

UPSC CIVIL SERVICES · PRELIMS &amp; MAINS GS PAPER III

# Environment & Ecology

Complete notes for Prelims and Mains: concepts made simple, current data up to 2026, original diagrams and verified previous year questions.

Compiled by Arvind KrS

**28**

CHAPTERS

**9**

UNITS

**274**

PYQS 2011–2026

**132**

ORIGINAL DIAGRAMS

## IN THIS BOOK

- |                                      |                            |
|--------------------------------------|----------------------------|
| 01 Basics of Environment and Ecology | 02 Ecosystems              |
| 03 Biodiversity and Conservation     | 04 Environmental Pollution |
| 05 Climate Change                    | 06 Energy and Environment  |
| 07 Environmental Governance          | 08 Disaster Management     |
| 09 Acts and Protected Areas          |                            |

## Environment & Ecology

Notes for UPSC Prelims and Mains GS Paper III

2027 Edition · Compiled October 2026 · Compiled by Arvind KrS

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# Contents

|                |                                                                                   |            |
|----------------|-----------------------------------------------------------------------------------|------------|
| <b>UNIT 01</b> | <b>Basics of Environment and Ecology</b>                                          | <b>5</b>   |
| 01             | Environment, Habitat and Ecosystem .....                                          | 6          |
| 02             | Ecology: Organisation and Principles .....                                        | 38         |
| 03             | Functions of an Ecosystem: Succession and Homeostasis .....                       | 65         |
| 04             | Functions of an Ecosystem: Energy Flow and Trophic Levels .....                   | 81         |
| 05             | Functions of an Ecosystem: Biogeochemical Cycles .....                            | 98         |
| <b>UNIT 02</b> | <b>Ecosystems</b>                                                                 | <b>114</b> |
| 06             | Wetland Ecosystems: Wetlands, Estuaries and Mangroves .....                       | 115        |
| 07             | Natural Ecosystems: Biomes, Aquatic Ecosystems and Ecosystem Services .....       | 132        |
| <b>UNIT 03</b> | <b>Biodiversity and Conservation</b>                                              | <b>147</b> |
| 08             | Biodiversity and Loss of Biodiversity .....                                       | 148        |
| 09             | Biodiversity Conservation: Protected Areas, Laws and Global Agreements .....      | 172        |
| 10             | Wildlife Conservation I: Trade, Laws, Red List and Big Cats .....                 | 193        |
| 11             | Wildlife Conservation II: Elephants, Rhinos, Dolphins, Turtles and Vultures ..... | 209        |
| <b>UNIT 04</b> | <b>Environmental Pollution</b>                                                    | <b>223</b> |
| 12             | Air Pollution: Sources and Major Pollutants .....                                 | 224        |
| 13             | Air Pollution: Effects and Control .....                                          | 239        |
| 14             | Water Pollution .....                                                             | 255        |
| 15             | Soil Pollution and Land Degradation .....                                         | 270        |
| 16             | Solid and Hazardous Waste Management .....                                        | 283        |
| <b>UNIT 05</b> | <b>Climate Change</b>                                                             | <b>296</b> |
| 17             | Greenhouse Effect and Global Warming .....                                        | 297        |
| 18             | Impacts of Climate Change .....                                                   | 308        |
| 19             | Climate Mitigation: Sequestration, Geoengineering and Carbon Markets .....        | 319        |
| 20             | International Climate Negotiations .....                                          | 330        |

|    |                                                                       |     |
|----|-----------------------------------------------------------------------|-----|
| 21 | India and Climate Change: Commitments, Missions and Initiatives ..... | 340 |
|----|-----------------------------------------------------------------------|-----|

---

|                |                               |            |
|----------------|-------------------------------|------------|
| <b>UNIT 06</b> | <b>Energy and Environment</b> | <b>349</b> |
|----------------|-------------------------------|------------|

|    |                                        |     |
|----|----------------------------------------|-----|
| 22 | Renewable Energy and Clean Fuels ..... | 350 |
|----|----------------------------------------|-----|

---

|                |                                 |            |
|----------------|---------------------------------|------------|
| <b>UNIT 07</b> | <b>Environmental Governance</b> | <b>363</b> |
|----------------|---------------------------------|------------|

|    |                                                |     |
|----|------------------------------------------------|-----|
| 23 | Environmental Laws, Institutions and EIA ..... | 364 |
|----|------------------------------------------------|-----|

|    |                                                                   |     |
|----|-------------------------------------------------------------------|-----|
| 24 | Sustainable Development and Global Environmental Governance ..... | 380 |
|----|-------------------------------------------------------------------|-----|

|    |                                                     |     |
|----|-----------------------------------------------------|-----|
| 25 | Agriculture, Food Systems and the Environment ..... | 393 |
|----|-----------------------------------------------------|-----|

---

|                |                            |            |
|----------------|----------------------------|------------|
| <b>UNIT 08</b> | <b>Disaster Management</b> | <b>405</b> |
|----------------|----------------------------|------------|

|    |                           |     |
|----|---------------------------|-----|
| 26 | Disaster Management ..... | 406 |
|----|---------------------------|-----|

---

|                |                                 |            |
|----------------|---------------------------------|------------|
| <b>UNIT 09</b> | <b>Acts and Protected Areas</b> | <b>416</b> |
|----------------|---------------------------------|------------|

|    |                                                |     |
|----|------------------------------------------------|-----|
| 27 | Environmental and Wildlife Acts of India ..... | 417 |
|----|------------------------------------------------|-----|

|    |                                       |     |
|----|---------------------------------------|-----|
| 28 | Protected Area Network of India ..... | 427 |
|----|---------------------------------------|-----|

UNIT 01

5 CHAPTERS

# Basics of Environment and Ecology

*Environment, ecology and ecosystems: components, levels of organisation, succession, energy flow and nutrient cycles.*

## CHAPTERS

|    |                                                           |    |
|----|-----------------------------------------------------------|----|
| 01 | Environment, Habitat and Ecosystem                        | 6  |
| 02 | Ecology: Organisation and Principles                      | 38 |
| 03 | Functions of an Ecosystem: Succession and Homeostasis     | 65 |
| 04 | Functions of an Ecosystem: Energy Flow and Trophic Levels | 81 |
| 05 | Functions of an Ecosystem: Biogeochemical Cycles          | 98 |

## TOPICS COVERED IN THIS UNIT

### 01 Environment, Habitat and Ecosystem

Environment: Meaning and Components · Ecology and Related Terms · Habitat · Ecosystem · Abiotic Components and Limiting Factors · Biotic Components of an Ecosystem

### 02 Ecology: Organisation and Principles

Ecology and Its Levels of Organisation · Population · Community · Ecological Niche and Niche Partitioning · Biome · Ecotone and Ecocline · Biosphere · Adaptation · Variation and Mutation · Natural Selection and Theories of Evolution · Adaptive Radiation and Convergent Evolution · Speciation · Extinction

### 03 Functions of an Ecosystem: Succession and Homeostasis

Ecological Succession · Types of Succession · Succession on Land and in Water · The Climax Community · Disturbance and Succession in a Changing World · Homeostasis in Ecosystems

### 04 Functions of an Ecosystem: Energy Flow and Trophic Levels

Energy in Ecosystems · Productivity · Trophic Levels · Food Chains · Food Webs · Interactions Between Species · Ecological Pyramids · Energy Flow and the Ten Per Cent Law · Bioaccumulation and Biomagnification

### 05 Functions of an Ecosystem: Biogeochemical Cycles

Nutrients and Their Cycles · The Water Cycle · The Carbon Cycle · The Nitrogen Cycle · The Methane Cycle · The Phosphorus Cycle · The Sulphur Cycle

ENVIRONMENT & ECOLOGY

PRELIMS · GS PAPER III

# Environment, Habitat and Ecosystem

01

Pollution, biodiversity, climate change, conservation: every topic in this subject eventually comes back to a few basic ideas. What is the environment? Where does an organism live, and what does it do there? How do living things and their physical surroundings work together as an ecosystem? If these terms are clear, the rest of the subject becomes much easier to organise.

They also matter in their own right in Prelims. Many questions turn on the difference between two closely related words, such as habitat and niche, decomposer and detritivore, or producer and consumer. A loose idea of either word is usually enough to pick the wrong option.

## SYLLABUS

PRELIMS

General issues on Environmental Ecology, Bio-diversity and Climate Change

MAINS · GS PAPER III

Conservation, environmental pollution and degradation, environmental impact assessment

## CONTENTS

|                                            |                                      |
|--------------------------------------------|--------------------------------------|
| 01 Environment: Meaning and Components     | 02 Ecology and Related Terms         |
| 03 Habitat                                 | 04 Ecosystem                         |
| 05 Abiotic Components and Limiting Factors | 06 Biotic Components of an Ecosystem |
| 07 Key Terms at a Glance                   | 08 Previous Year Questions           |

## 01 Environment: Meaning and Components

The word comes from the French *environner*, to surround. At its simplest, the **environment is everything around an organism that affects its life**. Ecologists put it more precisely: it is the **sum of all the physical, chemical and biological conditions** acting on an organism or a group of organisms.

- It supplies what every organism needs, namely **energy, food, water, oxygen, shelter and space**, and it takes back what the organism releases: heat, carbon dioxide and wastes.
- The influence runs both ways. The environment shapes organisms through **natural selection**; organisms in turn reshape the environment. Earthworms make soil, corals build reefs and people build cities.
- Even an individual's visible traits are a joint product. Its **phenotype** (size, colour, form) comes from its **genotype interacting with the environment**. Two cuttings of the same plant, one grown in shade and one in sun, end up looking quite different.
- The environment keeps changing: within minutes as a cloud passes, over a season with the monsoon, and over thousands of years with ice ages.

*“environment” includes water, air and land and the inter-relationship which exists among and between water, air and land, and human beings, other living creatures, plants, micro-organism and property.*

Section 2(a), Environment (Protection) Act, 1986: the definition used in Indian law

## The Four Spheres of the Environment

Geographers describe the Earth's physical environment as four interacting spheres. The atmosphere, hydrosphere and lithosphere are physical. The fourth, the **biosphere**, is the thin zone where the other three overlap and life is possible.

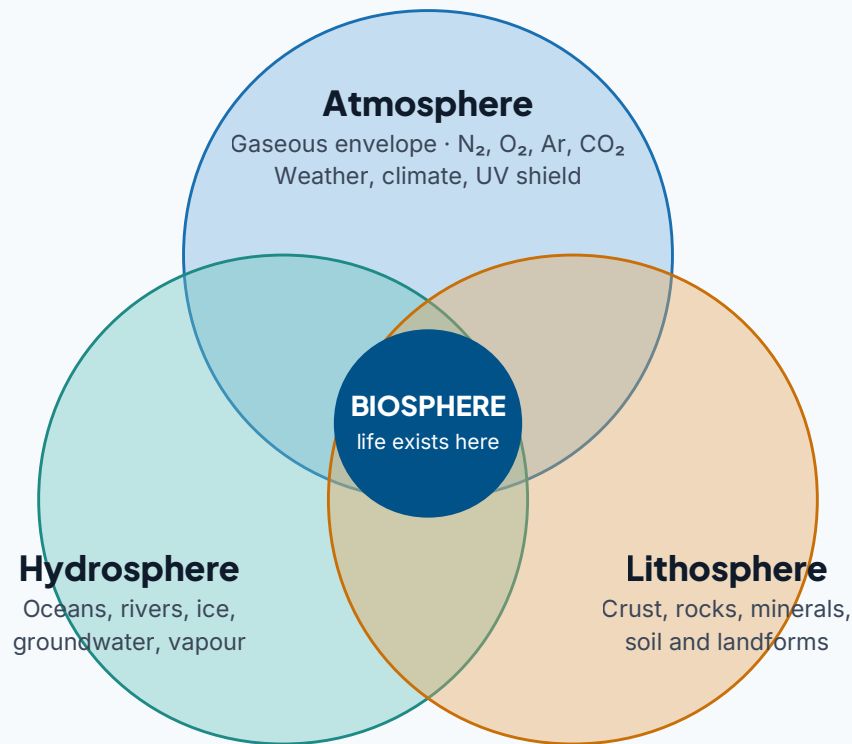
The biosphere runs mostly on sunlight captured by green plants. It is not entirely solar-powered, though. Near deep-sea hydrothermal vents, where no light ever reaches, whole communities live on energy that bacteria extract from chemicals such as hydrogen sulphide.



**Fig. 1.1** The whole biosphere in one frame: Earth photographed by the crew of Apollo 17 in 1972

| SPHERE             | WHAT IT IS                                                                                                                                                                                          | WHY IT MATTERS TO LIFE                                                                                                                                                                     |
|--------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Atmosphere</b>  | The envelope of gases around the Earth: nitrogen (about <b>78%</b> ), oxygen (about <b>21%</b> ), argon (about <b>0.93%</b> ), carbon dioxide (about <b>0.04%</b> ), plus water vapour and aerosols | Supplies O <sub>2</sub> for respiration and CO <sub>2</sub> for photosynthesis; the ozone layer screens out harmful UV; it moves heat and moisture around the globe as weather and climate |
| <b>Hydrosphere</b> | All the water on Earth: oceans, ice caps and glaciers, groundwater, lakes, rivers and water vapour                                                                                                  | The medium for nearly all the chemistry of life; habitat for aquatic organisms; its high specific heat moderates temperatures                                                              |

| SPHERE             | WHAT IT IS                                                                                                         | WHY IT MATTERS TO LIFE                                                                                                                     |
|--------------------|--------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Lithosphere</b> | The rigid outer shell, made of the crust and the uppermost mantle, with its rocks, minerals, landforms and soil    | Source of mineral nutrients; soil anchors plants and stores water; landforms shape local climate                                           |
| <b>Biosphere</b>   | The life-supporting zone, from a few kilometres down in rocks and ocean trenches to a few kilometres up in the air | The only place in the universe where life is known to exist; it ties the other three together through flows of energy and cycles of matter |



The biosphere is not a separate layer: it is the narrow zone where air, water and land overlap and support life.

**Fig. 1.2** The biosphere sits where the atmosphere, hydrosphere and lithosphere overlap

**Carbon dioxide is a tiny share of the air, but it is rising fast. At Mauna Loa the annual average reached about 427 ppm (0.0427%) in 2025, against roughly 280 ppm before the Industrial Revolution. The figures of 0.03% or 0.038% found in older books are out of date.**

### ■ How much water, and where?

Almost all of Earth's water is salt water in the oceans. Only about 2.5% is fresh, and most of that is not in rivers and lakes. Ice caps and glaciers hold more than two-thirds of all fresh water, and groundwater holds most of the rest. Surface water in rivers, lakes and swamps, together with soil moisture and water vapour, adds up to only about 1% of the fresh water.

### All water on Earth



### Where the fresh water is



Rivers, lakes, swamps, soil moisture, air and living things together hold only about 1.2% of fresh water, so the water we see on land is a tiny sliver; groundwater holds roughly 25 times more.

Fig. 1.3 Fresh water is scarce, and most of it is locked in ice or underground

## Natural and Human-Made Environment

- The **natural environment** is land, water, air, soil, plants and animals that exist without human design: a forest, a river, a coral reef.
- The **human-made (anthropogenic) environment** is what people have shaped or built: farms, villages, cities, dams, roads and industries.
- Most real landscapes are a blend of the two. A sacred grove, a tank-fed village or a tea estate is partly natural and partly made by people, and many environmental problems arise where the two meet.

