestion
  - Loss of heat energy to the environment during respiration
  - Excretion of the waste products of metabolism e.g. carbon dioxide, water, and urea
- As a result of this, the biomass at each trophic level will also decrease as energy availability decreases

Your notes



The energy stored in the biomass of organisms can be represented by a pyramid of energy

Examiner Tip

Remember that pyramids of energy should be drawn to scale and the units used should be the amount of energy, per unit area, per year e.g. kJ m^{-2} $year^{-1}$