Unit 4 · Ecology

STUDY NOTES

Key terms

Biological (ecological) pyramid: bars of number, biomass or energy per trophic level; producers at the base.

Biomass: total dry mass of living matter at a level (g/m^2).

Spindle-shaped: narrow, wide, narrow; inverted at the base.

Transfer efficiency: higher level ÷ lower level × 100%.

Ten percent law: only about 10% of a level's energy reaches the next.

Biogeochemical cycle: an element's circulation between living things and air, water, soil, rocks.

Reservoir: large long-term store. **Exchange pool**: taken up and given back quickly.

Gaseous cycle: main store air or sea; fast (O, C, N).

Sedimentary cycle: main store rocks and soil; slow (P, S).

Nitrogen fixation: N_2 → ammonia, ammonium or nitrate.

Assimilation: roots take up nitrate and ammonium, make proteins.

Ammonification: dead matter, urine, dung → ammonia or ammonium.

Nitrification: ammonium → nitrite → nitrate.

Denitrification: nitrate → nitrogen gas.

Leaching: nitrate washed out of the soil by rainwater.

Formulas

- $E_n = E_1 \times (0.1)^{n-1}$ (producers are level 1)
- efficiency = energy at higher level ÷ energy at lower level × 100%
- going down the chain: × 10 for each step
- sunlight caught by producers: usually 1–2%, often less
- **in the exam, 10% unless given another figure**

4.1 Biological pyramids

Elton, 1927, *Animal Ecology*: pyramids of numbers (Eltonian pyramids).

Rules

- producers at the base, then primary, secondary, tertiary consumers
- one trophic level per bar, measured the same way, same area or volume
- decomposers are not a bar

	Numbers	Biomass	Energy
shows	individuals	dry mass	energy taken in
unit	number per area	g/m^2	kJ/m^2 per year
time	a moment	a moment	a period (year)
shape	upright, spindle, inverted	upright, or inverted (some seas, lakes)	**always upright**
inverted case	tree and insects; parasites	phytoplankton and zooplankton	never
weakness	a tree = a blade of grass	misses growth and eating rate	hardest to measure

Examples

- **numbers, upright**: grassland; pond
- **numbers, spindle**: forest in summer: few trees, many insects, fewer birds
- **numbers, inverted**: tree → birds → lice
- **biomass, upright**: land; Silver Springs 809, 37, 11, 1.5 g/m^2
- **biomass, inverted**: English Channel: phytoplankton 4 g/m^2, zooplankton 21 g/m^2
- **energy**: Silver Springs 87,100, 14,100, 1,600, 88 kJ/m^2 a year

Why inverted biomass is possible: a snapshot; phytoplankton live only a few days, divide and are eaten fast, so a year's food far exceeds the zooplankton's mass.

Why energy can't invert: each level's energy all came from below; more than that would be energy from nothing.

4.2 Energy transfer

Sunlight → producers (photosynthesis) → consumers.

At each level

1. part not digested: droppings
2. most lost in **respiration**, as heat
3. a little becomes new body, for the next level

Some die and go to decomposers, who give it off as heat too.

Level	Energy (kJ)
sunlight	1,000,000
rice (producers), 1% caught	10,000
grasshoppers (primary)	1,000
frogs (secondary)	100
snakes (tertiary)	10

Ten percent law (Lindeman, 1942, Cedar Bog Lake): **at each step of a food chain, only about 10% of the energy**

of one trophic level is passed on and stored in the next; about 90% is lost, mostly as heat.

- real efficiencies: about 5–20%; Silver Springs about 16%, 11%, 5.5%
- warm-blooded animals pass on less

Energy flows one way:

- light → food → heat
- never recycled
- needs steady sunlight

Matter goes round.

So

- food chains short: 3–5 levels
- top carnivores few (Nepal: thousands of deer, 429 tigers)
- eating lower in the chain feeds more people

4.3 Biogeochemical cycles

Oxygen cycle

Air: about 21% O_2.

Gives O_2: photosynthesis (the O_2 comes from **water**)
$6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$

Takes O_2

- **respiration**: $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$ + energy
- **decay** (aerobic decomposers)
- **burning**: $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$
- **rusting**: $4Fe + 3O_2 \rightarrow 2Fe_2O_3$; **weathering**

Ozone, 15–35 km up: $O_2 \xrightarrow{UV} 2O$; $O + O_2 \rightarrow O_3$; takes in most harmful UV.

Carbon cycle

Air: about 0.04% CO_2.

1. **photosynthesis**: CO_2 → sugar
2. **feeding**: plants → herbivores → carnivores
3. **respiration**: back to CO_2
4. **decomposition**: dead bodies, leaves, dung
5. **fossil fuels**: buried dead matter → coal, oil, gas over millions of years
6. **burning**: back to CO_2
7. **the sea**: dissolves and gives off CO_2; shells → **limestone**, the largest store

Human change: about 280 ppm before 1800 → 427 ppm in 2025 (Mauna Loa); burning fossil fuels, cutting forests.

Nitrogen cycle

Air: 78% N_2 (N≡N triple bond); plants take **nitrate and ammonium** only.

Step	Change	By
1. Fixation	N_2 → ammonia, nitrate	see below
2. Assimilation	nitrate, ammonium → proteins	plants; animals by eating
3. Ammonification	dead matter, urine, dung → ammonium	decomposers (*Bacillus*, fungi)
4. Nitrification	$NH_4^+ \rightarrow NO_2^-$	*Nitrosomonas*
	$NO_2^- \rightarrow NO_3^-$	*Nitrobacter*
5. Denitrification	$NO_3^- \rightarrow N_2$	*Pseudomonas*

Fixation

- **biological** (enzyme nitrogenase):
  - *Rhizobium* (legume nodules)
  - *Azotobacter*, *Clostridium* (free-living)
  - *Nostoc*, *Anabaena* (cyanobacteria; *Anabaena* in *Azolla*)
- **lightning** (small share):
  - $N_2 + O_2 \rightarrow 2NO$
  - $2NO + O_2 \rightarrow 2NO_2$
  - $4NO_2 + 2H_2O + O_2 \rightarrow 4HNO_3$
- **industrial** (Haber): $N_2 + 3H_2 \rightleftharpoons 2NH_3$; ammonia → urea
  - iron catalyst
  - about 450 °C
  - about 200 times the air's pressure

Where: nitrification needs oxygen (well-aired soil); denitrification in waterlogged, airless soil.

Human change: about half of the 413 million tonnes fixed each year is by people; extra nitrate → algae in lakes → oxygen used up → fish die.

Nepal: buys all its fertilizer; legumes and *Azolla* put in nitrogen for free.

COMMON MISTAKES

✗ Pyramid of energy can be inverted
✓ **never**; biomass can.

✗ Decomposers recycle energy
✓ they recycle **matter**.

✗ Fixation = nitrification
✓ fixation starts from **N_2**; nitrification from **ammonium**.

✗ O_2 of photosynthesis comes from CO_2
✓ from **water**.

✗ $(0.1)^n$
✓ $(0.1)^{n-1}$: count the steps.

✗ *Nitrobacter* makes nitrite
✓ *Nitrosomonas* makes nitrite; *Nitrobacter* nitrate.

✗ Decomposers drawn as a bar
✓ not a bar.