Class 12 Biology Formula Sheet Chapter 12 Ecosystem

Class 12 Biology (12th) — NCERT 2026-27 / Latest Edition

Chapter 12: Ecosystem

Productivity, decomposition, energy flow, ecological pyramids, nutrient cycles

Also see for this chapter: NCERT Solutions | Revision Notes | Exemplar Solutions

Chapter-Wide Key Quantitative Reference

Parameter	Typical Value / Range	Biological Significance
Photosynthetically Active Radiation (PAR)	$< 50\,\%$ of incident solar radiation	Only this fraction drives photosynthesis
PAR captured by plants	2–$10\,\%$ of PAR	Tiny conversion sustains the whole biosphere
Lindeman's energy-transfer law	$\sim 10\,\%$ per trophic step	Limits food chains to 4–5 links
Global annual NPP (biosphere)	~ 170 billion t dry organic / yr	~ 115 t on land, ~ 55 t in oceans
Ocean share of NPP vs surface	~ 55 t out of 170 t on $\sim 70\,\%$ surface	Oceans are nutrient-limited
Productivity units	g m^{-2} yr^{-1} or kcal m^{-2} yr^{-1}	Standardised for ecosystem comparison
Decomposition: optimum O_2	aerobic; warm + moist	Speeds catabolism; anaerobiosis halts it
Decomposition: optimum T, moisture	$\sim 25\,°$C, water-saturated soil	Microbial activity peaks
Detritus C/N ratio — quick decay	low C/N, high N & sugars	Decay completes in weeks–months
Detritus C/N ratio — slow decay	high C/N, lignin/chitin rich	Decay takes years (humus accumulates)
Atmospheric carbon reservoir	~ 700 Gt C	Pool that fixes/releases CO_2
Oceanic carbon reservoir	$\sim 38{,}000$ Gt C	Largest mobile C pool
Major reservoir of P (Earth's crust)	sedimentary rocks (apatite)	Slow weathering; no atmospheric phase

1 12.1 Ecosystem — Structure and Function

Defines the ecosystem as a functional unit of biotic + abiotic components, with four operational aspects (productivity, decomposition, energy flow, nutrient cycling) and structural attributes (species composition + stratification).

Ecosystem — the functional unit

An **ecosystem** = all interacting biotic + abiotic components of a defined area; it can be terrestrial (forest, grassland, desert) or aquatic (pond, lake, river, estuary). The four functional aspects are: **Productivity, Decomposition, Energy flow, Nutrient cycling**. Two key structural attributes are **Species composition** (catalogue of species) and **Stratification** (vertical layering — trees occupy top strata, shrubs the middle, herbs the bottom).

Pond as a model ecosystem

A pond shows every ecosystem function in miniature. **Abiotic:** water + dissolved nutrients + bottom soil + solar input + climate cycle. **Autotrophs:** phytoplankton, algae, floating / submerged / marginal plants. **Consumers:** zooplankton, free-swimming + bottom-dwelling animals. **Decomposers:** fungi, bacteria, flagellates (abundant at the bottom). Energy flows unidirectionally from sun → producers → consumers → dissipated as heat.

2 12.2 Productivity

Productivity = the rate at which producers fix solar energy into biomass. GPP is the gross capture; NPP is what is left after the plant's own respiration; secondary productivity is consumer biomass formation. All three obey strict definitions and unit conventions.

Primary Productivity — basic definitions

Primary production (biomass) — total dry organic matter or energy produced by autotrophs per unit area per unit time.

Productivity (rate of biomass production):

$$\text{Productivity} = \frac{\text{Biomass produced}}{\text{Area} \times \text{Time}}$$

Units: $\mathbf{g\,m^{-2}\,yr^{-1}}$ or $\mathbf{kcal\,m^{-2}\,yr^{-1}}$.

Standardised area–time units allow productivity of **vastly different ecosystems** (desert vs forest vs ocean) to be compared on the same footing. Standing crop (biomass present at a moment) is *not* productivity — productivity is the **rate**, not the stock.

