DP Biology – C4.2

Transfers of energy and matter

- Why can matter be recycled in ecosystems when energy cannot?
- What makes up for the energy that each group of living things in an ecosystem loses?

SL statements C4.2.1–22. Textbook pp. 578–601.
Image: tropical forest in Thailand. Vyacheslav Argenberg, CC BY 4.0.



Objectives for each class

Class	Statements	By the end of the class, you can...
1	C4.2.1–5	Explain open systems and sunlight as the energy source, draw food chains and webs, and describe how decomposers get energy
2	C4.2.6–10	Compare autotrophs, including chemoautotrophs, with heterotrophs, and assign trophic levels
3	C4.2.11–14	Draw energy pyramids, and explain energy losses, heat, and how many trophic levels are possible
4	C4.2.15–16	Compare primary and secondary production, and use the units correctly
5	C4.2.17–19	Draw the carbon cycle, explain carbon sinks and sources, and explain combustion
6	C4.2.20–22	Analyse the Keeling curve, and explain interdependence and the recycling of elements

Ecosystems are open systems

C4.2.1

System	Energy	Matter
Open	Enters and leaves	Enters and leaves
Closed	Enters and leaves	Cannot enter or leave

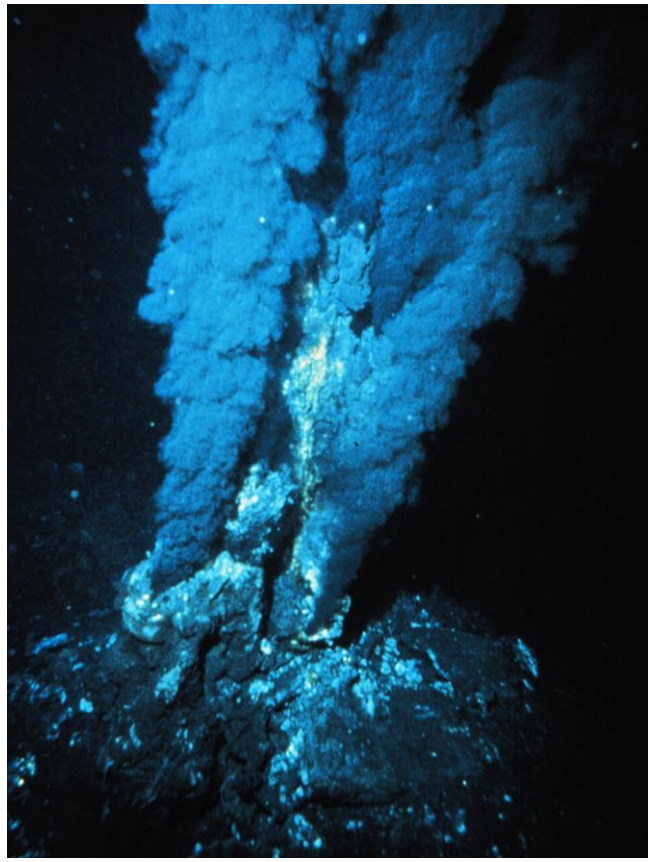
- Ecosystems are open: for example, sunlight enters, heat leaves, and animals or seeds move in and out
- A sealed bottle with plants in it is close to a closed system

Discussion

A sealed bottle garden has survived for decades. What must enter it and leave it? Why is light essential, and why can it survive with no new matter?

Sunlight sustains most ecosystems

C4.2.2



Black smoker vent. P. Rona, OAR/NURP, public domain.

- Producers use light to make carbon compounds
- Consumers depend on sunlight indirectly, by feeding on producers or on other consumers

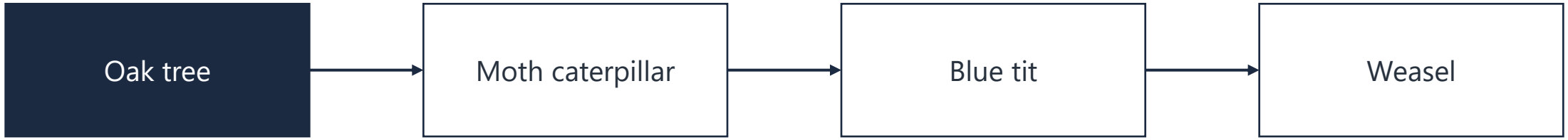
Exceptions

Caves and the deep ocean get no light. In caves, streams and bats bring in dead organic matter, and some bacteria use chemical energy. At deep-sea vents, bacteria oxidize sulfur compounds to make carbon compounds, and they support whole communities.