## Biotic and Abiotic: Where the Line Falls

Every component of the environment belongs to one of two groups:

- **Biotic components** are living organisms *and* everything produced by living or once-living organisms.
- **Abiotic components** are non-living physical and chemical factors: sunlight, temperature, water, air, rocks, minerals and the chemistry of soil and water.

### ■ “Biotic” covers more than living things

- Products of life remain biotic after death. Bones, shells, coral skeletons, feathers, hair, dung, leaf litter, dead and decaying matter (detritus) and fossils all count.
- **Coal, petroleum and natural gas are biotic in origin**, since they formed from buried plants and plankton. Resource geography calls the same fuels *non-renewable*. Origin and renewability are two separate ways of classifying a resource, and questions sometimes mix them up deliberately.
- In everyday ecology, “biotic” and “living” are used almost interchangeably, because it is living organisms that drive ecosystem processes.

### ■ Is soil biotic or abiotic?

- Soil is a **mixture of both**. Its mineral particles (sand, silt and clay), water and air are abiotic. Its roots, microbes, earthworms and decaying litter are biotic.

- **Humus** is the dark, spongy, jelly-like organic matter that remains once most decomposition is over. The process that forms it is called *humification*; it happens naturally in soil and is deliberately speeded up when compost is made.
- Humus comes from living matter, yet ecologists usually treat it as abiotic. It no longer has the structure of the organisms it came from, and it breaks down only very slowly (*mineralisation*).
- Its value to soil is hard to overstate:
  - it supplies nutrients, especially **nitrogen**, and stores them for the long term;
  - it holds on to nutrient ions so they are not washed away;
  - it increases the soil's **microporosity**, so the soil holds more moisture;
  - it gives fertile soils their dark colour.

## ■ Organic and inorganic compounds

| BASIS                     | ORGANIC COMPOUNDS                                                                                     | INORGANIC COMPOUNDS                                                                                                                |
|---------------------------|-------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------|
| <b>Working rule</b>       | Contain carbon, usually with at least one carbon–hydrogen (C–H) bond                                  | Usually have no C–H bonds                                                                                                          |
| <b>Examples</b>           | Carbohydrates (glucose, starch, cellulose), proteins, lipids, nucleic acids (DNA, RNA), methane, urea | Water, mineral salts, acids, bases and metals; also CO <sub>2</sub> , CO, carbonates and cyanides, even though they contain carbon |
| <b>Role in ecosystems</b> | Store chemical energy and pass it along food chains                                                   | The raw nutrients that producers take up and that cycle back to the environment                                                    |

The C–H rule has exceptions. **Urea**, CO(NH<sub>2</sub>)<sub>2</sub>, has no C–H bond but is still classed as organic: it is a product of metabolism, and its carbon is bound in organic functional groups. It also has a place in the history of science. In **1828** Friedrich Wöhler made urea in the laboratory from inorganic starting material, the first time anyone showed that an organic compound did not need a living body to produce it.

## | Carrying Capacity, Assimilative Capacity and Ecological Footprint

Three ideas link the environment to sustainable development, and they appear together in Prelims statements.

- **Carrying capacity:** the largest population of a species that an environment can support indefinitely with the food, water and space available.
- **Assimilative (absorptive) capacity:** how much waste an environment can absorb and break down without being harmed. A river that cleans itself downstream of a small town is working within its assimilative capacity; the same river below a large untreated sewage outfall is not.
- An environment stays healthy as long as two conditions hold:
  - resources are not used faster than they regenerate;
  - wastes are not produced faster than they can be assimilated.
- **Ecological footprint:** the area of biologically productive land and water needed to produce what a population consumes and to absorb its wastes, chiefly its carbon dioxide. By current estimates, humanity as a whole uses resources as though it had about **1.7 Earths**, which is an ecological overshoot.

- A narrower measure, the **land footprint**, counts the land needed to produce the goods consumed by a person, a company or a country, including land abroad.

## 02 Ecology and Related Terms

**Ecology** comes from the Greek *oikos* (house or dwelling place) and *logos* (study). The German zoologist **Ernst Haeckel coined the word in 1866**. It is the science of how organisms interact **with one another and with their physical surroundings**, and of how those interactions decide where organisms live and in what numbers.

- **Autecology** studies one species in relation to its environment, for example how sand temperature decides whether olive ridley hatchlings come out male or female.
- **Synecology** studies whole communities and ecosystems, for example how the plants and animals of a mangrove forest depend on one another.
- Ecology is a branch of science. **Environmentalism** is a set of values and a social movement that draws on ecology. It holds that people should live in step with the rhythms of nature rather than manipulate it for short-term gain, and it treats damaged ecosystems as something that can and should be restored.

### Telling the Key Terms Apart

| TERM                    | MEANING                                                                                                           | IN ONE WORD      |
|-------------------------|-------------------------------------------------------------------------------------------------------------------|------------------|
| <b>Environment</b>      | All the surroundings, living and non-living, that affect an organism; it may or may not contain life              | Surroundings     |
| <b>Habitat</b>          | The particular place where an organism naturally lives and finds what it needs                                    | Address          |
| <b>Ecological niche</b> | The organism's functional role together with all the conditions and resources it uses                             | Profession       |
| <b>Ecosystem</b>        | A community of organisms and its physical environment, working as a unit through energy flow and nutrient cycling | Working unit     |
| <b>Biosphere</b>        | All the ecosystems of the Earth taken together                                                                    | Global ecosystem |
| <b>Ecology</b>          | The science that studies all of the above                                                                         | Subject          |

#### REMEMBER

- Every habitat is part of an environment, but not every environment is a habitat. The surface of the Moon has an environment but supports no life, so it is no one's habitat.

- An ecosystem contains many habitats, and the biosphere contains every ecosystem. Since the biosphere includes all life on Earth, it also holds the largest possible population of any level of organisation.
- Ecology is a subject, not a place. When people speak of “the ecology of a region”, they mean the web of relationships found there.

03

## Habitat

A **habitat** is the natural home of an organism, the physical place where it lives, feeds, shelters and breeds. Ecologists like to call it the organism's “**address**”. Each habitat has its own abiotic conditions (temperature, moisture, light, soil or water chemistry) and its own biotic conditions (food, predators, competitors).

- **Shared by many species:** one pond is home to algae, water lilies, insects, frogs, fish and snails.
- **Any scale:** from the open ocean to the underside of a stone.
- **Changes with time:** a seasonal wetland is a lake during the monsoon and a grassland in the dry months, and different species use each phase.
- **Specific to each species:** a dense forest is ideal for a hornbill but useless to a blackbuck, which needs open grassland.
- **Tied to a native range:** a species occurs naturally only where its habitat exists within its evolutionary home. The indri is a lemur found only in Madagascar, the bonobo lives in the forests of the Democratic Republic of the Congo, and the elk ranges across North America and parts of Asia. None of them is native to Brazil or Indonesia.

A related term is **biotope**: a well-defined area with fairly uniform environmental conditions that supports a particular community of plants and animals. It is almost a synonym of habitat, but it refers to the place of a whole community rather than one species, and it is usually small. A pond, a park, a hedgerow and even an aquarium can each be described as a biotope. Biotopes work best when they stay connected to the surrounding landscape rather than cut off from it.

### Types of Habitats



Freshwater lake: Loktak, Manipur

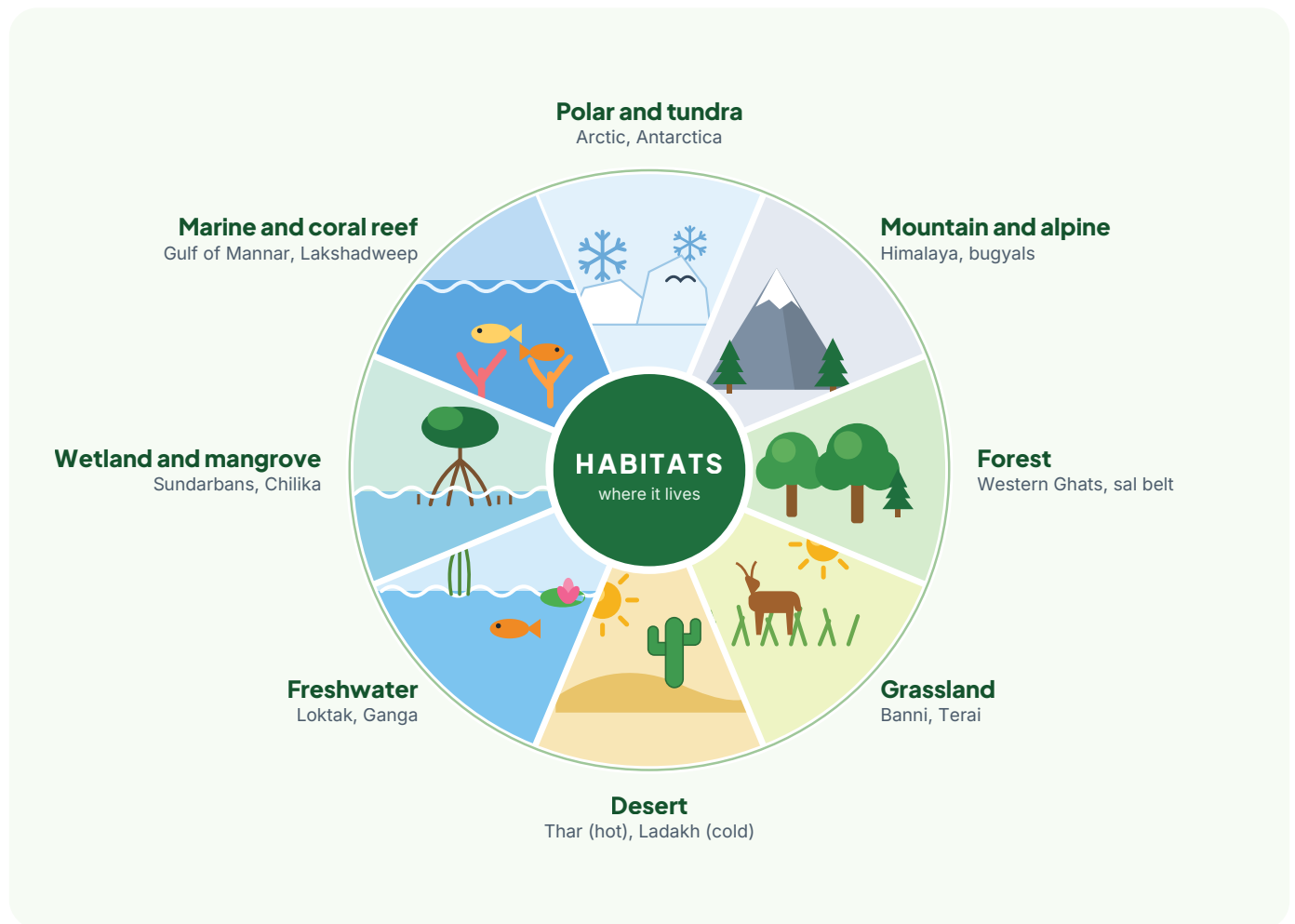


Hot desert: khejri trees in the Thar



Estuarine: mangroves of the Sundarbans

**Fig. 1.4** Three Indian habitats with very different limiting conditions: still fresh water, extreme dryness and changing salinity



**Fig. 1.5** The major habitats of the Earth, with Indian examples

| HABITAT                            | DEFINING CONDITIONS                                             | INDIAN EXAMPLES                                                                         |
|------------------------------------|-----------------------------------------------------------------|-----------------------------------------------------------------------------------------|
| <b>Forest</b>                      | Shade, high humidity, layered vegetation, deep leaf litter      | Evergreen forests of the Western Ghats; sal forests of central India                    |
| <b>Grassland</b>                   | Open canopy; shaped by fire, grazing and seasonal rain          | Banni grasslands of Kutch, Terai grasslands, the shola-grassland mosaic of the Nilgiris |
| <b>Hot desert</b>                  | Very little rain; a wide gap between day and night temperatures | Thar Desert of Rajasthan                                                                |
| <b>Cold desert and alpine</b>      | Low temperature, thin air, strong UV, short growing season      | Ladakh and Spiti; the alpine meadows ( <i>bugyals</i> ) of Uttarakhand                  |
| <b>Freshwater: still (lentic)</b>  | Standing water, layered by temperature and light                | Loktak Lake with its <i>phumdis</i> , Dal Lake, village ponds                           |
| <b>Freshwater: flowing (lotic)</b> | Current, well-oxygenated water, shifting channels               | Ganga and Brahmaputra; the Chambal, home of the gharial                                 |

| HABITAT                     | DEFINING CONDITIONS                                                       | INDIAN EXAMPLES                                                                    |
|-----------------------------|---------------------------------------------------------------------------|------------------------------------------------------------------------------------|
| <b>Brackish / estuarine</b> | Fresh and salt water mix; salinity rises and falls with tides and seasons | Chilika and Pulicat lagoons; the Sundarbans                                        |
| <b>Marine</b>               | High, steady salinity; light fades with depth                             | Coral reefs of the Gulf of Mannar, Lakshadweep and the Andaman and Nicobar Islands |

Animals are also grouped by the part of a habitat they use:

- **Arboreal** animals live in trees: the lion-tailed macaque, the Malabar giant squirrel and the peacock (Gooty) tarantula. The tarantula is a critically endangered *spider*, not a crustacean, and lives in tree holes in a small area of forest in Andhra Pradesh.
- **Fossorial** animals burrow, such as the Indian pangolin.
- The other groups are **aquatic**, **terrestrial** and **aerial** animals.



**Fig. 1.6** The peacock (Gooty) tarantula: an arboreal spider confined to a small patch of forest in the Eastern Ghats

## Microhabitat

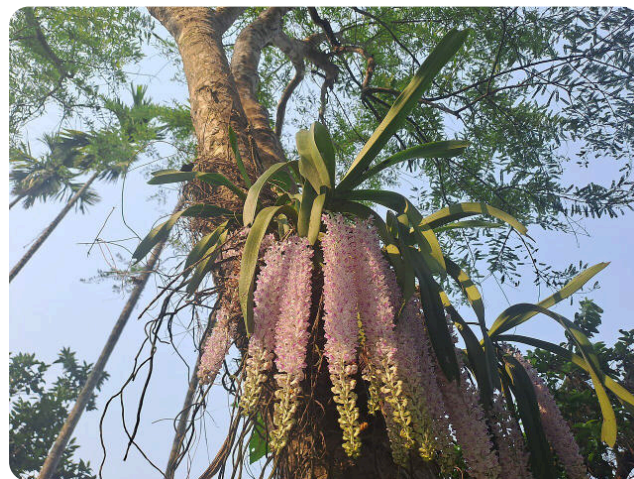
A **microhabitat** is a small patch within a larger habitat that has its own distinct conditions. A single forest contains many of them:

- the damp, dark space under a fallen log;
- cracks in tree bark;
- the leaf litter on the forest floor;
- the water held in a pitcher plant;
- the gut of a termite, where microbes digest wood.

Tree branches high in the canopy are the microhabitat of **epiphytes**, plants that grow on other plants purely for support and light. Many orchids, ferns and mosses are epiphytes. They do not take food from the host, so they are not parasites. Their spongy aerial roots (velamen in orchids) soak up moisture from humid air and rain.

The **foxtail orchid** is a good Indian example. It is an epiphyte and the **State flower of both Assam and Arunachal Pradesh**. Do not assume it is endemic, though: it occurs widely across South and South-East Asia.

Microhabitats explain how one large tree can support hundreds of species. They are also why clearing dead wood and leaf litter quietly reduces biodiversity.