GPP, R, NPP — the core ecosystem equation

Gross Primary Productivity (GPP) — total rate at which autotrophs fix solar energy into organic matter via photosynthesis.

Plant respiration (R) — fraction of GPP burnt by the plant itself to power its own metabolism.

Net Primary Productivity (NPP) — biomass available to heterotrophs (herbivores + decomposers):

$$\boxed{\mathbf{NPP} = \mathbf{GPP} - \mathbf{R}}$$

Equivalent form: $\mathbf{GPP} = \mathbf{NPP} + \mathbf{R}$.

NPP / GPP ratio (assimilation efficiency of autotrophs):

$$\frac{\mathbf{NPP}}{\mathbf{GPP}} = 1 - \frac{\mathbf{R}}{\mathbf{GPP}}$$

Typical value ≈ 0.3–0.7; lower in mature forests (high R), higher in young grasslands.

Only NPP is **ecologically available** for the next trophic level. GPP is what was *captured*; R is the *tax*; NPP is what the rest of the food web actually receives.

Secondary Productivity

Secondary productivity = rate of formation of *new organic matter* by consumers (heterotrophs).

$$\mathbf{SP} = \frac{\text{Biomass gained by consumers}}{\text{Area} \times \text{Time}}$$

Units: same as primary productivity ($\mathbf{g\,m^{-2}\,yr^{-1}}$).

Consumers don't fix solar energy; they re-package existing organic matter from lower trophic levels. SP is therefore **always smaller than the NPP feeding it** — most of the consumed energy is lost as heat or excreted.

Global productivity benchmarks

Quantity	Value	Note
Biosphere annual NPP	~ 170 billion t dry	Total organic matter / yr
Terrestrial NPP	~ 115 billion t / yr	On $\sim 30\,\%$ of Earth surface
Oceanic NPP	~ 55 billion t / yr	On $\sim 70\,\%$ of Earth surface
PAR fraction of incident sun	$< 50\,\%$	Wavelengths 400–700 nm
PAR captured by plants	2–$10\,\%$	Conversion efficiency

Oceans cover most of Earth yet contribute only $\sim 32\,\%$ of global NPP because surface waters are **nutrient-limited** (especially N, P, Fe). Land productivity scales with light + water + N availability.

Factors controlling primary productivity

Primary productivity depends on (i) the **plant species** inhabiting the area (their photosynthetic capacity), (ii) availability of **nutrients** (N, P, K, micronutrients), (iii) **environmental factors** — light, temperature, water, CO_2. Hence the same area gives different productivities in different seasons and different soils.

GPP, NPP and biomass mix-up

GPP = total energy fixed by photosynthesis. **NPP** = GPP $-$ R (what's left after plant respiration). **Standing crop / biomass** = the *stock* of organic matter present at a given moment, not a rate. Don't confuse a rate (g m^{-2} yr^{-1}) with a stock (g m^{-2}).

3 12.3 Decomposition

Decomposition converts complex organic detritus into CO_2, water, and mineral nutrients. It runs as five overlapping processes: fragmentation, leaching, catabolism, humification, mineralisation — and obeys first-order kinetics with rate constant k set by detritus chemistry and climate.

Decomposition — the five-step process

Step	Agent	What happens
Fragmentation	Detritivores (earthworm)	Detritus broken into smaller particles
Leaching	Water (gravity)	Soluble inorganic nutrients washed into soil; precipitate as unavailable salts
Catabolism	Bacterial & fungal enzymes	Detritus → simpler inorganic substances
Humification	Soil microbes (partial)	Dark amorphous **humus**; colloidal, nutrient reservoir; very slow to decompose further
Mineralisation	Microbes (specific)	Humus → **inorganic nutrients** (NH_4^+, NO_3^-, PO_4^{3-}, etc.)

All five steps operate **simultaneously** on the detritus, not sequentially. Mineralisation is the final release that makes nutrients re-available to autotrophs.

Decomposition kinetics — first-order rate law

Loss of detritus mass follows first-order kinetics:

$$\frac{dM}{dt} = -k\,M$$

Integrated form (Olson, 1963 — litter-decay model):

$$M(t) = M_0\,e^{-kt}$$

where M_0 = initial detritus mass; $M(t)$ = mass remaining at time t (yr); k = decomposition rate constant (yr^{-1}).