In water, light is absorbed as it passes down, so producers are limited to the upper layers.

Food chains

C4.2.3



- A food chain shows the flow of chemical energy through a sequence of organisms
- Each feeds on the previous organism, and chemical energy passes on as it does

Common mistake

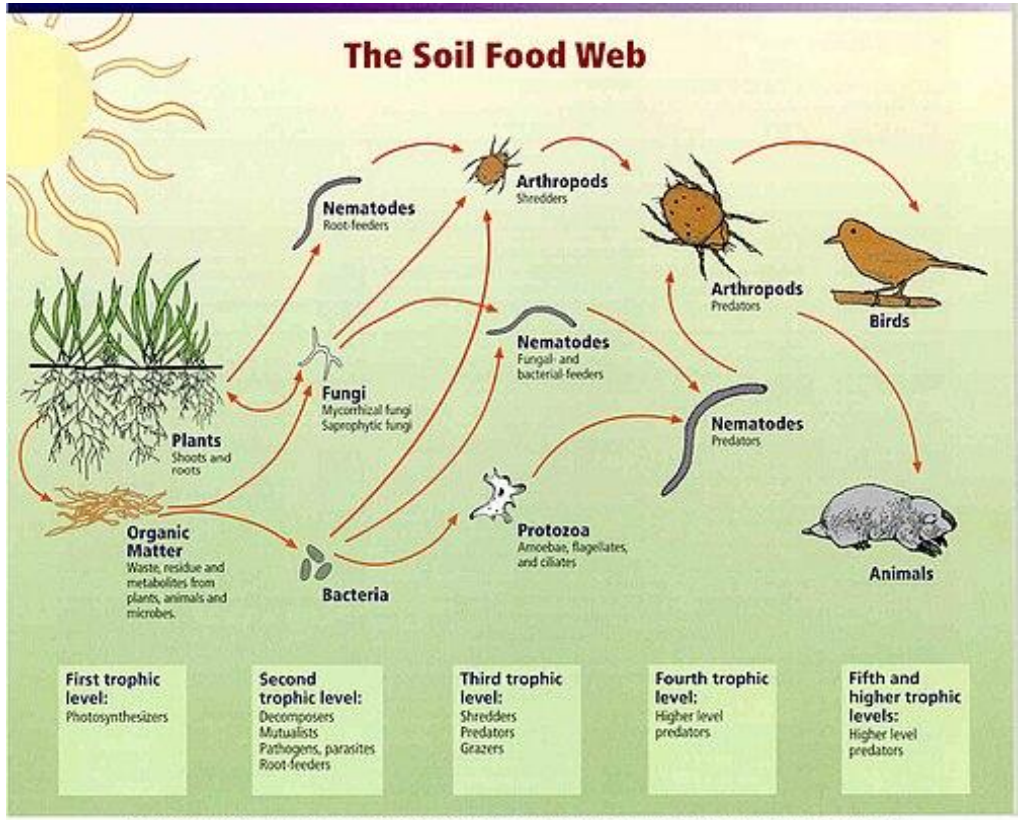
Arrows show the direction of energy and biomass transfer. They point to the organism that eats. They do not mean "is eaten by" in reverse.

Activity

Build a food chain with at least four organisms from your own area. Name the producer and each consumer.

Food webs

C4.2.4



Relationships between soil food web, plants, organic matter, and birds and mammals
Image courtesy of USDA Natural Resources Conservation Service
http://soils.usda.gov/sqi/soil_quality/soil_biology/soil_food_web.html.

The soil food web. USDA, public domain.

- A **food web** joins many food chains together
- Many consumers have a varied diet, so they appear at more than one place
- Arrows show transfer of energy and biomass

Activity

Draw a food web from a list of local species. What might happen if one species were removed?