**Fig. 1.7** Foxtail orchid (*Rhynchostylis retusa*), an epiphyte and the State flower of Assam and Arunachal Pradesh

## Habitat and Ecological Niche

If the habitat is the address, the **ecological niche is the profession**. A niche describes the role a species plays in its community: what it eats, what eats it, when and where it is active, and the full range of conditions it can tolerate and resources it uses.

### How the idea developed

- **Joseph Grinnell (1917)** saw the niche as the set of *environmental conditions* a species needs. This is the *habitat niche*.
- **Charles Elton (1927)** saw it as the species' *functional role*, especially its place in the food web. This is the *functional niche*.
- **G. Evelyn Hutchinson (1957)** described the niche as an *n-dimensional hypervolume*. Every factor (temperature, food size, humidity and so on) is one axis, and the niche is the space within which the species can survive. He also separated two versions of it:
  - the **fundamental niche**, everything the species *could* use if it had no competitors;
  - the **realised niche**, the smaller part it *actually* uses once competition and predation take effect.

| BASIS          | HABITAT                                             | ECOLOGICAL NICHE                                                                                        |
|----------------|-----------------------------------------------------|---------------------------------------------------------------------------------------------------------|
| <b>Meaning</b> | The physical place where an organism lives          | Its functional role plus all the conditions and resources it uses                                       |
| <b>Nature</b>  | Spatial: a location                                 | Functional: a way of life                                                                               |
| <b>Sharing</b> | Many species share one habitat                      | No two species hold exactly the same niche in the same place for long                                   |
| <b>Example</b> | A hornbill and a woodpecker live in the same forest | The hornbill eats fruit and spreads seeds; the woodpecker drills bark for insects. Their niches differ. |

The last row reflects the **competitive exclusion principle** stated by G.F. Gause in **1934**: when two species compete for exactly the same limited resources, one eventually pushes the other out. Species that share a habitat avoid this by **niche partitioning**. They feed at different heights, at different times of day, or on prey of different sizes. That is how several species of warbler can feed in one tree, or several egrets in one marsh, without one wiping out the others.

#### CONCEPT CHECK

The term that covers “not only the physical space occupied by an organism, but also its functional role in the community” is the **ecological niche**, not the habitat. Two other terms are common distractors:

- **Home range**: the area an individual animal moves through regularly.

- **Ecotone:** the transition zone between two ecosystems.

## Why Habitat Matters for Conservation

- Global assessments rank the **conversion of land and sea** as the **largest direct cause of biodiversity loss**. In practice this means habitat being cleared, drained, ploughed or built over. It comes ahead of direct exploitation, climate change, pollution and invasive species.
- **Habitat specialists** suffer most because they have nowhere else to go:
  - the **Great Indian Bustard** of the semi-arid grasslands, which also dies in collisions with overhead power lines;
  - the **Hangul** deer, now confined largely to Dachigam National Park.
- **Fragmentation** breaks a large habitat into isolated patches. Small, cut-off populations lose genetic variety, and animals moving between the patches come into conflict with people. Elephants crossing farmland between forest blocks are the familiar example.
- **Connectivity** between protected areas therefore matters as much as their size. Corridors keep seasonal migration routes open, enlarge the effective habitat and allow genes to flow between populations.
- Protected areas, corridors, eco-sensitive zones and wetland conservation are all, at heart, ways of **protecting habitat**. Each is covered in the conservation chapters.



**Fig. 1.8** Great Indian Bustards need wide, open grasslands, a habitat that has shrunk to a few pockets

04

## Ecosystem

An **ecosystem** is a **community of living organisms together with its physical environment, functioning as a single unit**. Energy flows through it and nutrients cycle between its living and non-living parts. The British ecologist **Arthur Tansley coined the term in 1935**. He wanted a word that made it clear organisms cannot be studied apart from the environment they live in.

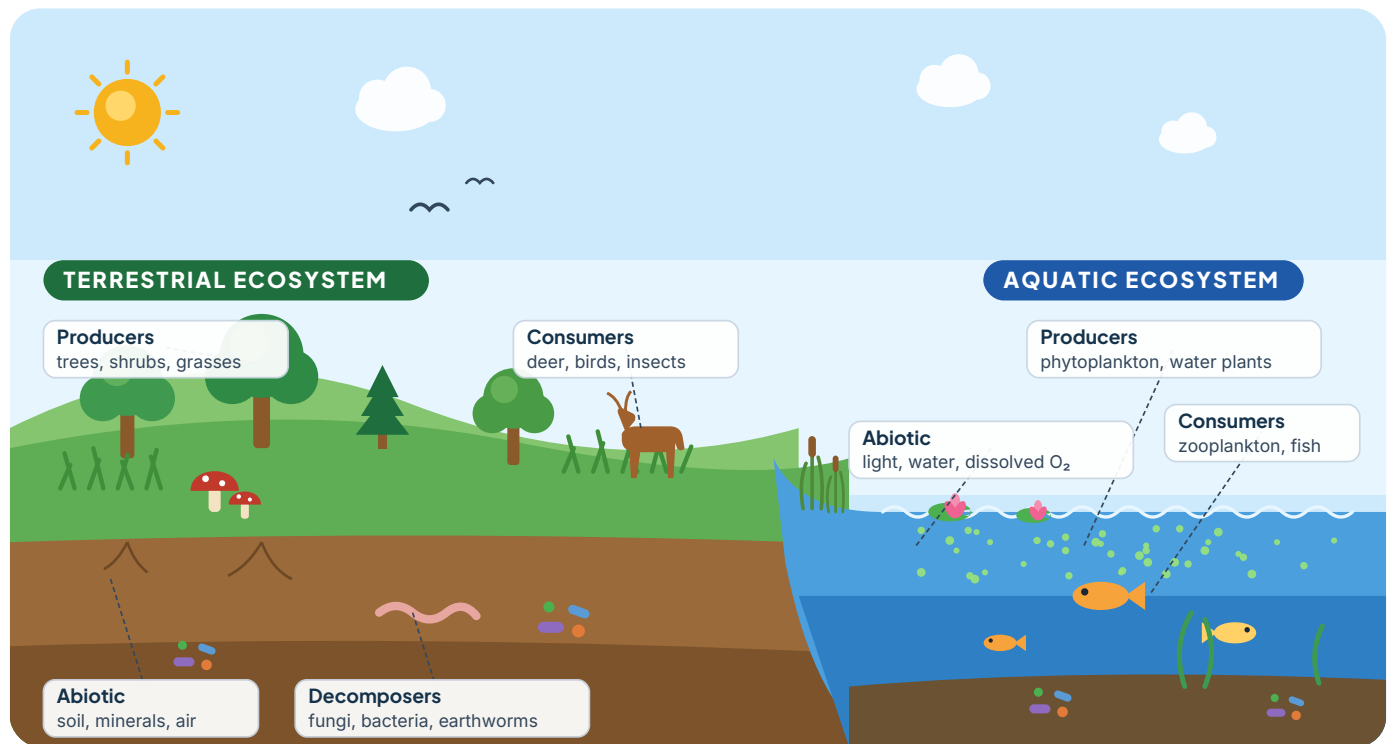


Fig. 1.9 A land and a water ecosystem side by side: each has producers, consumers, decomposers and an abiotic setting

## Characteristics of an Ecosystem

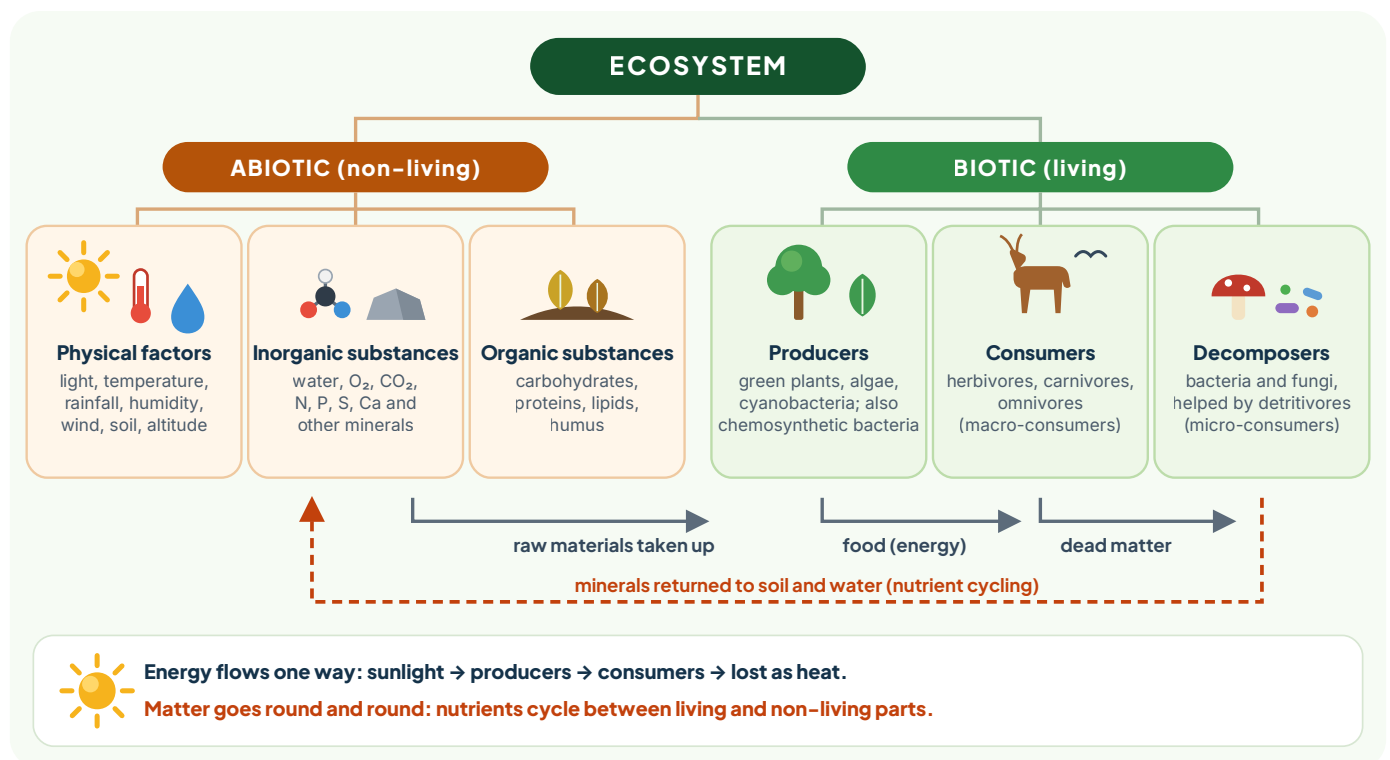


Fig. 1.10 Components of an ecosystem and how they are linked

- **The living and non-living parts cannot be separated.** Producers need sunlight, CO<sub>2</sub>, water and minerals; consumers need producers; decomposers return minerals to the soil and water.
- **Energy flows one way, while matter cycles.** Solar energy enters, passes along food chains and leaves as heat, so it is never reused. Carbon, nitrogen, phosphorus and other nutrients go round in cycles.

- **It regulates itself, within limits.** Feedback keeps populations and nutrient levels fairly steady (ecological homeostasis). A strong enough shock can tip the system into a different state.
- **Diversity brings stability.** An ecosystem is called stable when its overall properties, such as total biomass and the mix of species, vary little from year to year. Large ecosystems rich in species are usually the most stable, because they have more links between species and more “back-up” species to take over when one declines. In long-running grassland experiments, plots with more plant species showed noticeably smaller swings in total biomass through droughts.
- **It changes over time** through ecological succession, and responds to disturbances such as fire, floods and grazing.
- **It has no fixed size.** A drop of pond water, a rotting log, a lake, a forest and the whole biosphere can each be studied as an ecosystem.
- **It is an open system.** Ecosystems exchange energy and matter with their surroundings: rivers carry nutrients to estuaries, and migratory birds move energy between continents. The Earth as a whole is a little different:
  - it is effectively *closed for matter*, since apart from a trickle of meteorites in and light gases out, the same atoms are recycled;
  - it is *open for energy*, receiving sunlight and radiating heat to space.

## Structure and Function of an Ecosystem

| STRUCTURE: WHAT IT IS MADE OF                                                                                                                        | FUNCTION: WHAT IT DOES                                                                  |
|------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------|
| <b>Species composition:</b> which plants, animals and microbes are present                                                                           | <b>Productivity:</b> the rate at which producers fix energy as new biomass              |
| <b>Stratification:</b> vertical layering, such as canopy, understorey, shrub and herb layers in a forest, or the surface and bottom layers of a lake | <b>Energy flow:</b> the one-way transfer of energy through trophic levels               |
| <b>Standing crop:</b> the biomass present per unit area at a given time                                                                              | <b>Decomposition:</b> breaking dead matter down into simple inorganic substances        |
| <b>Standing state:</b> the quantity of nutrients in the soil or water at a given time                                                                | <b>Nutrient cycling:</b> the movement of elements between organisms and the environment |
| <b>Abiotic setting:</b> climate, soil, water and topography                                                                                          | <b>Regulation and change:</b> homeostasis and ecological succession                     |

Each function in the right-hand column has a chapter of its own later in these notes: food chains and trophic levels, ecological pyramids, productivity, biogeochemical cycles and succession.

## Types of Ecosystems

Ecosystems are first divided by origin into **natural** and **human-made** ones, and natural ecosystems are then split by medium into **terrestrial** and **aquatic**.

## ■ Natural ecosystems

- **Terrestrial:** forests, grasslands, deserts, tundra and mountains. At the global scale these are grouped into **biomes**.
- **Aquatic:** freshwater (lentic ponds and lakes, lotic streams and rivers, and wetlands); marine (open ocean, coral reefs, deep sea); and transitional systems (estuaries, lagoons, mangroves and salt marshes, where fresh and salt water meet).

## ■ Human-made (artificial) ecosystems

Croplands, plantations, orchards, reservoirs, aquaculture ponds, aquaria and cities are all human-made ecosystems.