Half-life of detritus: $t_{1/2} = \frac{\ln 2}{k} \approx \frac{0.693}{k}$

Typical k values:

Tropical rainforest litter $k \approx 1$–4 yr^{-1} (fast)
Temperate deciduous $k \approx 0.3$–0.5 yr^{-1}
Boreal / lignin-rich $k \approx 0.05$–0.2 yr^{-1} (slow; humus accumulates)

A higher k means a **shorter half-life** and faster nutrient recycling. Conditions that raise k: high temperature, high moisture, high N content, low lignin / chitin.

Climatic and chemical control of k

Factor	Effect on k	Mechanism
Temperature ↑ (warm)	$k\uparrow$	Microbial enzyme activity rises
Soil moisture ↑ (moist)	$k\uparrow$	Microbes need water film
Anaerobiosis (water-logged)	$k\downarrow$	Aerobic catabolism halts
Low temperature (boreal)	$k\downarrow$	Microbes inactive
N content of detritus ↑	$k\uparrow$	Microbial growth N-limited
Lignin / chitin content ↑	$k\downarrow$	Resistant polymers
Water-soluble sugars ↑	$k\uparrow$	Easy carbon source

Combination of **warm + moist** drives the highest k — explains why tropical leaf litter vanishes in months while boreal needles take decades. **Decomposition is largely an aerobic, O_2-requiring process.**

Detritus, humus, detritivores

Detritus = dead plant remains (leaves, bark, flowers) + animal remains + faecal matter; the **raw material** for decomposition. **Detritivores** (earthworm, woodlice, millipedes) are the animals that mechanically fragment detritus. **Humus** is the dark colloidal end-product of humification; it is a **nutrient reservoir**, resistant to further attack, and slowly releases inorganic nutrients via mineralisation.

4 12.4 Energy Flow

Energy flow through an ecosystem is **unidirectional** (sun → producers → consumers → heat) and quantitatively governed by Lindeman's $10\,\%$ law. Two parallel routes: grazing food chain (GFC) and detritus food chain (DFC).

Lindeman's 10% law of energy transfer

At each trophic step, only about $10\,\%$ of the energy at trophic level n is incorporated into trophic level $n+1$; the remaining $\sim 90\,\%$ is dissipated as heat (respiration), excretion, and unconsumed biomass.

$$\boxed{E_{n+1} \approx 0.10 \times E_n}$$

After N successive transfers (producers $\longrightarrow$ N-th consumer):

$$E_{N+1} \approx E_1 \times (0.10)^N$$

Worked check: $E_1 = 10{,}000$ kJ at producers $\Rightarrow$ $E_5 \approx 1$ kJ at the quaternary consumer.

This is why food chains rarely exceed **4–5 trophic levels** — beyond that, the residual energy can't sustain a viable population. The rule is empirical, not exact; observed efficiencies vary from $\sim 5\,\%$ (terrestrial GFC) to $\sim 20\,\%$ (some aquatic systems).

Ecological efficiency — formal definition

The **ecological efficiency** (or trophic-level transfer efficiency, TLTE) between two adjacent trophic levels:

$$\boxed{\eta = \frac{E_{n+1}}{E_n} \times 100\ \%}$$

where E_n = energy (or biomass / productivity) at trophic level n.

Related component efficiencies:

$$\text{Assimilation efficiency} = \frac{\text{Energy assimilated}}{\text{Energy ingested}} \times 100\,\%$$

$$\text{Production efficiency} = \frac{\text{Energy in new biomass}}{\text{Energy assimilated}} \times 100\,\%$$

$$\text{Exploitation efficiency} = \frac{\text{Energy ingested by level } n+1}{\text{Energy in level } n} \times 100\,\%$$

$\eta \approx 10\,\%$ is the product of these three component efficiencies (each ~ 30–$50\,\%$). Endotherms (mammals, birds) have **low production efficiency** (~ 1–$3\,\%$) because most assimilated energy is burnt to maintain body temperature; ectotherms (fish, insects) can reach ~ 10–$30\,\%$.