Decomposers get energy from dead matter

C4.2.5



Earthworm. USDA NRCS, public domain.

- Energy reaches decomposers as carbon compounds in **dead organic matter**
- This includes faeces, dead parts of organisms and dead whole organisms
- Saprotrophs secrete enzymes and absorb the products
- Detritus feeders such as earthworms ingest the dead matter



Fungi. Bernard Spragg, public domain.

Key idea

Decomposers release energy in cell respiration, and as they do so they recycle elements, which return to the environment and become available to producers.

Autotrophs

C4.2.6–7

- **Autotrophs** use an external energy source to make carbon compounds from simple inorganic molecules
- Energy is needed both for fixing carbon, and for the reactions that build macromolecules

Type	Energy source	Examples
Photoautotroph	Light	Plants, algae, cyanobacteria
Chemoautotroph	Oxidation reactions	Iron-oxidizing bacteria, sulfur bacteria at deep-sea vents

Example: iron-oxidizing bacteria

These bacteria oxidize iron(II) ions, Fe^{2+}, to iron(III) ions. The reaction releases energy, which is used to make ATP. ATP then supplies the energy to fix carbon dioxide. Oxidation reactions release energy, which is why they are useful to living organisms.

Heterotrophs, and energy release in respiration

C4.2.8–9

- **Heterotrophs** take in carbon compounds from other organisms, and use them to build what they need
- Proteins and nucleic acids are digested, internally or externally, and the products are assimilated

	Consumers	Saprotrophs
Food	Living or recently killed organisms	Dead organic matter
Digestion	Mostly internal	External

Both groups respire

Autotrophs and heterotrophs both release energy by oxidizing carbon compounds in cell respiration. This powers active transport, movement, and making large molecules. Plants respire too, all the time and not only at night.

Trophic levels

Level	Name	Example
1	Producer	Oak tree
2	Primary consumer	Caterpillar
3	Secondary consumer	Blue tit
4	Tertiary consumer	Weasel

Remember

An omnivore can be at more than one level, because its diet varies.