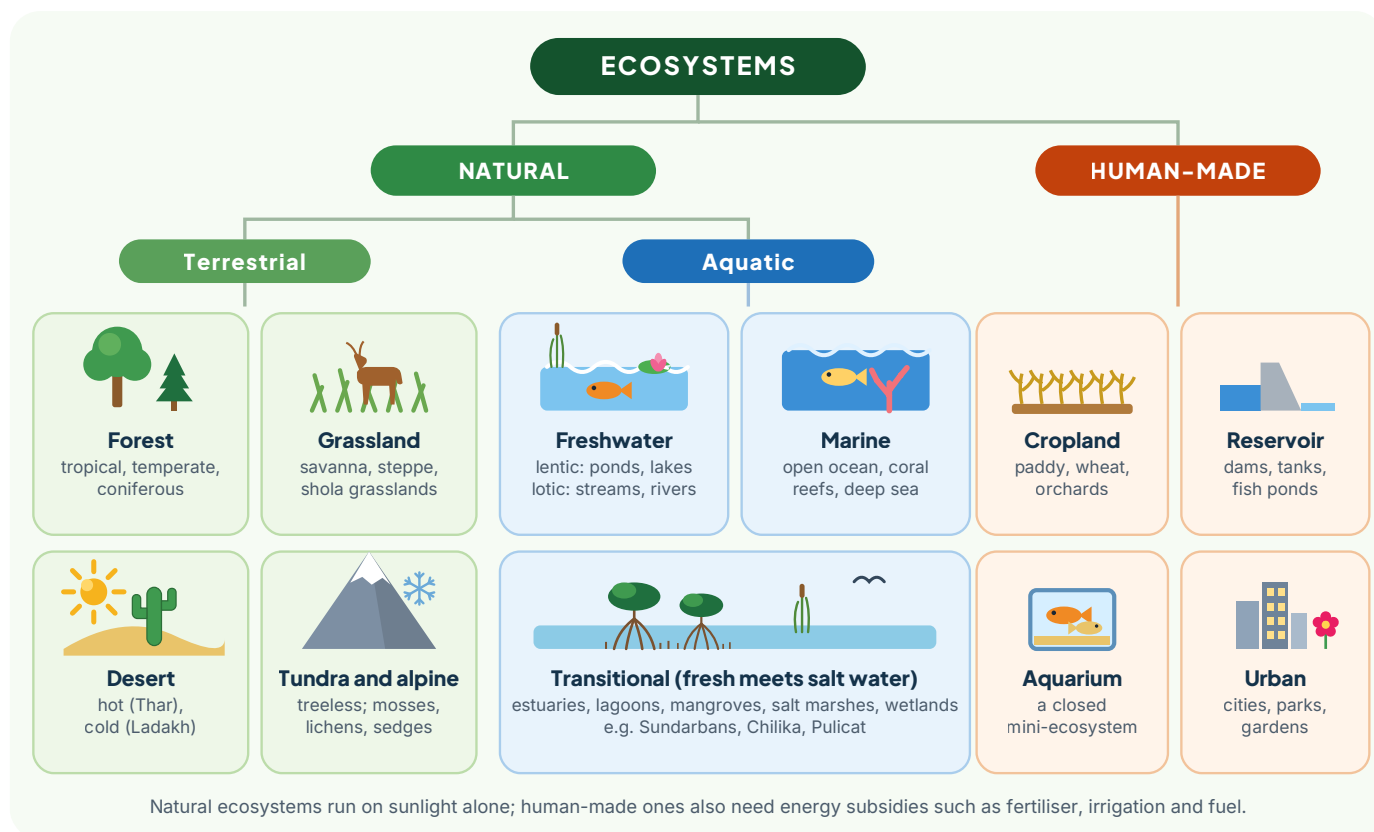


Fig. 1.11 Classification of ecosystems

| BASIS                    | NATURAL ECOSYSTEM                   | HUMAN-MADE ECOSYSTEM                                                                        |
|--------------------------|-------------------------------------|---------------------------------------------------------------------------------------------|
| <b>Species diversity</b> | High, with many interacting species | Low, often a single crop (monoculture)                                                      |
| <b>Energy source</b>     | Sunlight alone                      | Sunlight plus <b>energy subsidies</b> : fertiliser, irrigation, pesticides, fuel and labour |
| <b>Nutrient cycling</b>  | Largely closed and self-sustaining  | Open; nutrients carried away with the harvest have to be replaced                           |

| BASIS                  | NATURAL ECOSYSTEM                                   | HUMAN-MADE ECOSYSTEM                                        |
|------------------------|-----------------------------------------------------|-------------------------------------------------------------|
| <b>Self-regulation</b> | Strong, through predators, competition and feedback | Weak; prone to pest outbreaks and needs constant management |
| <b>Stability</b>       | Generally more resilient                            | Breaks down quickly once management stops                   |

#### INDIA LINK

Several traditional systems fall between the two columns and make good Mains examples of sustainable use:

- sacred groves such as the *devrais* of Maharashtra and the *kavus* of Kerala;
- the *zabo* farming system of Nagaland;
- the paddy-cum-fish culture of the Apatani plateau in Arunachal Pradesh.

Each shows that a human-made system can keep high diversity and recycle its own nutrients.

05

## Abiotic Components and Limiting Factors

Abiotic factors set the stage on which life plays out. They are usually grouped as follows:

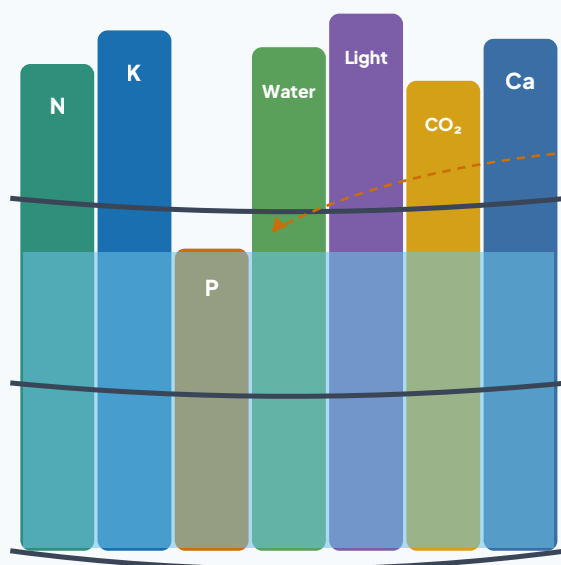
| GROUP                       | FACTORS                                                                                 | EXAMPLE OF INFLUENCE                                                           |
|-----------------------------|-----------------------------------------------------------------------------------------|--------------------------------------------------------------------------------|
| <b>Climatic</b>             | Light, temperature, precipitation, humidity, wind                                       | Rainfall decides whether a region carries forest, grassland or desert          |
| <b>Edaphic (soil)</b>       | Texture, structure, pH, minerals, soil water, aeration, humus                           | Moisture-holding black soils suit cotton; acidic laterites suit tea and cashew |
| <b>Topographic</b>          | Altitude, slope, aspect (the direction a slope faces)                                   | Vertical bands of vegetation in the Himalaya                                   |
| <b>Inorganic substances</b> | Water, CO <sub>2</sub> , O <sub>2</sub> , nitrogen, phosphorus, sulphur, calcium, salts | Raw materials taken up by producers                                            |
| <b>Organic substances</b>   | Carbohydrates, proteins, lipids, humus                                                  | The bridge between the living and non-living worlds, recycled by decomposers   |

### Limiting Factors

An organism needs many things at once. Its growth, survival or spread, though, is often controlled by **the one factor in shortest supply, or furthest from its ideal level**. That factor is called the **limiting factor**.

## ■ Liebig's Law of the Minimum

- The German chemist **Justus von Liebig** popularised it in **1840** while studying crop nutrition.
- Growth depends on the nutrient that is **scarcest relative to the plant's needs**, not on the total supply of nutrients. Adding more of a plentiful nutrient achieves nothing while the scarce one stays short.
- Typical limiting nutrients:
  - **nitrogen** in most land ecosystems;
  - **phosphorus** in most freshwater lakes, which is why phosphate-rich sewage and detergents set off algal blooms (eutrophication);
  - **iron** in large stretches of the open ocean such as the Southern Ocean. This is why "ocean iron fertilisation" has been tried as a way to boost plankton and draw down CO<sub>2</sub>.



### The shortest stave sets the level

Water spills out at the height of the shortest stave, however tall the others are.

In the same way, a crop held back by phosphorus will not grow more if we add only nitrogen or water. Growth rises only when the scarce nutrient is supplied, until another factor becomes limiting.

#### Liebig's law of the minimum

growth is set by the scarcest resource

Fig. 1.12 Liebig's barrel: the shortest stave, here phosphorus, sets the level the barrel can hold

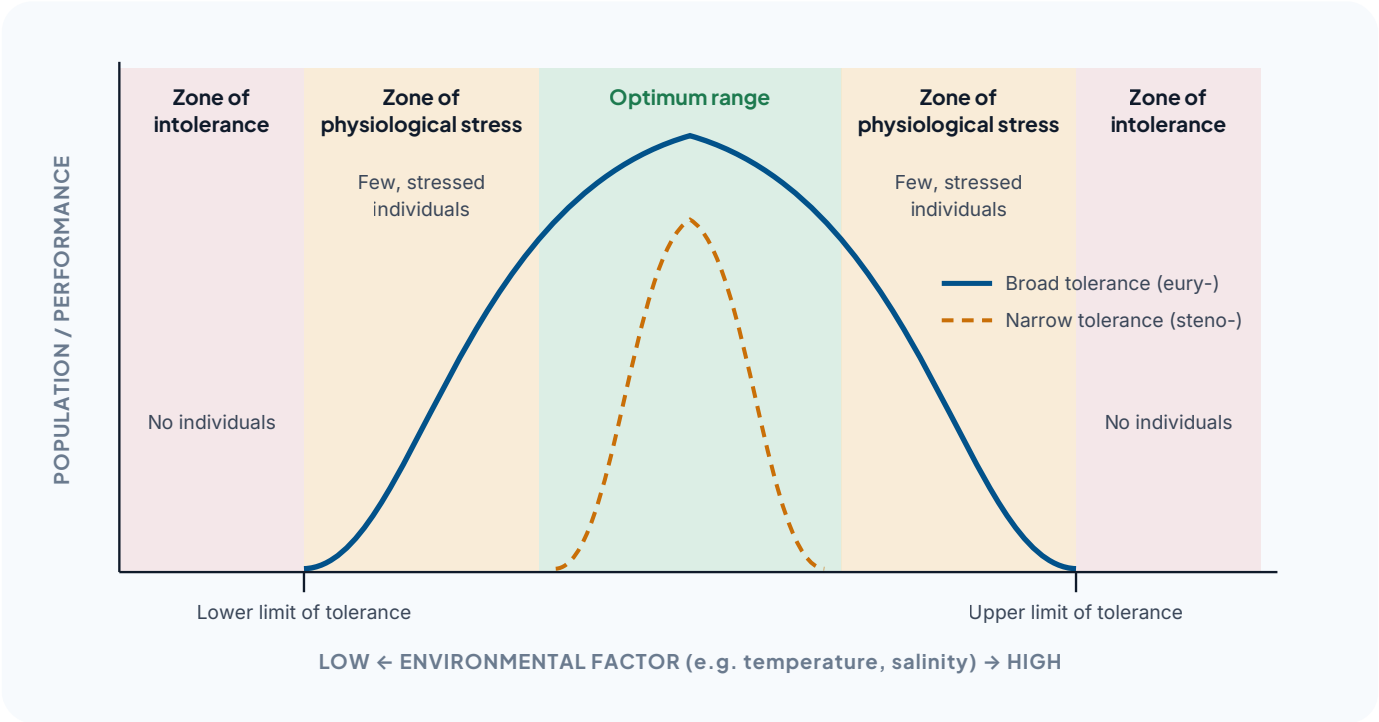
## ■ Blackman's Law of Limiting Factors

- **F.F. Blackman** stated it for photosynthesis in **1905**.
- When a process depends on several factors, its rate is set by the factor **closest to its minimum value**.
- On a cold, bright winter morning, photosynthesis may be held back by low temperature even though there is plenty of light. More light will not speed it up; warmth will.

## ■ Shelford's Law of Tolerance

- **Victor Shelford** proposed it in **1913**. It extends Liebig's idea: **too much of a factor can limit an organism just as surely as too little**.
- Every species has a **range of tolerance** for each factor, bounded by a lower and an upper limit:
  - the **optimum**, where it does best, lies inside the range;
  - **zones of physiological stress** lie on either side of the optimum;
  - beyond the limits, the species cannot survive.

- Species with **wide tolerance** for many factors tend to be **widespread**. Those with narrow ranges are restricted and more vulnerable to change.
- Tolerance is usually **narrowest during reproduction**: eggs, seeds, embryos and larvae are more sensitive than adults.



**Fig. 1.13** Law of tolerance: performance peaks in the optimum range and falls to nothing beyond the limits

### ■ The “eury–steno” vocabulary

The prefix **eury-** (wide) is used for organisms that tolerate a broad range of a factor, and **steno-** (narrow) for those restricted to a small range.

| FACTOR           | EURY- (WIDE RANGE)                                                              | STENO- (NARROW RANGE)                                                                      |
|------------------|---------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------|
| Temperature      | Eurythermal: most temperate land animals, carp, many shore crabs                | Stenothermal: reef-building corals, Antarctic icefishes                                    |
| Salinity         | Euryhaline: hilsa, salmon and eels, which move between river and sea; mangroves | Stenohaline: most freshwater fishes such as rohu; most marine fishes; corals               |
| Food             | Euryphagic: generalists such as crows, rats and humans                          | Stenophagic: specialists such as the silkworm (mulberry leaves) and the koala (eucalyptus) |
| Depth / pressure | Eurybathic: species ranging from shallow to deep water                          | Stenobathic: species confined to one depth band                                            |
| Habitat          | Euryoecious: wide range of habitats                                             | Stenoecious: narrow range of habitats                                                      |

#### LIMITING FACTORS IN INDIAN LANDSCAPES

- **Tropical rainforests:** heavy rain leaches the topsoil, so after clearing it is nutrients, not water, that hold back regrowth. Under the closed canopy, light limits seedlings on the forest floor.
- **Thar Desert:** water outweighs everything else. Trees such as khejri (*Prosopis cineraria*) send their roots tens of metres down.
- **Ladakh:** low temperature, a short growing season and low oxygen pressure limit crops and people alike.
- **Rann of Kutch:** salinity allows only salt-tolerant plants. The Indian wild ass survives in the Little Rann.
- **Coral reefs:** sea water just 1–2 °C above the usual summer peak, held there for a few weeks, is enough to bleach corals.

## Major Abiotic Factors and Their Effects

### ■ Light

- **Intensity.** Plants adapted to bright sun are **heliophytes**; those adapted to shade are **sciophytes**, such as ferns and many forest-floor herbs.
  - Strong light produces small, thick *sun leaves* and favours root growth.
  - Weak light produces large, thin *shade leaves* and tall, weak stems.
  - Below a certain intensity, respiration outpaces photosynthesis and the plant cannot grow.
- **Quality.**
  - Chlorophyll absorbs mainly **red and blue** light and reflects green, which is why leaves look green.
  - Too much **ultraviolet** damages DNA and stunts growth.
  - In the sea, red light is absorbed close to the surface. **Red algae** can live deeper than green algae because their pigment, phycoerythrin, captures the blue-green light that penetrates further.
- **Duration.** Day length controls flowering, a response called **photoperiodism**.
  - Short-day plants: many rice varieties, soybean, chrysanthemum.
  - Long-day plants: wheat, radish, spinach.
  - Day-neutral plants: tomato, cucumber.

Day length also times bird migration and breeding.

- **In water**, photosynthesis happens only in the sunlit **photic zone**, down to about **200 m** in clear ocean water and much less in muddy rivers.

### ■ Temperature

- Temperature matters more than any other climatic factor because it sets the **speed of enzyme reactions**, and so of metabolism. It ranges from below **–50 °C** in polar winters to over 50 °C in hot deserts, and above 100 °C in hot springs and at deep-sea vents.
- It decides where species can live. Mango will not grow in the cold of Ladakh, the snow leopard never comes down to the plains, and reef-building corals are confined to warm tropical seas.

- **Altitude:** air temperature drops by about **6.5 °C for every kilometre** of height (the normal lapse rate). Climbing the Himalaya is therefore a little like travelling from the equator towards the poles. Vegetation changes in the same order, from tropical and subtropical forest in the foothills, through temperate broadleaf and conifer forests, to alpine meadows and permanent snow.