Trophic levels and food chains

Trophic level = position in the food chain by feeding relationship.

Level	Name	Example (terrestrial)
T1	Producer (autotroph)	Grass
T2	Primary consumer (herbivore)	Goat
T3	Secondary consumer (1° carnivore)	Wolf, snake
T4	Tertiary consumer (2° carnivore)	Eagle, tiger

Grazing Food Chain (GFC): Grass → Goat → Man.
Detritus Food Chain (DFC): Detritus → Bacteria/fungi (saprotrophs) → Detritivores → predators of detritivores.

In aquatic ecosystems, GFC dominates energy flow. In terrestrial ecosystems, **DFC carries a much larger fraction** of total energy. The two are interconnected, forming a **food web** — a species (e.g., a sparrow eating both seeds *and* insects) can occupy more than one trophic level simultaneously.

Standing crop — the snapshot of biomass

Standing crop = the mass of **living organisms (biomass) per unit area at a given moment**, expressed in fresh weight or — more accurately — **dry weight**. Dry weight is preferred because water content varies sharply between species and seasons. Standing crop is a *stock* (e.g., g m^{-2}), not a rate. Productivity is the *rate of change* of this stock.

NEET extension — why dry weight is preferred

Water content can be $> 90\,\%$ in lettuce yet $< 10\,\%$ in dry seeds. Fresh-weight comparisons would lie. Drying at 60–$80\,^{\circ}$C until constant mass strips water but preserves organic matter, giving a comparable yardstick.

5 12.5 Ecological Pyramids

Ecological pyramids stack the standing-crop variable (number, biomass, or energy) of each trophic level. Pyramids of energy are **always upright**; pyramids of number and biomass can be inverted in specific ecosystems.

The three ecological pyramids

Pyramid	Variable plotted	Shape & exception
Pyramid of **Number**	No. of individuals per trophic level	Usually **upright**; **inverted in a parasitic food chain** (one tree → many insects → many lice)
Pyramid of **Biomass**	Dry biomass per unit area	Usually upright; **inverted in sea** (small phytoplankton standing crop supports large zooplankton + fish stock)
Pyramid of **Energy**	Energy flow per unit area per unit time	**Always upright** — energy is always lost as heat between steps

Each bar is the **total** for that trophic level (every organism counted, not a sample). The base = producers; apex = top consumer. Use the rule: *If energy or biomass at level $n+1$ exceeds that at level n, the pyramid is inverted.*

Why the energy pyramid is never inverted

At every trophic step, energy is lost as heat (Second Law of Thermodynamics) and via excretion + unconsumed biomass. Hence:

$$E_{n+1} < E_n \quad \text{always}$$

A graphical statement of Lindeman's $10\,\%$ law. Energy at the producer base is always larger than energy at any higher level, so the pyramid stacks broad-base → narrow-apex — **strictly upright**.

Biomass pyramids can invert (low standing crop of fast-turnover phytoplankton supports a higher standing crop of slow-turnover fish) because **biomass is a stock, not a flux**. Energy flux cannot escape thermodynamics.

Limitations of ecological pyramids

Pyramids assume (i) a simple linear food chain — they cannot accommodate a **food web**; (ii) a species belongs to exactly one trophic level — yet many (humans, sparrows, omnivores) span multiple levels; (iii) saprophytes / decomposers are **not assigned** a place even though they handle most of the ecosystem's energy.

Pyramid of biomass — inverted is the exception, not the rule

On land, biomass pyramids are upright (a forest weighs far more than its herbivores, which weigh more than its carnivores). The **sea is the standard inverted case** — small phytoplankton biomass supports massive fish biomass because phytoplankton reproduce very fast (high turnover). Don't generalise the marine exception to land ecosystems.

Pyramids — quick recall

NBE = Number, Biomass, Energy.
Number can flip (*big tree, many insects*). | **Biomass** can flip in the sea (*phytoplankton → fish*). | **Energy NEVER flips** — heat loss is mandatory at every step.