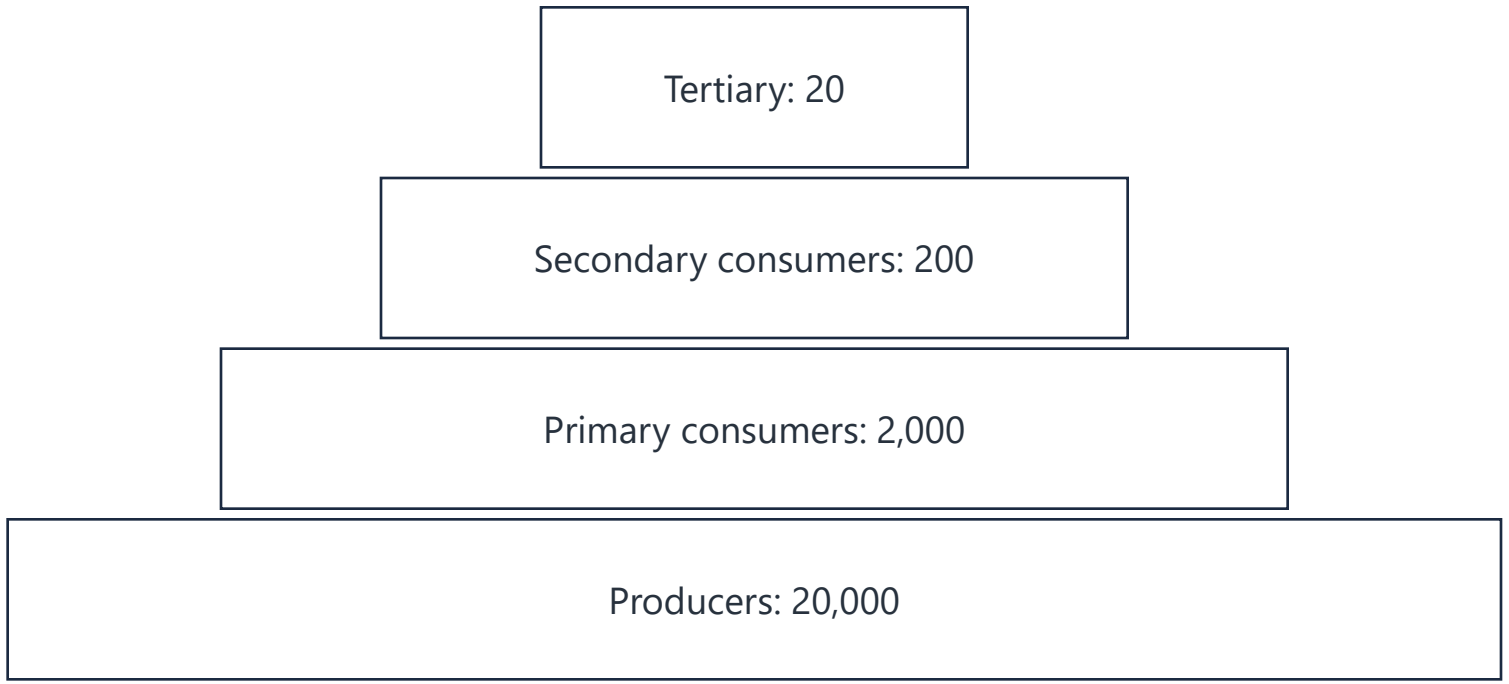
Note

Decomposers and detritus feeders are not usually placed in food chains. They still play a part in the transformation of energy, by feeding on dead matter from every level. You can represent them in a web, but do not give them a trophic level.

Energy pyramids

C4.2.11

Each bar shows energy per unit area per unit time. Figures here are in kJ m^{-2} yr^{-1} and are invented for practice.



- Bars are stepped, not triangular
- Producers go at the bottom
- Label every level
- Bars should be to scale where possible
- State the units

Practise with data from a local ecosystem.

Why energy falls along a food chain

C4.2.12

Loss	What happens
Not all is eaten	Bones, roots, wood or hair may not be consumed
Not all is digested	What is not absorbed leaves as faeces, and passes to decomposers
Respiration	Carbon compounds are oxidized for energy, so they cannot pass on
Death	Organisms that die before being eaten pass energy to decomposers

Rule of thumb

Often about 10% of energy passes to the next level, with a typical range of about 5–20%. Calculate the percentage for yourself: energy at the higher level, divided by energy at the lower level, times 100.

Respiration turns chemical energy into heat

C4.2.13

- Energy transfers are not 100% efficient
- Heat is produced when ATP is made in respiration, and when ATP is used in cells
- Muscle contraction, nerve impulses and bioluminescence all release heat too
- Heat passes to the abiotic environment, and it cannot be converted back into chemical energy

This answers the guiding questions

Matter can be recycled, because atoms are conserved and move between organisms and the environment. Energy cannot, because it enters as light and leaves as heat, which organisms cannot use. New sunlight must therefore keep arriving, to replace the energy that each group loses.

Why food chains are short

C4.2.14

- So much energy is lost at each stage that too little remains for further levels
- At each stage there are fewer or smaller organisms, so there is less biomass
- Energy content per unit mass is not reduced: there is simply less mass

Common mistake

Higher levels are not limited because their organisms are poorer in energy per gram. They are limited because there is much less biomass, and so less total energy.

Discussion

From an energy perspective, why does a given area of land feed more people if it grows crops than if it is used for raising cattle?

Primary production

C4.2.15

- **Primary production** is the build-up of carbon compounds in the biomass of autotrophs
- Units are mass of carbon per unit area per unit time, usually g m^{-2} yr^{-1}
- Biomes vary greatly in how much they accumulate

Biome	Relative primary production
Tropical rainforest	Very high: warm, wet and light all year
Temperate forest	High: limited by winter
Grassland	Moderate: limited by water
Desert and tundra	Low: limited by water or by temperature

Link: climate, which determines biome (B4.1), therefore affects primary production.