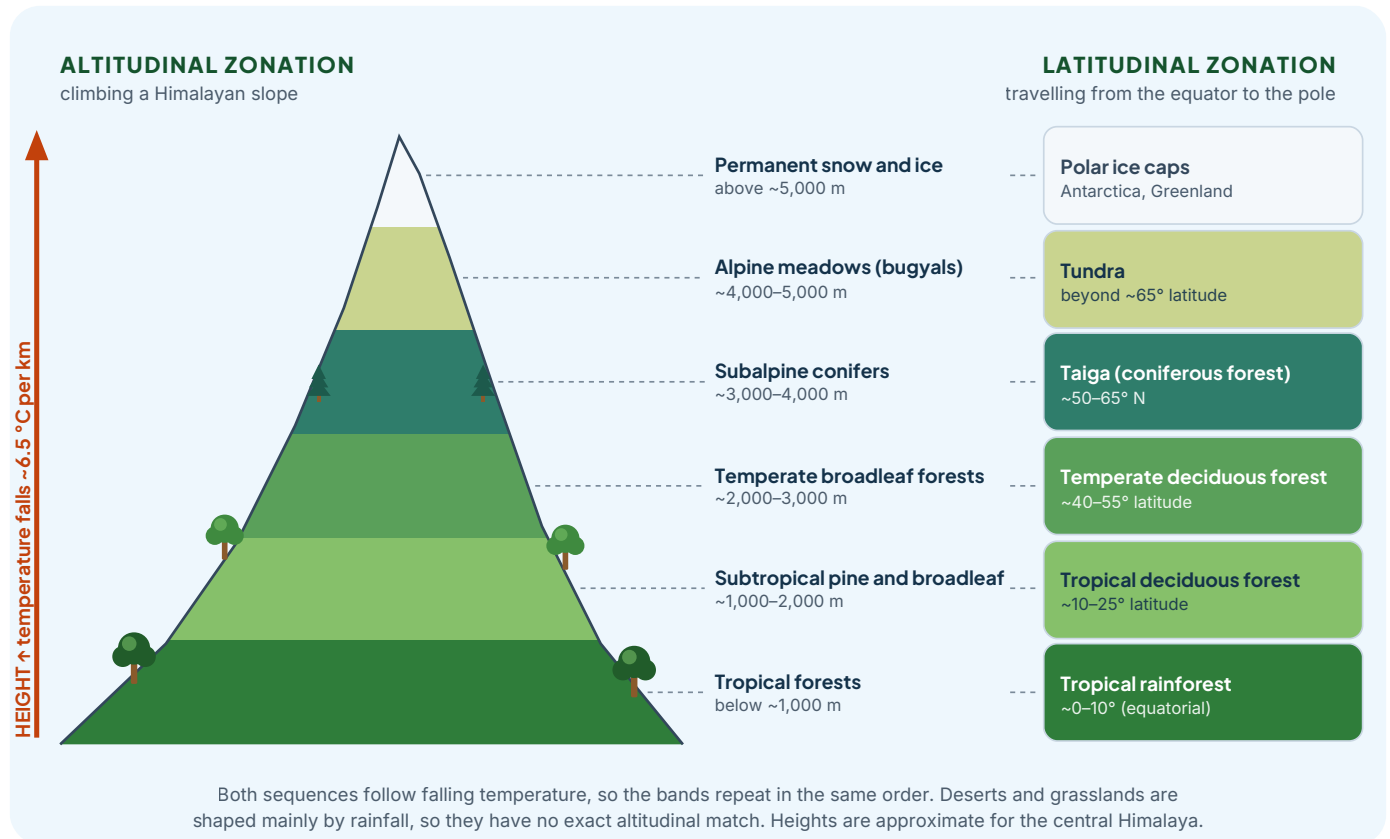
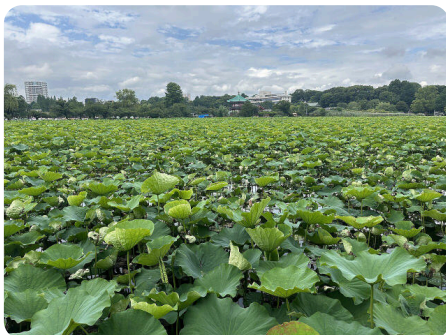


Fig. 1.14 Altitudinal and latitudinal zonation: climbing a mountain repeats the vegetation belts met on the way to the poles

- **Extremophile microbes** show how far life can stretch:
  - some archaea grow at up to about **122 °C** near hydrothermal vents;
  - **psychrophiles** grow in polar ice and permafrost below 0 °C;
  - **acidophiles** thrive below pH 3, a few close to pH 0.

## ■ Water and salinity



Hydrophyte: lotus



Xerophyte: leaves reduced to spines



Halophyte: mangrove breathing roots

Fig. 1.15 Plants are shaped by how much water, and how much salt, their habitat holds

- Life began in water, and water is still the medium of all cell chemistry. On land, **water supply is the main control on productivity**, which is why rainforests are productive and deserts are not.

- **Salinity**, measured in parts per thousand (ppt), varies widely:
  - below about **5 ppt** in inland fresh waters;
  - about **30–35 ppt** in the open sea;
  - above **100 ppt** in some hypersaline lagoons and salt lakes such as Sambhar.

| PLANT GROUP        | HABITAT               | KEY ADAPTATIONS                                                                                                     | EXAMPLES                                                                              |
|--------------------|-----------------------|---------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|
| <b>Hydrophytes</b> | In or on water        | Air-filled tissue (aerenchyma) for buoyancy; thin or no cuticle; reduced roots                                      | Lotus, water hyacinth, <i>Hydrilla</i>                                                |
| <b>Xerophytes</b>  | Dry desert soils      | Thick waxy cuticle, sunken stomata, small or spiny leaves, deep roots, stored water, CAM photosynthesis             | <i>Opuntia</i> , <i>Calotropis</i> , khejri, babul                                    |
| <b>Mesophytes</b>  | Moderate water supply | No extreme adaptations                                                                                              | Mango, most crop plants                                                               |
| <b>Halophytes</b>  | Salty soil and water  | Salt-excreting glands, fleshy leaves, breathing roots (pneumatophores), seeds that germinate on the tree (vivipary) | Mangroves ( <i>Rhizophora</i> , <i>Avicennia</i> ), <i>Salicornia</i> , <i>Suaeda</i> |

**Desert plants save water in three ways. They shrink the leaf surface, with tiny leaves or leaves reduced to spines while a flattened green stem takes over photosynthesis, as in *Opuntia*. They waterproof what is left, with hard, waxy leaves and sunken stomata. And they change the timing: CAM plants open their stomata only at night, when it is cool.**

## ■ Oxygen in water

- Water holds very little oxygen compared with air.
  - A litre of air contains roughly **280–300 mg** of oxygen.
  - A litre of well-aerated surface water holds only about **8–10 mg**, some thirty times less.
  - Oxygen also diffuses through water thousands of times more slowly than through air.
- Warm water holds even less. This is why fish kills are common in shallow ponds on hot summer nights, and why **dissolved oxygen** is a key limiting factor in aquatic ecosystems and a standard measure of water quality.

## ■ Soil (edaphic factors)

- **Texture**, the mix of sand, silt and clay, controls drainage and how much water the soil can hold.
- **pH** controls which nutrients plants can take up.
  - Most crops prefer **pH 6–7.5**.
  - Tea grows well on acidic soils.
  - Alkaline (*usar*) soils in parts of the Indo-Gangetic plain need gypsum before they can be farmed.

- pH also sorts the **soil microbes**:
  - fungi cope well with, and often dominate, acidic soils;
  - blue-green algae (cyanobacteria) prefer neutral to alkaline conditions;
  - most bacteria and protozoa do best near neutral.

This is one reason cyanobacterial biofertilisers work well in paddy fields, whose flooded soils move towards neutral pH.

- **Organic matter and soil organisms** govern fertility and structure. Together these properties decide the **natural vegetation** of a place and the crops it can grow.
- **Bare rock** is the extreme case of having no soil at all. Only **lichens** and **mosses** can colonise it, because they need no roots and take water and minerals directly from rain, dust and the rock surface.
  - Lichens even release weak acids that slowly break the rock down, which begins the soil.
  - Ferns need at least a thin soil.
  - Mushrooms are fungi that live on dead organic matter, so they cannot survive on bare rock.



Lichen on bare rock



Moss cushion on stone

**Fig. 1.16** Lichens and mosses can grow where there is no soil, which is why they are the first colonisers of bare rock

## ■ Topography

- **Altitude** changes temperature, air pressure and UV exposure.
- **Slope** affects drainage and soil depth; steep slopes carry thin soils that erode easily.
- **Aspect** is the direction a slope faces. In the Himalaya:
  - **south-facing slopes** catch more direct sun and are warmer and drier;
  - **north-facing slopes** stay cooler and moister and often carry denser forest.

One valley can therefore hold two quite different ecosystems.

## ■ Atmospheric gases and pH

- Oxygen makes up about 21% of the air at every height, but its **partial pressure falls with altitude**, and that is what causes altitude sickness. Over days, the body adjusts in three ways:
  - it makes more red blood cells;
  - it breathes faster;
  - haemoglobin binds oxygen less tightly, so more of it is released to the tissues.

- Most fresh waters lie between **pH 6.5 and 8.5**. **Seawater is mildly alkaline, at about pH 8.1**, not neutral. That figure has fallen by about 0.1 since pre-industrial times as the oceans absorb CO<sub>2</sub>. This is **ocean acidification**, and it threatens corals and shell-building animals.

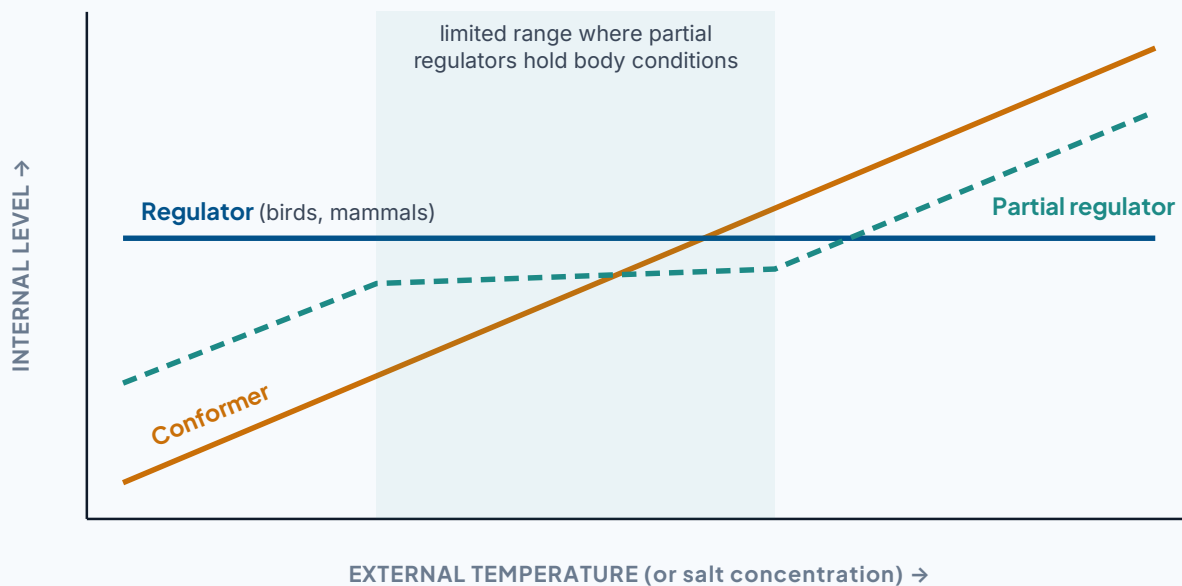
## ■ Frost, snow, wind and fire

- **Frost** freezes soil water, so roots cannot absorb it even as the leaves keep losing water. The plant suffers **physiological drought**.
  - Ice crystals forming between cells draw water out of them and injure the tissue.
  - Frost-damaged bark lets infections in, producing cankers.
- **Snow** shortens the growing season, and its weight can snap branches. A snow cover also works as an **insulating blanket**, keeping the soil and seedlings under it near 0 °C even when the air above is far colder.
- **Wind** speeds up water loss and, at the treeline, leaves stunted, flag-shaped trees (*krummholz*).
- **Fire** is a natural part of grasslands and dry forests.
  - Grasses survive it through buds below ground, and some trees through thick, fire-resistant bark.
  - The resin-rich needles of chir pine make Uttarakhand's pine forests especially prone to fire.

## | How Organisms Respond to Abiotic Stress

When conditions outside change, organisms cope in one of four broad ways.

| RESPONSE        | WHAT HAPPENS                                                                                                             | EXAMPLES                                                                                                                                                                                            |
|-----------------|--------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Regulate</b> | Keep the internal environment steady whatever happens outside (homeostasis), through thermoregulation and osmoregulation | Birds and mammals: sweating and panting in heat, shivering in cold                                                                                                                                  |
| <b>Conform</b>  | Let body temperature or body-fluid concentration follow the surroundings, because regulating would cost too much energy  | The great majority of animals and nearly all plants, including most fish and amphibians                                                                                                             |
| <b>Migrate</b>  | Move for a while to a better place and return when conditions improve                                                    | Amur falcons stopping in Nagaland on their way from East Asia to southern Africa; bar-headed geese flying over the Himalaya                                                                         |
| <b>Suspend</b>  | Shut down activity until the stress passes                                                                               | <b>Hibernation</b> in winter (bears); <b>aestivation</b> in summer (snails, some fish); <b>diapause</b> , a pause in development (zooplankton, insects); seed dormancy; bacterial and fungal spores |



**Fig. 1.17** Regulators hold their internal level steady, conformers follow the environment, and partial regulators manage only within a limited range

**Migration in practice: the Amur falcon.** These small falcons breed in south-eastern Siberia, northern China and Mongolia. Every autumn they stop over in Nagaland, around Doyang reservoir in Wokha district, before crossing the Arabian Sea to winter in southern Africa. The round trip covers some **22,000 km**, one of the longest migrations of any bird of prey.

As late as **2012**, well over a lakh of falcons were being trapped in Nagaland every season. Then village councils banned hunting, and former hunters became guides and guards. Today the birds return safely in huge numbers, which shows how much community conservation can achieve. They are still only passing through: India is a stopover, not their permanent home, and satellite tags record their routes but do not guide them.



**Fig. 1.18** An Amur falcon. Huge flocks rest at Doyang reservoir in Nagaland each October–November

- **Why small animals are rare in polar regions:** a small body has a large surface area relative to its volume, so it loses heat fast and must spend a great deal of energy just keeping warm.
- **Bergmann's rule:** among related warm-blooded animals, those in colder climates tend to have **larger bodies**.
- **Allen's rule:** mammals in colder climates tend to have **shorter ears and limbs**, which cuts heat loss.
- **Physiological adaptation:** desert mammals such as the kangaroo rat get most of their water as *metabolic water*, released when fat is broken down, and pass very concentrated urine.
- **Behavioural adaptation:** desert lizards bask when they are cold and retreat into burrows when they are hot. They control body temperature through behaviour rather than internal physiology.

- **Ecotypes:** over many generations, populations of one species living in different conditions can become genetically suited to their local environment. Such a locally adapted population is called an **ecotype**. Grasses growing on metal-rich mine waste, for example, often carry genes for metal tolerance that their neighbours in ordinary pasture lack.

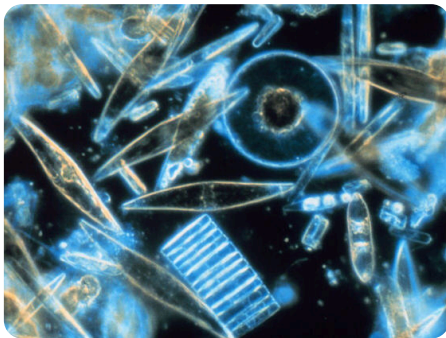
## 06 Biotic Components of an Ecosystem

The living part of an ecosystem is organised by **how organisms get their food**.