6 12.6 Nutrient Cycling — Carbon and Phosphorus

Nutrient cycling moves elements between living biomass and the four geochemical reservoirs (atmosphere, hydrosphere, lithosphere, biosphere). Two NCERT prototypes: the **gaseous** carbon cycle (atmosphere/ocean reservoir) and the **sedimentary** phosphorus cycle (Earth's crust reservoir).

Carbon cycle — global reservoirs and fluxes

Reservoir	C stock (Gt C)	Role
Oceans (dissolved CO_2, HCO_3^-)	$\sim 38{,}000$	Largest mobile pool
Fossil-fuel deposits	$\sim 4{,}000$–$10{,}000$	Slow-cycle pool (millions of yr)
Soil + detritus	$\sim 1{,}500$–$2{,}500$	Active pool; humus + microbes
Atmosphere (CO_2)	~ 700–870	Fast-exchange pool
Terrestrial biomass	~ 500–600	Living vegetation

Major annual fluxes (Gt C / yr):
Photosynthesis (atmosphere → biomass) ≈ 120
Plant + soil respiration (biomass → atmosphere) ≈ 120
Ocean ↔ atmosphere exchange ≈ 90 each way
Fossil-fuel combustion (anthropogenic) ≈ 10

At steady state, in = out for each reservoir. The ~ 10 **Gt C / yr from fossil fuels** is the imbalance that accumulates as atmospheric CO_2 — driver of climate change. Carbon is a **gaseous nutrient cycle**: reservoir = atmosphere + hydrosphere.

Carbon cycle — key biological equations

Photosynthesis (autotrophs fix C; catalysts: light & chlorophyll):

$$6\,CO_2 + 6\,H_2O \longrightarrow C_6H_{12}O_6 + 6\,O_2$$

Respiration (heterotrophs + autotrophs release C):

$$C_6H_{12}O_6 + 6\,O_2 \rightarrow 6\,CO_2 + 6\,H_2O + \text{energy (ATP)}$$

Ocean carbonate equilibrium:

$$CO_2(g) \rightleftharpoons CO_2(aq) + H_2O \rightleftharpoons H_2CO_3 \rightleftharpoons H^+ + HCO_3^- \rightleftharpoons 2H^+ + CO_3^{2-}$$

Combustion (anthropogenic release):

$$C_xH_y + \left(x + \tfrac{y}{4}\right) O_2 \;\rightarrow\; x\,CO_2 + \tfrac{y}{2}\,H_2O$$

Photosynthesis and respiration are mirror images: the same six C atoms cycle between CO_2 and glucose. **Ocean absorbs** $\sim 25\,\%$ of anthropogenic CO_2 via the carbonate equilibrium — at the cost of **ocean acidification**.

Phosphorus cycle — sedimentary, no atmospheric phase

Reservoir: rocks of the Earth's crust — chiefly **apatite**, $Ca_5(PO_4)_3(OH, F, Cl)$.

Key fluxes:

Weathering: $Ca_5(PO_4)_3OH + 4\,H_2CO_3 \rightarrow 5\,Ca^{2+} + 3\,HPO_4^{2-} + 4\,HCO_3^- + H_2O$

Plant uptake (via roots): $HPO_4^{2-}/H_2PO_4^- \longrightarrow$ organic P (DNA, ATP, phospholipids)

Decomposition + mineralisation: organic P $\rightarrow PO_4^{3-}$ (returned to soil)

Sedimentation: $PO_4^{3-} + Ca^{2+} \rightarrow$ insoluble Ca-phosphate → marine sediment → rock (cycle restart over geological time)

Mass-balance for a soil-plant compartment (steady state):

$$\frac{dP}{dt} = (\text{weathering} + \text{atmospheric deposition}) - (\text{plant uptake} + \text{leaching} + \text{runoff})$$

Why "sedimentary"? P has **no significant gaseous phase** (PH_3 is unstable, negligible flux). All cycling occurs through soil, water, and rock.

Because rock weathering is slow (millennia), P is the **limiting nutrient** in many freshwater + terrestrial ecosystems. The animal → soil leg goes through excreta + dead remains; phosphatase enzymes hydrolyse organic P to release PO_4^{3-}.