Secondary production

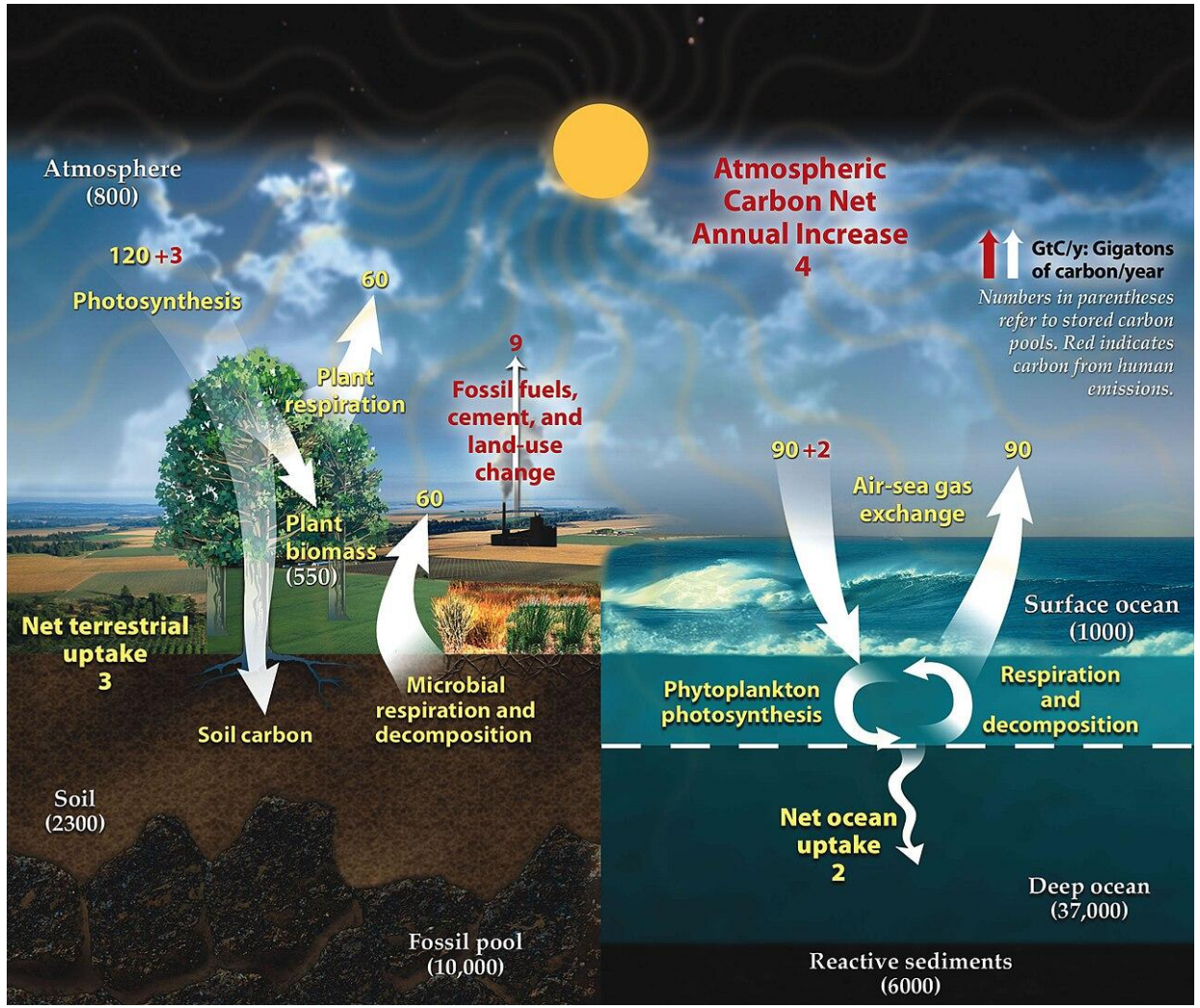
- **Secondary production** is the build-up of carbon compounds in the biomass of heterotrophs
- It is lower than primary production
- Biomass is lost when carbon compounds become carbon dioxide and water in respiration

	Primary production	Secondary production
Organisms	Autotrophs	Heterotrophs
Source of carbon	Carbon dioxide	Food
Amount	Higher	Lower

Key idea

Production of crops per unit area is always higher than production of meat.