### Producers (Autotrophs)

Autotrophs, or “self-feeders”, make their own organic food from simple inorganic substances. They form the base of every food chain.

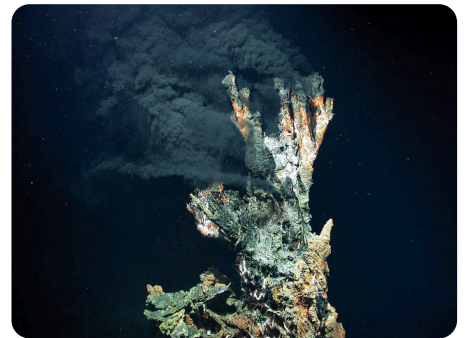
- **Photoautotrophs** use sunlight (photosynthesis). They include green plants, algae and cyanobacteria (blue-green algae), and in water the microscopic **phytoplankton**, such as diatoms, dinoflagellates and cyanobacteria.
- The oceans matter more than most people assume. **Marine phytoplankton and photosynthetic bacteria produce about half of the world's oxygen.**
  - **Rainforests are not the world's main oxygen source.** A mature forest uses almost as much oxygen in respiration and decay as it releases.
  - Not everything that floats in the sea is a producer. Copepods are tiny crustaceans that graze on phytoplankton, and most foraminifera are shelled protists that eat other organisms. Both are consumers.



Producers: diatoms



Consumer: a copepod



Chemosynthesis: a deep-sea black smoker

**Fig. 1.19** Plankton seen under the microscope, and a hydrothermal vent where food webs run on chemical energy instead of sunlight

- **Chemoautotrophs** get energy by oxidising inorganic chemicals (chemosynthesis). Examples:
  - **sulphur-oxidising bacteria** at deep-sea hydrothermal vents, which feed entire communities, including giant tube worms, in total darkness;
  - **nitrifying bacteria** (*Nitrosomonas*, *Nitrobacter*) in soil;
  - iron-oxidising bacteria.

### Consumers (Heterotrophs)

Heterotrophs, or “other-feeders”, cannot make their own food and depend directly or indirectly on producers.

## ■ Macroconsumers (phagotrophs)

Mostly animals that **ingest** other organisms or particles of organic matter.

| CATEGORY                              | FEEDS ON                                                     | EXAMPLES                                                        |
|---------------------------------------|--------------------------------------------------------------|-----------------------------------------------------------------|
| <b>Primary consumers (herbivores)</b> | Producers                                                    | Chital, nilgai, grasshopper, caterpillars; zooplankton in water |
| <b>Secondary consumers</b>            | Herbivores                                                   | Frogs, insect-eating birds, small fish, spiders                 |
| <b>Tertiary consumers</b>             | Secondary consumers                                          | Snakes that eat frogs, large predatory fish, birds of prey      |
| <b>Apex (top) predators</b>           | Prey from the highest levels; no natural predators as adults | Tiger, saltwater crocodile, orca                                |
| <b>Omnivores</b>                      | Both plants and animals                                      | Humans, sloth bear, wild boar, crows                            |

- **A species can occupy more than one trophic level.** Someone eating rice is a primary consumer; the same person eating fish is a secondary or tertiary consumer. The trophic level belongs to the **feeding link**, not to the species.
- **Filter feeders** strain tiny food particles out of water. Oysters, mussels, clams, sponges and barnacles do this, and so do some giants: baleen whales, the whale shark, manta rays and flamingos. Pelicans, catfish and octopuses do not. Pelicans scoop up whole fish, catfish forage along the bottom, and octopuses hunt.

## ■ Microconsumers (saprotrophs or osmotrophs)

Mostly bacteria and fungi. They release enzymes onto dead organic matter, digest it outside their bodies and **absorb** the dissolved products. This returns inorganic nutrients to the soil and water, a process called **mineralisation**. Without them, nutrients would stay locked up in dead bodies and producers would run short.

## | Decomposers, Detritivores and Scavengers

| GROUP                            | HOW THEY FEED                                                                                                                         | EXAMPLES                                                                               |
|----------------------------------|---------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------|
| <b>Decomposers (saprotrophs)</b> | Break dead matter down chemically, digesting it outside the body and absorbing it; they complete the recycling of nutrients           | Bacteria; fungi such as mushrooms, moulds and bracket fungi                            |
| <b>Detritivores</b>              | <b>Eat</b> detritus (dead leaves, wood, dung) and tear it into smaller pieces ( <i>fragmentation</i> ), which speeds up decomposition | Earthworms, millipedes, woodlice, termites, dung beetles, some crabs and sea cucumbers |
| <b>Scavengers</b>                | Eat the carcasses of dead animals                                                                                                     | Vultures, hyenas, jackals, crows                                                       |



Earthworm



Millipede



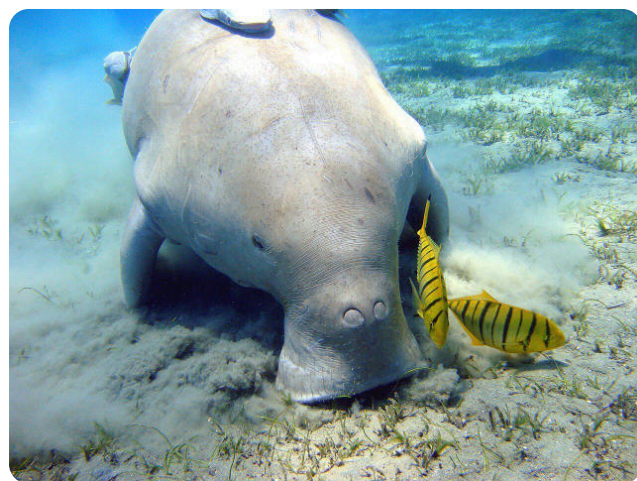
Woodlouse



Bracket fungus

**Fig. 1.20** Three detritivores that eat and shred dead matter, and a fungus that digests it chemically

The dugong shows how closely a species can be tied to one habitat. This “sea cow” grazes almost only on seagrass, leaving trails of uprooted plants across shallow meadows, and it cannot survive where those meadows are dredged, trawled or silted over. It is listed as Vulnerable by the IUCN and protected under Schedule I of the Wild Life (Protection) Act, 1972. Its seagrass beds matter for other reasons too: they shelter young fish and prawns, steady the sea floor and lock away carbon in their sediments, which makes them part of the coast's “blue carbon”. To protect them, Tamil Nadu notified India's first **Dugong Conservation Reserve**, covering about **448 sq km** of Palk Bay, in **2022**.



**Fig. 1.21** The dugong, a marine herbivore that lives on seagrass meadows

Some reptiles break other assumptions. Many vipers and sea snakes give birth to live young (they are **viviparous**) instead of laying eggs, an adaptation that lets the mother keep her developing young warm or, in the sea, away from shore.

#### COMMON CONFUSIONS

- **Jellyfish and seahorses are predators, not detritivores.** Jellyfish sting small animals; seahorses suck in tiny crustaceans.
- **Detritivores and decomposers do different jobs.** Detritivores *eat* dead matter and break it up physically; decomposers *digest it chemically* from the outside.
- **Vultures are scavengers, not decomposers.** When India's vultures crashed, poisoned by the veterinary drug diclofenac in cattle carcasses, the carcasses lay rotting and stray dog numbers and disease risk went up.
- **Herbivores are not only land animals.** Adult green sea turtles graze seagrass, and parrotfish and many surgeonfish graze algae. The **dugong**, a marine mammal of the Gulf of Mannar, Palk Bay, the Gulf of Kutch and the Andaman and Nicobar Islands, **feeds almost entirely on seagrass**.

## Special Modes of Nutrition

- **Mixotrophs** combine both ways of feeding. *Euglena* photosynthesises in light and absorbs organic food in the dark.

- **Insectivorous plants** photosynthesise but also trap insects, mainly for **nitrogen**, because they grow in nitrogen-poor soils and bogs. Examples:
  - the pitcher plant *Nepenthes khasiana*, endemic to Meghalaya;
  - sundew (*Drosera*);
  - bladderwort (*Utricularia*).
- **Parasitic plants** take food from a host:
  - *Cuscuta* (dodder) is a total stem parasite with no chlorophyll at all;
  - mistletoes such as *Loranthus* are partial parasites, which photosynthesise but draw water and minerals from the host.
- **Symbiotic partnerships** blur the line between producer and consumer. Examples are lichens (an alga or cyanobacterium living with a fungus), mycorrhizae (fungi on plant roots) and *Rhizobium* in legume root nodules. They are covered under species interactions.



Pitcher plant *Nepenthes khasiana*



Dodder (*Cuscuta*) on its host

**Fig. 1.22** An insect-trapping plant and a parasitic plant: two departures from the ordinary producer's way of life

## 07 Key Terms at a Glance

| TERM                    | ONE-LINE MEANING                                                                 |
|-------------------------|----------------------------------------------------------------------------------|
| <b>Environment</b>      | All the physical, chemical and biological conditions acting on an organism       |
| <b>Ecology</b>          | Study of interactions among organisms and with their environment (Haeckel, 1866) |
| <b>Habitat</b>          | The place where an organism naturally lives: its "address"                       |
| <b>Biotope</b>          | A small, uniform area supporting a particular community                          |
| <b>Microhabitat</b>     | A small patch within a habitat with its own conditions                           |
| <b>Ecological niche</b> | Functional role plus all conditions and resources used: its "profession"         |

| TERM                         | ONE-LINE MEANING                                                                |
|------------------------------|---------------------------------------------------------------------------------|
| <b>Ecosystem</b>             | Community plus physical environment working as one unit (Tansley, 1935)         |
| <b>Biosphere</b>             | The life-supporting zone of the Earth; all ecosystems together                  |
| <b>Carrying capacity</b>     | The largest population an environment can support indefinitely                  |
| <b>Ecological footprint</b>  | Productive area needed to supply a population's resources and absorb its wastes |
| <b>Limiting factor</b>       | The factor in shortest supply, or furthest from optimum, that controls growth   |
| <b>Law of tolerance</b>      | Both too little and too much of a factor limit an organism (Shelford, 1913)     |
| <b>Ecotype</b>               | A population genetically adapted to local conditions                            |
| <b>Autotroph</b>             | Makes its own food: photoautotroph (light) or chemoautotroph (chemicals)        |
| <b>Saprotroph</b>            | Digests dead matter outside its body and absorbs it (bacteria, fungi)           |
| <b>Detritivore</b>           | Eats and shreds detritus (earthworm, millipede, woodlouse)                      |
| <b>Filter feeder</b>         | Strains food particles from water (oyster, sponge, baleen whale)                |
| <b>Mixotroph</b>             | Both autotrophic and heterotrophic ( <i>Euglena</i> , insectivorous plants)     |
| <b>Regulator / conformer</b> | Keeps internal conditions constant / lets them follow the environment           |



## Previous Year Questions



2026

Which of the following statements with regard to the arrival of Amur Falcons at Doyang Lake in Nagaland each year from Mongolia is/are correct?

1. It showcases how sustained local conservation efforts can contribute to the arrival and protection of international migratory birds.
2. It reflects the global success of advanced tracking technologies that guide migratory birds back to their stopover sites.
3. It confirms that Amur Falcons have adapted to permanent residency in India due to favourable habitat changes.

Select the answer using the code given below:

**a** 1 only

**b** 1 and 2

**c** 2 and 3

**d** 3 only

**Answer: (a).** Community-led protection in Nagaland turned a hunting ground into a safe stopover. Tracking tags record migration but do not guide it, and the falcons remain long-distance migrants that move on to southern Africa.

2026

Consider the following statements about *Rhynchostylis retusa* (Foxtail orchid):

1. It is an epiphytic orchid.
2. The species is endemic to North-east India.
3. It is the State flower of Arunachal Pradesh and Assam.

Which of the statements given above is/are correct?

☐ a 1 only

☐ b 1 and 3

☐ c 2 and 3

☐ d 3 only

**Answer: (b).** It grows on tree branches as an epiphyte and is the State flower of both States, but it is spread across South and South-East Asia, so it is not endemic.

2025

With reference to the planet Earth, consider the following statements:

- I. Rain forests produce more oxygen than that produced by oceans.
- II. Marine phytoplankton and photosynthetic bacteria produce about 50% of world's oxygen.
- III. Well-oxygenated surface water contains several folds higher oxygen than that in atmospheric air.

Which of the statements given above is/are correct?

☐ a I and II

☐ b II only

☐ c I and III

☐ d None of the above statements is correct

**Answer: (b).** The oceans out-produce rainforests, which consume most of the oxygen they release. Air holds roughly thirty times more oxygen than even well-aerated water.

2025

Regarding Peacock tarantula (Gooty tarantula), consider the following statements:

- I. It is an omnivorous crustacean.
- II. Its natural habitat in India is only limited to some forest areas.
- III. In its natural habitat, it is an arboreal species.

Which of the statements given above is/are correct?

☐ a I only

☐ b I and III

☐ c II only

☐ d II and III

**Answer: (d).** It is a spider (an arachnid), not a crustacean. It lives in tree holes in a small forest area of the Eastern Ghats.

2024

Consider the following pairs:

Country : Animal found in its natural habitat

1. Brazil : Indri
2. Indonesia : Elk

### 3. Madagascar : Bonobo

How many of the pairs given above are correctly matched?

☐ a Only one

☐ b Only two

☐ c All three

☐ d None

**Answer: (d).** The indri lives only in Madagascar, the elk in North America and parts of Asia, and the bonobo in the Democratic Republic of the Congo.

2023

Consider the following statements :

1. Some microorganisms can grow in environments with temperature above the boiling point of water.
2. Some microorganisms can grow in environments with temperature below the freezing point of water.
3. Some microorganisms can grow in highly acidic environment with a pH below 3.

How many of the above statements are correct?

☐ a Only one

☐ b Only two

☐ c All three

☐ d None

**Answer: (c).** Hyperthermophiles grow above 100 °C at vents, psychrophiles below 0 °C in ice and permafrost, and acidophiles below pH 3.

2021

Which of the following are detritivores?

1. Earthworms
2. Jellyfish
3. Millipedes
4. Seahorses
5. Woodlice

Select the correct answer using the code given below.

☐ a 1, 2 and 4 only

☐ b 2, 3, 4 and 5 only

☐ c 1, 3 and 5 only

☐ d 1, 2, 3, 4 and 5

**Answer: (c).** Earthworms, millipedes and woodlice eat and shred dead matter. Jellyfish and seahorses are predators.

2021

Consider the following kinds of organisms:

1. Copepods
2. Cyanobacteria
3. Diatoms
4. Foraminifera

Which of the above are primary producers in the food chains of oceans?

☐ a 1 and 2

☐ b 2 and 3

☐ c 3 and 4

☐ d 1 and 4

**Answer: (b).** Cyanobacteria and diatoms photosynthesise. Copepods graze on phytoplankton, and most foraminifera feed on other organisms.

2021

In the nature, which of the following is/are most likely to be found surviving on a surface without soil?

1. Fern
2. Lichen
3. Moss
4. Mushroom

Select the correct answer using the code given below.

☐ a 1 and 4 only

☐ b 2 only

☐ c 2 and 3

☐ d 1, 3 and 4

**Answer: (c).** Lichens and mosses need no roots and colonise bare rock. Ferns need some soil, and mushrooms need dead organic matter.