Gaseous vs Sedimentary cycles — comparison

Feature	Gaseous cycle	Sedimentary cycle
Main reservoir	Atmosphere / hydrosphere	Earth's crust (rocks)
Example elements	C, N, O, H	P, S, Ca, K, Fe
Speed of cycling	Fast (yr to decades)	Slow (centuries to millennia)
Atmospheric phase?	Yes (CO_2, N_2, O_2)	Negligible
Limiting in ecosystems	Rarely	Often (P in lakes; Ca in chalk soils)

NCERT names **Carbon (gaseous)** and **Phosphorus (sedimentary)** as the two prototypes. Both cycles are powered by ecosystem-scale energy flow — without continuous photosynthesis + respiration + decomposition, the cycles would stall.

Ecosystem services

The products of ecosystem processes that benefit humans are called **ecosystem services**: pollination, seed dispersal, climate regulation, flood/drought control, nutrient cycling, soil formation, and — most quoted — **purification of air and water by forests**. Robert

Costanza et al. (1997) valued global ecosystem services at $\sim$ US \$33$trillion/yr$, roughly twice the global GNP at the time.

JEE/NEET extension — Costanza valuation

$\sim 50\,\%$ of the value comes from **soil formation**, $\sim 10\,\%$ each from recreation + nutrient cycling, smaller shares from climate regulation, habitat, raw materials. Out-of-syllabus but a high-recall exam fact.

Carbon and phosphorus cycle confusions

Carbon cycles through the atmosphere (CO_2) — gaseous, fast. **Phosphorus** has **no atmospheric phase** — it cycles via soil, water, and rock; sedimentary, slow. Don't write "phosphorus enters the atmosphere as PH_3" — that flux is negligible. The reservoir of carbon is the **oceans** ($\sim 38{,}000$ Gt) — not the atmosphere.

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Quick Reference — Ecosystem Formula Index

Concept / Quantity	Formula / Definition	Key Datum
GPP → NPP	NPP = GPP − R	NPP/GPP ≈ 0.3–0.7
Productivity	biomass / (area × time)	g m^{-2} yr^{-1}
Secondary productivity	rate of new biomass by consumers	always < NPP feeding it
Global NPP	~ 170 Gt dry / yr	ocean 55, land 115
PAR	$< 50\,\%$ of incident solar	400–700 nm
PAR capture by plants	2–$10\,\%$	sets food-chain ceiling
Lindeman's $10\,\%$ law	$E_{n+1} = 0.1\,E_n$	limits chains to 4–5
Ecological efficiency	$\eta = (E_{n+1}/E_n) \times 100\,\%$	typical $\sim 10\,\%$
Production efficiency	new biomass / assimilated	endotherms 1–$3\,\%$
After N transfers	$E_{N+1} = E_1(0.1)^N$	$E_5 \approx 10^{-4} E_1$
Decomposition kinetics	$M(t) = M_0\,e^{-kt}$	first-order in M
Detritus half-life	$t_{1/2} = 0.693/k$	tropics ~ 0.2 yr; boreal ~ 10 yr
Pyramid of number	individuals per level	inverts in parasitic chain
Pyramid of biomass	biomass per level (g m^{-2})	inverts in sea
Pyramid of energy	energy / area / time	**always upright**
Standing crop	living biomass at a moment	dry weight preferred
Photosynthesis	$6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$	C fixed into glucose
Respiration	$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$	C released to atmosphere
Atmospheric C pool	~ 700–870 Gt C	fast-exchange
Oceanic C pool	$\sim 38{,}000$ Gt C	largest mobile
Anthropogenic C flux	~ 10 Gt C / yr	climate-change driver
P reservoir	apatite, $Ca_5(PO_4)_3(OH, F, Cl)$	Earth's crust
P mass balance	dP/dt = inputs − outputs	weathering $\ll$ uptake $\Rightarrow$ P-limited
Gaseous vs sedimentary	atmosphere vs rock reservoir	C vs P prototypes