The carbon cycle



The carbon cycle. Adapted from US DOE, public domain.

Your diagram must include:

- Carbon dioxide in the air and water
- Photosynthesis
- Feeding
- Respiration in all organisms
- Decomposition of dead matter

Terms

A **pool** is a store of carbon, and a **flux** is the rate at which it moves between pools. Label arrows with the process.

Carbon sinks and carbon sources

C4.2.18

Ecosystem acts as	When	Net effect on carbon dioxide
A carbon sink	Photosynthesis exceeds respiration	Net uptake
A carbon source	Respiration exceeds photosynthesis	Net release

Discussion

A growing young forest is usually a sink. What could turn it into a source? Consider drought and fire, for example. Then consider a peat bog: why does peat store carbon, and what happens to it if the bog is drained? This topic connects to D4.3.

Combustion

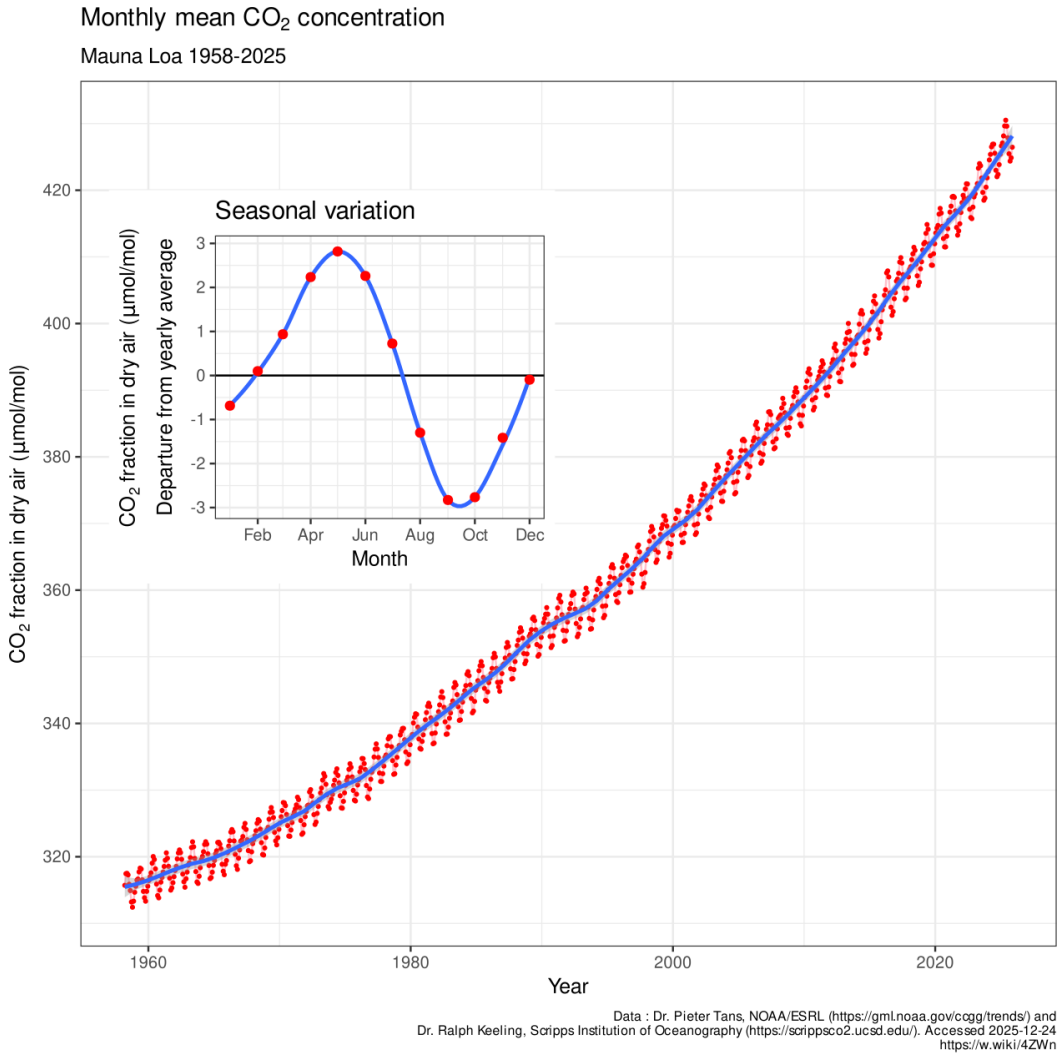
C4.2.19

Fuel	Origin	When formed
Biomass	Living or recently dead plant material	Recent