2021

With reference to the water on the planet Earth, consider the following statements:

1. The amount of water in the rivers and lakes is more than the amount of groundwater.
2. The amount of water in polar ice caps and glaciers is more than the amount of groundwater.

Which of the statements given above is/are correct?

☐ a 1 only

☐ b 2 only

☐ c Both 1 and 2

☐ d Neither 1 nor 2

**Answer: (b).** Ice holds about 69% of fresh water and groundwater about 30%, while rivers and lakes hold well under 1%.

2021

Which one of the following is a filter feeder?

☐ a Catfish

☐ b Octopus

☐ c Oyster

☐ d Pelican

**Answer: (c).** Oysters pump water through their gills and strain out plankton. The other three take larger prey.

2019

Consider the following statements:

1. Some species of turtles are herbivores.
2. Some species of fish are herbivores.
3. Some species of marine mammals are herbivores.
4. Some species of snakes are viviparous.

Which of the statements given above are correct?

☐ a 1 and 3 only

☐ b 2, 3 and 4 only

☐ c 2 and 4 only

☐ d 1, 2, 3 and 4

**Answer: (d).** Green sea turtles eat seagrass, parrotfish graze algae, dugongs and manatees eat seagrass, and many vipers and sea snakes bear live young.

2018

Which of the following leaf modifications occur(s) in the desert areas to inhibit water loss?

1. Hard and waxy leaves
2. Tiny leaves

### 3. Thorns instead of leaves

Select the correct answer using the code given below:

☐ a 2 and 3 only

☐ b 2 only

☐ c 3 only

☐ d 1, 2 and 3

**Answer: (d).** A waxy cuticle waterproofs the leaf, tiny leaves expose less surface, and spines do away with the leaf blade altogether.

2015

Which one of the following is the best description of the term 'ecosystem'?

☐ a A community of organisms interacting with one another

☐ b That part of the Earth which is inhabited by living organisms

☐ c A community of organisms together with the environment in which they live

☐ d The flora and fauna of a geographical area

**Answer: (c).** An ecosystem must include the non-living environment. Option (a) describes a community, (b) the biosphere and (d) the biota of a region.

2013

Which one of the following terms describes not only the physical space occupied by an organism, but also its functional role in the community of organisms?

☐ a Ecotone

☐ b Ecological niche

☐ c Habitat

☐ d Home range

**Answer: (b).** Habitat is only the place; niche adds the role. An ecotone is a transition zone, and a home range is the area an animal regularly uses.

2011

If a tropical rain forest is removed, it does not regenerate quickly as compared to a tropical deciduous forest. This is because

☐ a the soil of rain forest is deficient in nutrients

☐ b propagules of the trees in a rain forest have poor viability

☐ c the rain forest species are slow-growing

☐ d exotic species invade the fertile soil of rain forest

**Answer: (a).** A rainforest keeps most of its nutrients in living plants, not in the soil. Daily rain leaches the topsoil, so once the forest is cleared and burnt, little nutrient capital remains for regrowth.

UNIT 05

5 CHAPTERS

# Climate Change

*The science of global warming, its impacts, mitigation, global negotiations and India's climate policy.*

## CHAPTERS

|    |                                                                      |     |
|----|----------------------------------------------------------------------|-----|
| 17 | Greenhouse Effect and Global Warming                                 | 297 |
| 18 | Impacts of Climate Change                                            | 308 |
| 19 | Climate Mitigation: Sequestration, Geoengineering and Carbon Markets | 319 |
| 20 | International Climate Negotiations                                   | 330 |
| 21 | India and Climate Change: Commitments, Missions and Initiatives      | 340 |

## TOPICS COVERED IN THIS UNIT

### 17 Greenhouse Effect and Global Warming

Weather, Climate and Climate Change · The Greenhouse Effect · The Greenhouse Gases · How Much Has the World Warmed? · Natural Causes of Climate Change · Feedbacks and Tipping Points · The IPCC and Its Scenarios

### 18 Impacts of Climate Change

Warming Oceans and Rising Seas · Ocean Acidification · Coral Bleaching · The Melting Cryosphere · Extreme Weather · El Niño, La Niña and the Indian Ocean Dipole · Impacts on People and Nature · India's Vulnerability

### 19 Climate Mitigation: Sequestration, Geoengineering and Carbon Markets

Mitigation and Net Zero · Carbon Sequestration · Geoengineering · Putting a Price on Carbon · India's Carbon Market and Green Instruments

### 20 International Climate Negotiations

The Road So Far · The UN Framework Convention on Climate Change · The Paris Agreement · Recent COPs · Climate Finance · Negotiating Groups · Other Initiatives and Trackers

### 21 India and Climate Change: Commitments, Missions and Initiatives

India's Emissions Profile · India's Climate Commitments · The National Action Plan on Climate Change · Adaptation and Resilience · Other National Initiatives · India-Led Global Initiatives

ENVIRONMENT & ECOLOGY

PRELIMS · GS PAPER III

# Greenhouse Effect and Global Warming

Climate change is the defining environmental challenge of this century. The last eleven years have been the eleven warmest on record. In 2024 the planet was, for the first time, more than 1.5 °C warmer than in the late nineteenth century for a whole calendar year, and carbon dioxide in the air rose by a record amount. Understanding why requires a grasp of basic climate science. This chapter covers:

## SYLLABUS

PRELIMS

**General issues on Environmental Ecology, Bio-diversity and Climate Change**

MAINS · GS PAPER I

**Important geophysical phenomena; GS Paper III: Conservation, environmental pollution and degradation**

## CONTENTS

|                                        |                                   |
|----------------------------------------|-----------------------------------|
| 01 Weather, Climate and Climate Change | 02 The Greenhouse Effect          |
| 03 The Greenhouse Gases                | 04 How Much Has the World Warmed? |
| 05 Natural Causes of Climate Change    | 06 Feedbacks and Tipping Points   |
| 07 The IPCC and Its Scenarios          | 08 Key Terms at a Glance          |
| 09 Previous Year Questions             |                                   |

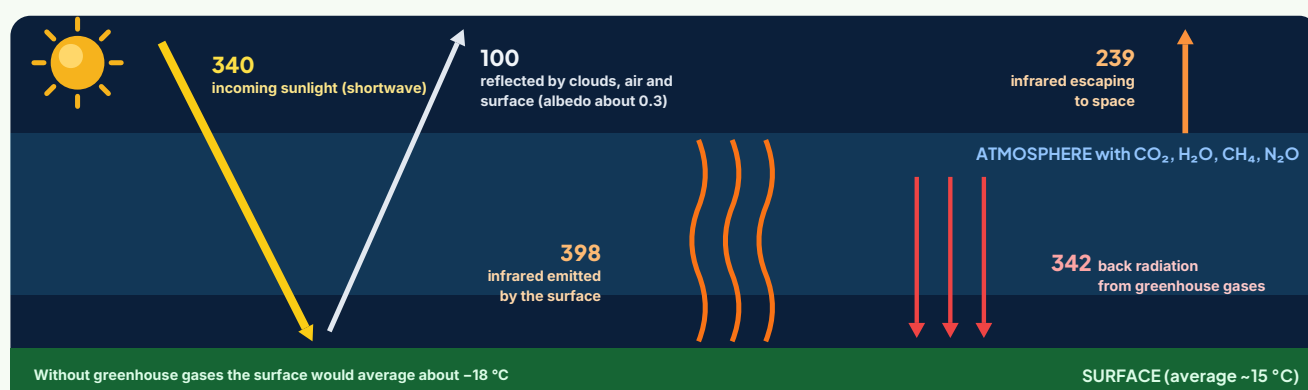
- how the Earth balances incoming sunlight and outgoing heat, and how greenhouse gases trap part of that heat;
- where each gas comes from and how powerful it is;
- how much the planet has already warmed, and the natural factors that also shape climate;
- the feedbacks and tipping points that could speed things up;
- the scientific assessments of the IPCC, which underpin global climate policy.

Later chapters cover the impacts of climate change, ways to cut emissions and remove carbon, the international negotiations, and India's own climate actions.

**Weather** is the state of the atmosphere at a place over hours or days. **Climate** is the average weather and its variability over a long period, conventionally 30 years. **Climate change** is a lasting change in the state of the climate. The UN Framework Convention on Climate Change uses the term for change **attributed directly or indirectly to human activity** that alters the composition of the global atmosphere, over and above natural variability. **Global warming** is the rise in the Earth's average surface temperature, the best-known symptom of that change.

The Sun's energy arrives mostly as visible light and other **shortwave** radiation. About 30% is reflected straight back to space by clouds, aerosols, ice and bright surfaces; this fraction is the Earth's **albedo**. The rest is absorbed, mostly by the land and oceans, which warm up and radiate heat back as **longwave infrared** radiation. Nitrogen and oxygen, which make up 99% of dry air, let infrared pass. Gases whose molecules have three or more atoms, such as **water vapour, carbon dioxide, methane, nitrous oxide and ozone**, absorb it and re-emit it in all directions, including back down to the surface.

**The Greenhouse Effect: Earth's Energy Budget (global average, W/m<sup>2</sup>)**



**Fig. 17.1** The Earth's average energy budget. Greenhouse gases absorb infrared from the surface and send much of it back down, keeping the surface far warmer than it would otherwise be.

- This natural **greenhouse effect** keeps the Earth's average surface temperature at about **15 °C**. Without it the average would be around **-18 °C**, and most water would be frozen.
- Because the atmosphere is largely transparent to incoming sunlight, it is **heated mainly from below**, by infrared from the warm surface (terrestrial radiation), not directly by the Sun. This is why temperature usually falls with height in the lower atmosphere.
- The **enhanced greenhouse effect** is the extra warming caused by human additions of greenhouse gases. More of these gases absorb more outgoing infrared, so the Earth must warm until it again sends out as much energy as it receives. Today the planet absorbs more energy than it loses. This **energy imbalance** has roughly doubled since the mid-2000s, and about 90% of the extra heat goes into the oceans.

**Radiative forcing**, measured in watts per square metre, is the change in the Earth's energy balance caused by a factor such as a greenhouse gas, aerosols or a change in solar output. Positive forcing warms; negative forcing (for example, from sulphate aerosols) cools.

03

## The Greenhouse Gases

Different gases trap heat with very different strength and stay in the air for very different times. To compare them, scientists use the **Global Warming Potential (GWP)**: the heat a gas traps over a period, usually 100 years, relative to the same mass of CO<sub>2</sub>, whose GWP is 1. Emissions of all gases are then expressed in tonnes of **CO<sub>2</sub>-equivalent (CO<sub>2</sub>e)**.

| GAS                                     | MAIN HUMAN SOURCES                                                                    | LIFETIME IN AIR                          | GWP (100-YR)                               | LEVEL IN 2024                      |
|-----------------------------------------|---------------------------------------------------------------------------------------|------------------------------------------|--------------------------------------------|------------------------------------|
| Carbon dioxide (CO <sub>2</sub> )       | Burning coal, oil and gas; cement; deforestation                                      | Centuries to millennia (no single value) | 1                                          | 423.9 ppm (152% of pre-industrial) |
| Methane (CH <sub>4</sub> )              | Livestock, rice paddies, landfills, coal mines, oil and gas leaks, wetlands (natural) | About 12 years                           | About 28 (higher, about 80, over 20 years) | 1,942 ppb (266% of pre-industrial) |
| Nitrous oxide (N <sub>2</sub> O)        | Nitrogen fertilisers, manure, industry, burning                                       | About 110 years                          | 273                                        | 338 ppb (125% of pre-industrial)   |
| Hydrofluorocarbons (HFCs)               | Refrigerants, air conditioners, foams, aerosols                                       | Months to decades                        | Up to about 14,600 (HFC-23)                | Rising fast                        |
| Perfluorocarbons (PFCs)                 | Aluminium smelting, electronics                                                       | Thousands of years                       | About 7,000 or more                        | Very low but persistent            |
| Sulphur hexafluoride (SF <sub>6</sub> ) | Electrical switchgear insulation                                                      | About 3,000 years                        | About 24,000, the highest                  | Very low but persistent            |
| Nitrogen trifluoride (NF <sub>3</sub> ) | Making flat screens and solar cells                                                   | About 500 years                          | About 17,000                               | Very low                           |

- **Water vapour** is the most abundant greenhouse gas and contributes most to the natural greenhouse effect. Its amount, however, is controlled by temperature, not by direct human emissions, so it acts as a **feedback** that amplifies warming rather than as a driver.
- **Carbon dioxide** causes about two-thirds of the warming from long-lived greenhouse gases. Because a large part of each emission stays in the air for centuries, warming depends on **cumulative** emissions. Concentrations rose by a record 3.5 ppm between 2023 and 2024, driven by fossil fuels plus wildfires and weakened land and ocean sinks during a hot El Niño year.

- **Methane** is the second most important gas. It is about 80 times more powerful than CO<sub>2</sub> over 20 years but breaks down within about a decade, oxidising to CO<sub>2</sub> and water. Cutting it gives the quickest slowdown in warming. **Rice paddies** are a major anthropogenic source of both methane (from flooded, oxygen-poor soils) and nitrous oxide (from fertiliser). Vast amounts of methane are also locked in **methane hydrates** beneath the seafloor and in Arctic permafrost, which warming could release.
- **Ozone** in the troposphere is a greenhouse gas and pollutant (Chapter 12). **Black carbon**, though a particle rather than a gas, warms the air and darkens snow. Methane, tropospheric ozone, black carbon and HFCs are grouped as **short-lived climate pollutants**.
- **Cement** production alone causes about 7–8% of global CO<sub>2</sub> emissions. Most comes from heating limestone, which converts it into lime and releases CO<sub>2</sub> in a process called calcination; the rest comes from the fuel burned in kilns.
- The Kyoto Protocol's "basket" covers six gases or groups: CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O, HFCs, PFCs and SF<sub>6</sub>. NF<sub>3</sub> was added in 2012.



Methane bubbles from decaying organic matter frozen into lake ice



A thaw slump where Arctic permafrost is collapsing as it warms

## 04 How Much Has the World Warmed?

Continuous measurements of CO<sub>2</sub> began in 1958 at **Mauna Loa** in Hawaii, an isolated mountain far from local pollution, under the scientist **Charles David Keeling**. The resulting **Keeling Curve** shows two things. CO<sub>2</sub> rises every year, and it zigzags with the seasons, dipping each northern summer as the vast forests of the northern hemisphere absorb it, and rising again in winter.

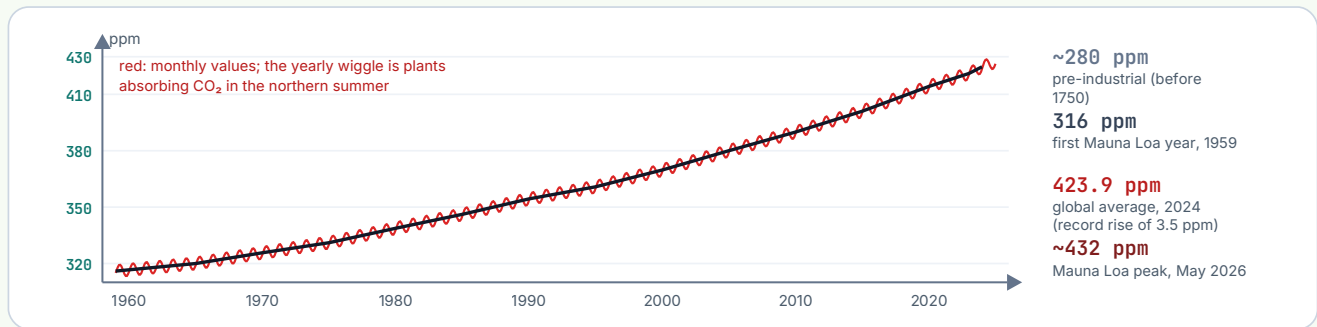
- **Temperature:** 2024 was the warmest year on record, about **1.55 °C** above the 1850–1900 average. **2025**, at about **1.44 °C**, was the second or third warmest, even though it began and ended with a cooling La Niña. 2015–2025 were the eleven warmest years on record. The long-term human-caused warming is now about 1.3–1.4 °C. A single year above 1.5 °C does not mean the Paris goal is breached, because that goal refers to a 20-year average.
- **Emissions:** fossil CO<sub>2</sub> emissions reached a record of about **38 billion tonnes** in 2025. Total greenhouse gas emissions were about 57.7 billion tonnes CO<sub>2</sub>e in 2024.



