Unit 4

Answers: Ecology

Quick checks

1 b One tree is narrower than 2,000 caterpillars, and the 20 birds are narrower again: narrow, wide, narrow, a spindle inverted at the base. The pyramid of biomass for the same chain is upright, because the tree weighs far more than the caterpillars.

2 b Biomass is measured at one moment, and phytoplankton grow and are eaten so fast that their mass at any moment can be less than the zooplankton's. Energy is measured over a year, and the phytoplankton always take in more energy than the animals that eat them.

3 c The hawk is at level 5, four steps above the grass: $50{,}000 \times (0.1)^4 = 5$ kJ.

4 c Respiration releases food energy for the organism's work, and it ends as heat, which no organism can use to make food again. The energy in dead bodies and droppings goes to the decomposers, and their respiration turns it into heat too.

5 c Photosynthesis takes carbon dioxide from the air and builds its carbon into sugar. Respiration, burning and decomposition all give carbon back to the air as carbon dioxide.

6 b Legumes host *Rhizobium*, which fixes nitrogen gas into ammonia in the nodules. When the roots and leftover plants rot, that fixed nitrogen stays in the soil for the next crop.

7 c *Nitrosomonas* does the first step of nitrification (ammonium → nitrite) and *Nitrobacter* the second (nitrite → nitrate). *Rhizobium* fixes nitrogen; *Pseudomonas* denitrifies.

1 a. **c** Every level gets its energy from the level below and loses some as heat, so each bar of a pyramid of energy is narrower than the one under it. Numbers and biomass can be inverted.

1 b. **c** Each feeder is more numerous than the one it lives on: one tree, many birds, thousands of lice. The bars get wider upward.

1 c. **b** Secondary consumers are at level 3, two steps up: $8{,}000 \times (0.1)^2 = 80$ kJ.

1 d. **b** The plant splits water with light energy, and the oxygen of the water is given off as gas. The oxygen of the carbon dioxide ends up in the sugar and in water.

1 e. **c** Nitrification is done by *Nitrosomonas* (ammonium → nitrite) and *Nitrobacter* (nitrite → nitrate).

1 f. **d** Phosphorus has no common gas; its main reservoir is rocks and soil, so its cycle is sedimentary and slow. The other three have their main reservoir in the air.

2 a. Each trophic level gets all its energy from the level below, and at every step most of it is lost as heat in respiration, droppings and dead bodies. So each level always takes in less energy than the one below it, and every bar is narrower than the bar under it.

2 b. Only about 10% of the energy passes from each level to the next. At the fifth level only about 0.01% of the producers' energy is left, too little to support another population of animals. So food chains end after four or five steps.

2 c. Energy enters as sunlight and leaves as heat, and no living thing can turn heat back into food, so energy can't be used again. Matter is not used up: decomposers break dead bodies and dung into simple substances (carbon dioxide, water, ammonium, minerals) that plants take up again.

2 d. Nitrogen gas, N_2, is held by a very strong triple bond, and plants can't break it. They can take up nitrogen only as nitrate or ammonium from the soil. If the soil has too little of these, the plant runs short of nitrogen even though the air around it is 78% nitrogen.

3 i.

Pyramid of biomass	Pyramid of energy
Shows the dry mass of living matter at each level.	Shows the energy taken in by each level.
A snapshot at one moment.	A flow over a period of time.
Unit: g/m².	Unit: kJ/m² per year.
Can be inverted (phytoplankton and zooplankton in some seas).	Can never be inverted.

3 ii.

Nitrogen fixation	Nitrification
Changes nitrogen gas of the air into ammonia, ammonium or nitrate.	Changes ammonium in the soil into nitrite and then nitrate.
Done by *Rhizobium*, *Azotobacter*, cyanobacteria, lightning and factories.	Done by *Nitrosomonas* and *Nitrobacter*.
Brings new nitrogen into the soil from the air.	Changes nitrogen already in the soil from one form to another.

3 iii.

Nitrification	Denitrification
Ammonium → nitrite → nitrate.	Nitrate → nitrogen gas.
By *Nitrosomonas* and *Nitrobacter*.	By denitrifying bacteria such as *Pseudomonas*.
Needs oxygen: well-aired soil.	Happens where oxygen is short: waterlogged soil.
Gives plants nitrate.	Takes nitrogen out of the soil, back to the air.

4 a. **Upright, a grassland:** a wide bottom bar of grass plants; above it a narrower bar of grasshoppers; above that a narrower bar of frogs; a small top bar of snakes.

Inverted, a parasite chain: a narrow bottom bar of one tree; above it a wider bar of birds; above that a very wide bar of lice on the birds.

In both, label the levels: producers, primary consumers, secondary consumers (and tertiary consumers).

4 b. In some seas the phytoplankton weigh less, at any moment, than the zooplankton eating them, so the pyramid of biomass is inverted. The phytoplankton live only a few days, but they divide very fast and are replaced as fast as they are eaten. Over a year they make far more food than their mass at any one time, so they can support a greater mass of zooplankton. Their pyramid of energy is still upright.