Peat	Part-decayed plant matter in waterlogged ground	Thousands of years ago
Coal	Buried peat, compressed over time	Hundreds of millions of years ago
Oil and natural gas	Buried remains of marine organisms	Millions of years ago

Key idea

These stores of carbon release carbon dioxide when burnt. Lightning sometimes sets fire to forests naturally, but human activity greatly increases the amount of combustion. Stores formed over millions of years are being released within a short time.

The Keeling curve



Carbon dioxide at Mauna Loa. Oeneis, CC BY-SA 4.0.

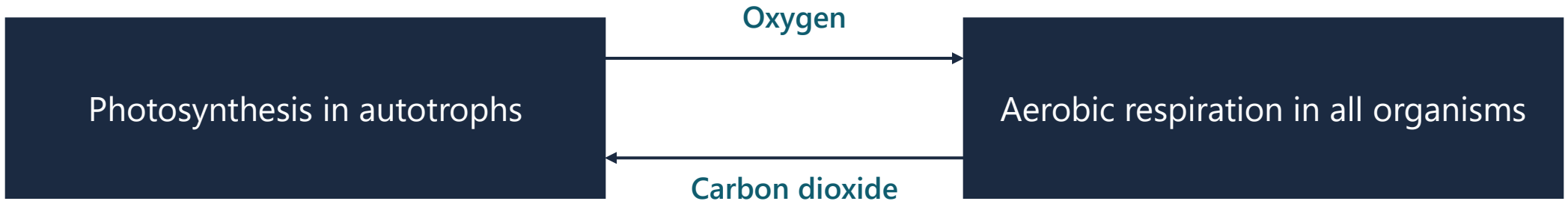
Feature	Explanation
Long-term rise	More combustion of fossil fuels, and deforestation
Yearly rhythm	Less in northern summer, as photosynthesis is higher; more in winter, as respiration exceeds it

Why it matters

Measured since 1958 by Charles Keeling at Mauna Loa, Hawaii. This long, careful record is key evidence. Why is the yearly pattern driven by the northern hemisphere?