**Fig. 17.2** The Mauna Loa Observatory in Hawaii, where continuous CO<sub>2</sub> measurements began in 1958

- **Remaining carbon budget:** only about 170 billion tonnes of CO<sub>2</sub> can still be emitted for a 50% chance of limiting warming to 1.5 °C. That is roughly four years of current emissions.
- **Where we are heading:** if all national pledges are fully met, warming would reach about **2.3–2.5 °C** this century; current policies point to about **2.8 °C**. The world is likely to overshoot 1.5 °C, at least temporarily, in the early 2030s.

#### The Keeling Curve: Carbon Dioxide at Mauna Loa, 1959–2025



**Fig. 17.3** Atmospheric CO<sub>2</sub> has risen from about 316 ppm in 1959 to over 420 ppm today, far above the pre-industrial level of about 280 ppm

### Where Does Our CO<sub>2</sub> Go?

Of the CO<sub>2</sub> emitted each year, roughly **half stays in the atmosphere**. About a quarter is absorbed by the **oceans**, partly through photosynthesis by phytoplankton and partly by dissolving, which makes seawater more acidic (Chapter 18). About a quarter to a third is taken up by **land**, mainly forests. CO<sub>2</sub> does not escape to the upper stratosphere or space, and is not removed by being trapped in polar ice. **Carbon fertilisation** is the extra plant growth caused by higher CO<sub>2</sub> concentrations; it partly explains the land sink. Both sinks are weakening as the planet warms: hot, dry years cut forest uptake, and warmer water dissolves less CO<sub>2</sub>.

## 05 Natural Causes of Climate Change

- **Milankovitch cycles** are slow changes in the Earth's orbit and tilt. They involve **eccentricity** (about 100,000 years), **obliquity** or axial tilt (about 41,000 years) and **precession** (about 23,000 years). They redistribute sunlight and pace the ice ages over tens of thousands of years, far too slowly to explain modern warming.
- **Solar variability:** the Sun's output varies slightly over the 11-year sunspot cycle. Measured solar output has not increased since the 1950s, while temperatures have risen sharply.
- **Volcanoes:** large eruptions inject sulphur dioxide into the stratosphere, where it forms reflective sulphate aerosols. **Mount Pinatubo** (Philippines, 1991) cooled global temperatures by about 0.5 °C for a year or two. Volcanic CO<sub>2</sub> is less than 1% of human emissions.
- **Internal variability:** ocean–atmosphere cycles such as **El Niño and La Niña** (the El Niño–Southern Oscillation) make individual years warmer or cooler.



**Fig. 17.4** The 1991 eruption of Mount Pinatubo, whose sulphate haze cooled the planet for about two years

- **Attribution:** when these natural factors are combined in climate models, they produce no warming since 1950. Only when human greenhouse gases and aerosols are added do the models match the observed rise. The IPCC concludes that human influence has warmed the climate "**unequivocally**".

## 06 Feedbacks and Tipping Points

**Climate feedbacks** are processes that either amplify (positive feedback) or dampen (negative feedback) an initial change. The main negative feedback is simple: a warmer Earth radiates more heat to space. The positive ones are worrying:

- **water vapour:** warmer air holds more moisture, which traps more heat;
- **ice-albedo:** as bright snow and sea ice melt, darker surfaces absorb more sunlight;
- **permafrost thaw:** frozen Arctic soils, holding about twice as much carbon as the atmosphere, release CO<sub>2</sub> and methane as they thaw;
- **weakening carbon sinks** and more frequent **forest fires**.

Because of feedbacks, the **climate sensitivity** (the long-term warming from a doubling of CO<sub>2</sub>) is about 3 °C, with a likely range of 2.5–4 °C, rather than the roughly 1.2 °C that CO<sub>2</sub> would cause on its own.

### Feedbacks That Amplify Warming, and Tipping Points to Avoid



**Fig. 17.5** Positive feedbacks amplify warming; beyond certain thresholds some systems may tip into new states that are hard to reverse

A **tipping point** is a threshold beyond which a part of the climate system changes in a self-sustaining and often irreversible way, even if warming stops. Examples:

- collapse of the Greenland and West Antarctic ice sheets;
- a slowdown or collapse of the **Atlantic Meridional Overturning Circulation (AMOC)**, the ocean "conveyor" that includes the Gulf Stream;
- dieback of the Amazon rainforest;
- abrupt permafrost thaw;
- the loss of warm-water coral reefs, which scientists warn are already at or past their tipping point.

The risk of crossing several of them rises sharply between 1.5 °C and 2 °C of warming.

The **Intergovernmental Panel on Climate Change (IPCC)** was set up in **1988** by the World Meteorological Organization and the UN Environment Programme. It does not conduct its own research. Instead, thousands of volunteer scientists assess published research, and governments approve the summaries line by line. Its reports are produced by three working groups: physical science; impacts, adaptation and vulnerability; and mitigation.

- Its **Assessment Reports** (1990, 1995, 2001, 2007, 2014 and the Sixth in 2021–23) underpin the UN climate negotiations. The IPCC shared the **2007 Nobel Peace Prize** with Al Gore.
- **Key findings of the Sixth Assessment Report (AR6)**: human influence has unequivocally warmed the climate. The world was about 1.1 °C warmer in 2011–2020 than in 1850–1900. Many changes, such as sea-level rise and ice-sheet loss, are irreversible for centuries. Limiting warming to 1.5 °C needs global greenhouse gas emissions to fall about 43% by 2030 and 60% by 2035 from 2019 levels, reaching net-zero CO<sub>2</sub> around 2050.
- **Seventh cycle**: under its chair **Jim Skea** (since 2023), the IPCC is preparing a **Special Report on Climate Change and Cities**, due in March 2027, and a methodology report on carbon dioxide removal. Governments have struggled to agree a timeline for the main Seventh Assessment Report.
- AR6 projects warming under five **Shared Socioeconomic Pathways (SSPs)**, which combine stories of social and economic development with emission levels.

## How Hot? Warming by 2081–2100 Under the IPCC Scenarios

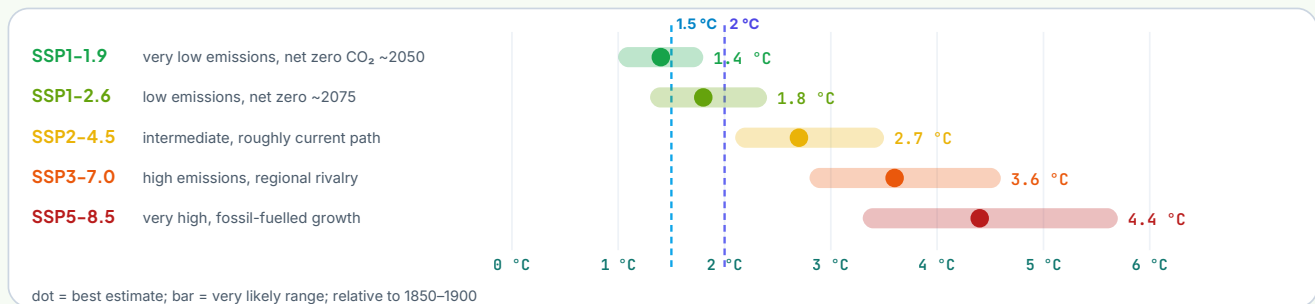


Fig. 17.6 Projected warming by the end of the century under the five IPCC scenarios; only the lowest keeps warming near 1.5 °C

## Measuring and Valuing Emissions

- A **carbon footprint** is the total greenhouse gas emissions caused by a person, product, organisation or country, in CO<sub>2</sub>e.
- The **Greenhouse Gas Protocol**, developed by the World Resources Institute and the World Business Council for Sustainable Development, is the most widely used international accounting tool for governments and companies to quantify and manage emissions. It divides a company's emissions into three scopes: **Scope 1**: direct emissions from its own operations; **Scope 2**: emissions from the electricity it buys; **Scope 3**: emissions in its supply chain and from the use of its products.
- The **Common Carbon Metric**, supported by UNEP's Sustainable Buildings and Climate Initiative, is a standard method for **measuring the carbon footprint of building operations** around the world.

- The **Social Cost of Carbon** is a monetary estimate of the long-term damage done by emitting one more tonne of CO<sub>2</sub> in a given year. It is used to weigh the costs and benefits of climate policies.

USING THIS CHAPTER IN MAINS

Climate science questions in GS Papers I and III ask candidates to explain the greenhouse effect, the role of each gas, natural versus human causes, and the evidence for warming. A good answer:

- defines the enhanced greenhouse effect with the energy-budget diagram;
- quotes current data (CO<sub>2</sub> about 424 ppm, 2024 at 1.55 °C, record emissions, a remaining 1.5 °C budget of only a few years);
- notes why methane and other short-lived pollutants are the fastest lever;
- explains feedbacks and tipping points to show the urgency of action;
- uses IPCC findings and SSP projections to show what is at stake.

08

Key Terms at a Glance

| TERM                           | ONE-LINE MEANING                                                            |
|--------------------------------|-----------------------------------------------------------------------------|
| Albedo                         | Fraction of sunlight reflected; about 0.3 for the Earth                     |
| Greenhouse effect              | Trapping of outgoing infrared by gases; keeps the Earth near 15 °C          |
| Radiative forcing              | Change in the energy balance (W/m <sup>2</sup> ) caused by a factor         |
| GWP                            | Heat trapped by a gas relative to CO <sub>2</sub> over a set period         |
| CO <sub>2</sub> -equivalent    | Emissions of any gas expressed as the CO <sub>2</sub> with the same warming |
| Short-lived climate pollutants | Methane, tropospheric ozone, black carbon, HFCs                             |
| Keeling Curve                  | Record of CO <sub>2</sub> at Mauna Loa since 1958                           |
| Carbon budget                  | Total CO <sub>2</sub> that can still be emitted for a given warming limit   |
| Carbon fertilisation           | Faster plant growth due to higher CO <sub>2</sub>                           |
| Climate sensitivity            | Warming from doubled CO <sub>2</sub> ; about 3 °C                           |
| Tipping point                  | Threshold beyond which change becomes self-sustaining                       |
| Milankovitch cycles            | Orbital changes that pace ice ages                                          |

| TERM                  | ONE-LINE MEANING                                        |
|-----------------------|---------------------------------------------------------|
| SSPs                  | IPCC Shared Socioeconomic Pathways used for projections |
| Social Cost of Carbon | Monetary damage from one extra tonne of CO <sub>2</sub> |



## Previous Year Questions



2025

Consider the following statements:

Statement I: Studies indicate that carbon dioxide emissions from cement industry account for more than 5% of global carbon emissions.

Statement II: Silica-bearing clay is mixed with limestone while manufacturing cement.

Statement III: Limestone is converted into lime during clinker production for cement manufacturing.

Which one of the following is correct in respect of the above statements?

- a Both Statement II and Statement III are correct and both of them explain Statement I
- b Both Statement II and Statement III are correct but only one of them explains Statement I
- c Only one of the Statements II and III is correct and that explains Statement I
- d Neither Statement II nor Statement III is correct

**Answer: (b).** Both are true, but only the conversion of limestone to lime (which releases CO<sub>2</sub>) explains the emissions.

2024

Consider the following statements:

Statement-I: The atmosphere is heated more by incoming solar radiation than by terrestrial radiation.

Statement-II: Carbon dioxide and other greenhouse gases in the atmosphere are good absorbers of long wave radiation.

Which one of the following is correct in respect of the above statements?

- a Both Statement-I and Statement-II are correct and Statement-II explains Statement-I
- b Both Statement-I and Statement-II are correct, but Statement-II does not explain Statement-I
- c Statement-I is correct, but Statement-II is incorrect
- d Statement-I is incorrect, but Statement-II is correct

**Answer: (d).** The atmosphere is heated mainly from below by terrestrial (longwave) radiation.

2021

The 'Common Carbon Metric', supported by UNEP, has been developed for

- a assessing the carbon footprint of building operations around the world
- b enabling commercial farming entities around the world to enter carbon emission trading
- c enabling governments to assess the overall carbon footprint caused by their countries
- d assessing the overall carbon footprint caused by the use of fossil fuels by the world in a unit time

**Answer: (a).** It is a standard method for buildings.

2020

Which one of the following statements best describes the term 'Social Cost of Carbon'? It is a measure, in monetary value, of the

- a long-term damage done by a tonne of CO<sub>2</sub> emissions in a given year
- b requirement of fossil fuels for a country to provide goods and services to its citizens, based on the burning of those fuels
- c efforts put in by a climate refugee to adapt to live in a new place
- d contribution of an individual person to the carbon footprint on the planet Earth

**Answer: (a).**

2018

Which of the following statements best describes "carbon fertilization"?

- a Increased plant growth due to increased concentration of carbon dioxide in the atmosphere
- b Increased temperature of Earth due to increased concentration of carbon dioxide in the atmosphere
- c Increased acidity of oceans as a result of increased concentration of carbon dioxide in the atmosphere
- d Adaptation of all living beings on Earth to the climate change brought about by the increased concentration of carbon dioxide in the atmosphere

**Answer: (a).**

2016

What is Greenhouse Gas Protocol?

- a It is an international accounting tool for government and business leaders to understand, quantify and manage greenhouse gas emissions
- b It is an initiative of the United Nations to offer financial incentives to developing countries to reduce greenhouse gas emissions and to adopt eco-friendly technologies
- c It is an inter-governmental agreement ratified by all the member countries of the United Nations to reduce greenhouse gas emissions to specified levels by the year 2022
- d It is one of the multilateral REDD+ initiatives hosted by the World Bank

**Answer: (a).** It was developed by WRI and WBCSD.

2012

The increasing amount of carbon dioxide in the air is slowly raising the temperature of the atmosphere, because it absorbs

- ☐ a the water vapour of the air and retains its heat
- ☐ b the ultraviolet part of the solar radiation
- ☐ c all the solar radiations
- ☐ d the infrared part of the solar radiation

**Answer: (d).** CO<sub>2</sub> absorbs infrared (heat) radiation.

2011

Human activities in the recent past have caused the increased concentration of carbon dioxide in the atmosphere, but a lot of it does not remain in the lower atmosphere because of

1. its escape into the outer stratosphere.
2. the photosynthesis by phytoplankton in the oceans.
3. the trapping of air in the polar ice caps.

Which of the statements given above is/are correct?

- ☐ a 1 and 2
- ☐ b 2 only
- ☐ c 2 and 3
- ☐ d 3 only

**Answer: (b).** The ocean, including its phytoplankton, is a major carbon sink.

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9

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274

PYQS 2011–2026

132

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| 05 | Climate Change                    | 5 ch · p296 |
| 06 | Energy and Environment            | 1 ch · p349 |
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