4 c. **Ten percent law:** at each step of a food chain, only about 10% of the energy of one trophic level is passed on to the next; about 90% is lost, mostly as heat.
Diagram: sunlight → producers (rice, 10,000 kJ) → primary consumers (grasshoppers, 1,000 kJ) → secondary consumers (frogs, 100 kJ) → tertiary consumers (snakes, 10 kJ), with an arrow labeled “heat” leaving each level, and arrows from each level to the decomposers for dead bodies and droppings, which also give off heat.
Producers catch about 1% of the sunlight in photosynthesis. At every level part of the food is not digested (droppings), most is used up in respiration and lost as heat, and only a little becomes new body for the next level to eat. So energy decreases at each level, and flows one way: it is never recycled.

4 d. A biogeochemical cycle is the circulation of an element (such as carbon, oxygen or nitrogen) between the living parts of an ecosystem and its non-living parts (air, water, soil and rocks) by chemical and physical processes.
They are important because the amount of each element on Earth is fixed: the cycles return the elements in dead matter, dung and breath to the air, water and soil, so that plants can use them again. Without them, the elements needed for life would be locked up in dead matter and life would stop.

4 e. Oxygen is given to the air by photosynthesis of green plants and algae, which split water with light energy and release oxygen: $6_2 + 6_2 \rightarrow {}_{6126} + 6_2$.
Oxygen is taken from the air by respiration of plants, animals and people, by decay (respiration of decomposers), by burning of fuels, and by the rusting of iron and the weathering of rocks. Respiration and burning make carbon dioxide and water, which plants use again in photosynthesis. High in the air, ultraviolet light turns some oxygen into ozone (O_3), which breaks back into oxygen.
Diagram: oxygen in the air in the middle (or at one side), with an arrow from plants into it labeled “photosynthesis”, and arrows out of it to animals and plants (“respiration”), decomposers (“decay”), fires and engines (“burning”), iron and rocks (“rusting, weathering”), and the ozone layer.

4 f. Carbon dioxide in the air is taken in by green plants in photosynthesis and built into food. Animals get carbon by eating plants. Plants, animals and decomposers return carbon to the air as carbon dioxide by respiration; decomposers also break down dead bodies and dung. Some dead matter, buried for millions of years, became coal, oil and natural gas; burning them returns their carbon to the air as carbon dioxide. The sea takes in and gives off carbon dioxide, and shells of sea animals become limestone.
Diagram: carbon dioxide in the air, with arrows to green plants (“photosynthesis”), plants to animals (“eaten”), plants and animals to dead matter (“death”), dead matter to fossil fuels (“buried, millions of years”), and arrows back to the air labeled “respiration”, “decay” and “burning”.

4 g.

1. **Nitrogen fixation:** nitrogen gas of the air is changed into ammonia or nitrate by *Rhizobium* (in legume root nodules), free-living *Azotobacter* and *Clostridium*, cyanobacteria such as *Nostoc* and *Anabaena*, by lightning (as nitrates in rain) and by factories (Haber process, urea).
2. **Assimilation:** plants take up nitrate and ammonium and make proteins; animals get nitrogen by eating plants.
3. **Ammonification:** decomposers (such as *Bacillus* and fungi) change the proteins and urea of dead matter, urine and dung into ammonia/ammonium.
4. **Nitrification:** *Nitrosomonas* changes ammonium into nitrite, and *Nitrobacter* nitrite into nitrate.
5. **Denitrification:** denitrifying bacteria such as *Pseudomonas*, in waterlogged soil, change nitrate back into nitrogen gas.

Diagram: nitrogen gas in the air at the top; arrows down to "nitrogen-fixing bacteria", "lightning" and "factories"; then ammonium → nitrite → nitrate in the soil; nitrate → plants → animals; plants and animals → dead matter, urine, dung → ammonium; and nitrate → nitrogen gas, labeled "denitrification".

4 h.

Carbon: burning coal, oil and gas returns carbon to the air much faster than it was buried, and cutting forests removes plants that take carbon dioxide in. So the carbon dioxide in the air has risen from about 280 ppm before 1800 to about 427 ppm in 2025, warming the Earth.

Nitrogen: fertilizer factories (the Haber process), growing legumes, and engines and fires now fix about as much nitrogen as all natural processes together. Extra nitrate washes from fields into rivers and lakes, where it feeds thick growths of algae that use up the water's oxygen; some escapes as nitrous oxide, a greenhouse gas.

5 a.

$$\frac{1{,}800}{15{,}000} \times 100\% = 12\%$$

Energy not passed on: $15{,}000 - 1{,}800 =$ **13,200 kJ/m² per year** (88%), lost mostly as heat or passed to decomposers.
12% transferred.

5 b.

By the ten percent law, from level 2 to level 4: $20{,}000 \times (0.1)^2 = 200$ kJ. The snake would get about 200 kJ, not 50 kJ. 50 kJ means an efficiency of $\sqrt{50/20{,}000} = 0.05$, 5% a step: possible in a real ecosystem (efficiencies run from about 5% to 20%), but not by the ten percent law.

5 c.

i. Bar lengths: grass $600 \div 50 =$ **12 cm**; grasshoppers $40 \div 50 =$ **0.8 cm**; spiders $6 \div 50 = 0.12$, drawn as **0.5 cm**; lizard **0.5 cm**. The pyramid is upright, with grass at the base.

ii. Grass 9,000 kJ; grasshoppers **900 kJ**; spiders **90 kJ**; lizard **9 kJ**.

5 d. Level 1: 100,000; level 2: 10,000; level 3: 1,000; level 4: 100; level 5: 10; level 6: 1 kJ. Level 5 has 10 kJ (at least 5); level 6 has only 1 kJ. So the chain can have **five trophic levels**.