Photosynthesis and respiration depend on each other

C4.2.21



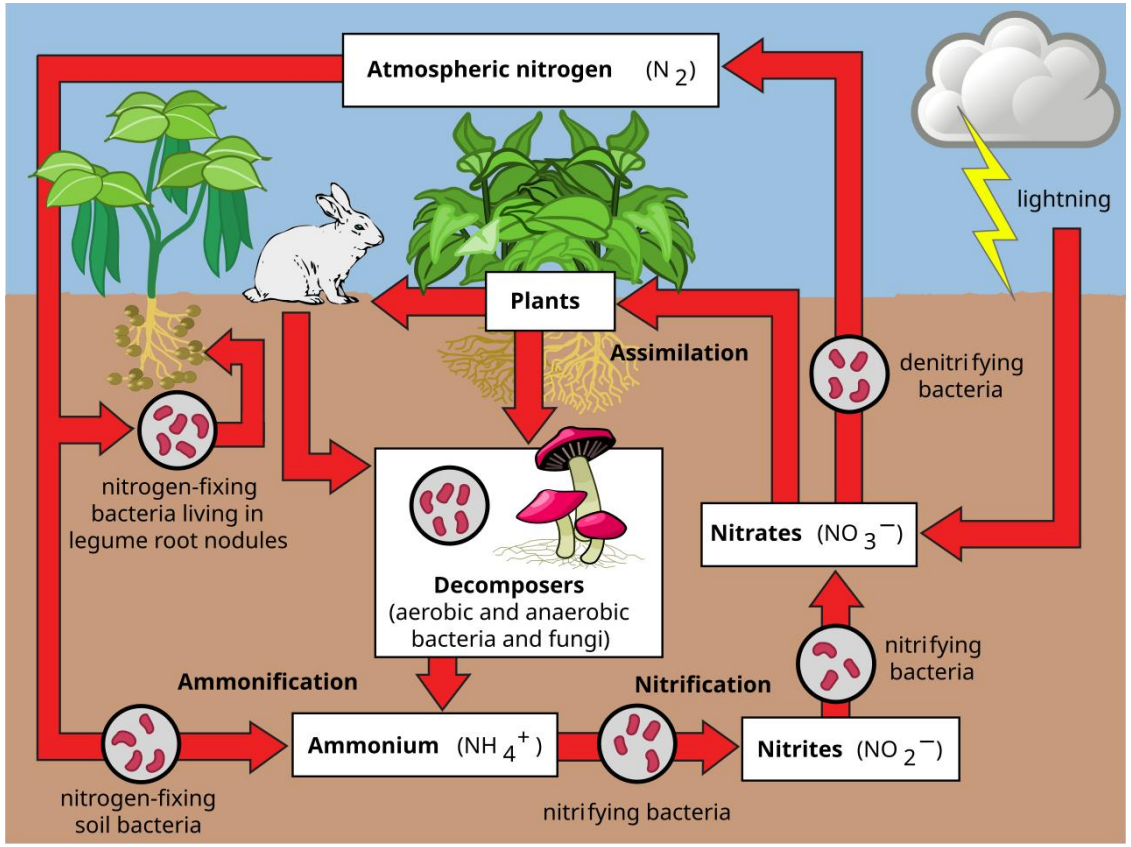
- Aerobic respiration depends on oxygen from photosynthesis
- Photosynthesis depends on carbon dioxide from respiration
- The quantities that move each year are huge

Key idea

There was very little oxygen in the atmosphere before photosynthesis evolved. Oxygen-producing photosynthesis made aerobic respiration, and so large active organisms, possible.

All elements are recycled

C4.2.22



The nitrogen cycle. CC BY-SA 3.0.

- Every element that living organisms need is recycled, not just carbon
- Autotrophs obtain elements from air, water and soil
- Heterotrophs obtain them from their food
- **Decomposers** play a key role, as they return elements from dead matter to the environment

Key idea

You do not need to know the details of individual nutrient cycles. Understand the general principle.

Check that you can explain

1. Open and closed systems
2. Why sunlight is the main source, and the exceptions
3. Food chains and food webs
4. Autotrophs and heterotrophs
5. Trophic levels
6. Energy pyramids
7. Reasons for energy loss
8. Why food chains are short
9. Primary and secondary production
10. Carbon cycle diagram
11. Carbon sinks and sources
12. Combustion of fossil fuels
13. The Keeling curve
14. Recycling of all elements

Exit activity: 5 minutes

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

1. Explain why energy cannot be recycled in an ecosystem.
2. State three reasons for energy loss between trophic levels.
3. Explain why atmospheric carbon dioxide at Mauna Loa falls during the northern summer.

Image credits

Virgin tropical forest in southern Thailand, Khlong Phanom, Surat Thani.jpg – Vyacheslav Argenberg – CC BY 4.0

Blacksmoker in Atlantic Ocean.jpg – P. Rona / OAR/National Undersea Research Program (NURP); NOA – Public domain

Soil food webUSDA.jpg – USDA – Public domain

Earthworm in a No-till Field near Brookings, SD (14366341997).jpg – USDA NRCS South Dakota – Public domain

Mycena haematopus. (42029182981).jpg – Bernard Spragg. NZ from Christchurch, New Zealand – Public domain

Carbon cycle.jpg – Diagram adapted from U.S. DOE, Biological and Environmental – Public domain

Mauna Loa CO2 monthly mean concentration.svg – Oeneis – CC BY-SA 4.0

Nitrogen Cycle 2.svg – File:Nitrogen Cycle.svg: **Cicle_del_nitrogen_de.svg:** Cicle_ – CC BY-SA 3.0

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