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UPSC CSE MAINS

GEOGRAPHY OPTIONAL

PAPER I

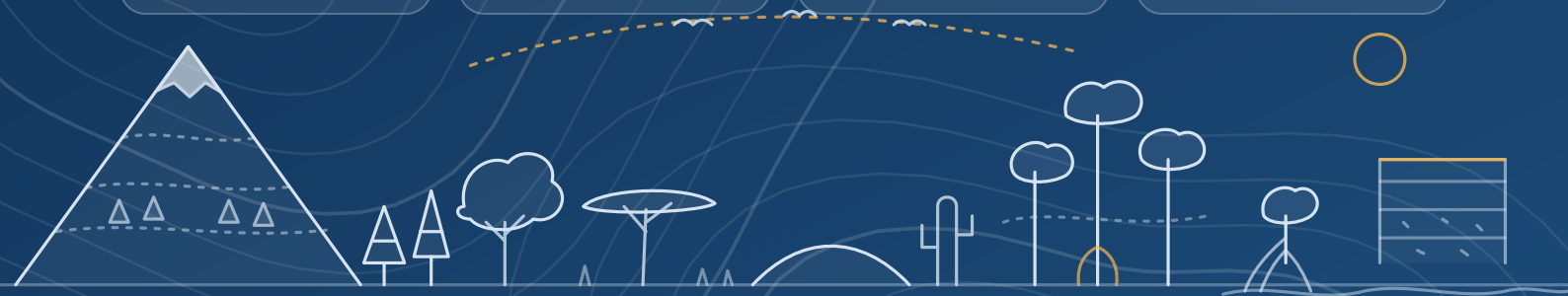
Biogeography Notes

The complete Biogeography section of Paper I — soils, the distribution of plants and animals, forests, wildlife and gene pools, and climate change, with previous year questions.

Compiled by Arvind KrS

SOILS | BIOMES AND REALMS | PLANT SUCCESSION | FORESTS AND WILDLIFE | CLIMATE CHANGE

23	6	74	124
Chapters	Units	Previous year questions	Diagrams and figures



IN THIS BOOK

01 Foundations of Biogeography

02 Soils

03 Distribution of Plants and Animals

04 Forests

05 Wildlife and Gene Pools

06 Climate Change and Human Impact

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Geography Optional — Biogeography

Paper I · Physical Geography: Biogeography

Mains 2027 Edition · Compiled October 2026

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Questions or corrections: support@lotusarise.com

How to read these notes

Every chapter is marked against the questions UPSC has actually asked on it, so the points that matter most stand out on the first read and are quick to find at revision.

Clearing upper catchments turns rivers flashy and silt-laden.

Yellow marker: key point. A point that carries the ideas UPSC has asked about in this chapter. Read these first, and make sure each one is in your answer.

Dispersal is the movement of organisms or their propagules away from their place of origin.

Blue marker: definition. The cleanest definition of a term, ready to open an answer with.

Soil formation is controlled by **climate, organisms, relief, parent material and time**.

Saffron underline: PYQ term. A key term or phrase that appears in this chapter's previous year questions.

Plant Succession PYQ 2022 · 2017 · 2015 +1

PYQ tag on a heading. The years in which UPSC asked about this section. Sections without a tag are background or linking material.

PYQ RADAR **8** questions Last asked **2026**

PYQ radar. At the start of each chapter: how many times the topic has been asked, and how recently. The contents page shows the same count for every chapter.

Suggested method. First read: the whole chapter. Revision: the yellow and blue marks, the tagged headings and the PYQ list at the end of the chapter. Last week before Mains: the PYQ list alone, answering each question in your head from the marked points.

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UNIT 01 | 3 CHAPTERS

Foundations of Biogeography

Biogeography: meaning, scope and development; biodiversity and endemism; biogeographic realms and regions.

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GEOGRAPHY OPTIONAL | PAPER I · BIOGEOGRAPHY

Biogeography: Definition, Scope, and Development of Biogeography

PYQ RADAR *No direct question yet: read for concepts, examples and links to other topics*

CONTENTS

01 Definition, Nature and Scope of Biogeography
02 Scope of Biogeography: Sub-fields
03 Historical Development of Biogeography
04 Previous Year Questions

- **Biogeography** is the branch of **physical geography** **most closely allied to biology**, since both study plants and animals. It is the study of **the distribution of organisms and ecosystems across geographical space and through geological time**.
  - Organisms are spread unevenly over the Earth's land and water. Biogeography describes these **spatial patterns of flora and fauna** and explains the processes behind them.
  - It draws on biology, **geography**, ecology, geology and evolutionary science, and links life to its environment.
- Its roots reach back to ancient Greece, where **Aristotle** first noted regularities in where animals and plants live. It became a **systematic science only in the nineteenth century**:
  - **Alexander von Humboldt** traced the climatic logic of plant zonation;
  - **Charles Darwin** and **Alfred Russel Wallace** supplied the evolutionary mechanism that explains why related species differ from place to place.
- Two threads run through the whole field:
  - **ecological explanation** answers "why here, now?": present climate, soil and species interactions;
  - **historical explanation** answers "why here and not elsewhere, given the past?": continental drift, glaciations, dispersal, speciation and extinction.

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01 Definition, Nature and Scope of Biogeography

How scholars have defined it

- Geographers arrived at the same idea from different angles:

SCHOLAR	DEFINITION	EMPHASIS
Laurence Dudley Stamp	"The science of geographical distribution of living things, animals and vegetation"	Distribution
Francis John Monkhouse	"The study of geographical aspects of plant and animal life, especially in terms of areal distribution"	Areal (spatial) pattern
A classical definition	"The science dealing with the geographical distribution of plants and animals over the earth"	Global scale
Joy Tivy (1982)	Both a biological and a geographical science, whose field is "the biologically inhabited part of the lithosphere, atmosphere and hydrosphere", that is, the biosphere	The biosphere as its field
Margaret Swainson Anderson	The "biological relations between man (considered as animal) and the whole of his animate and inanimate environment"	Man–environment relations
Modern definition	The study of the distribution of species and ecosystems in geographic space and through geological time	Space and time together

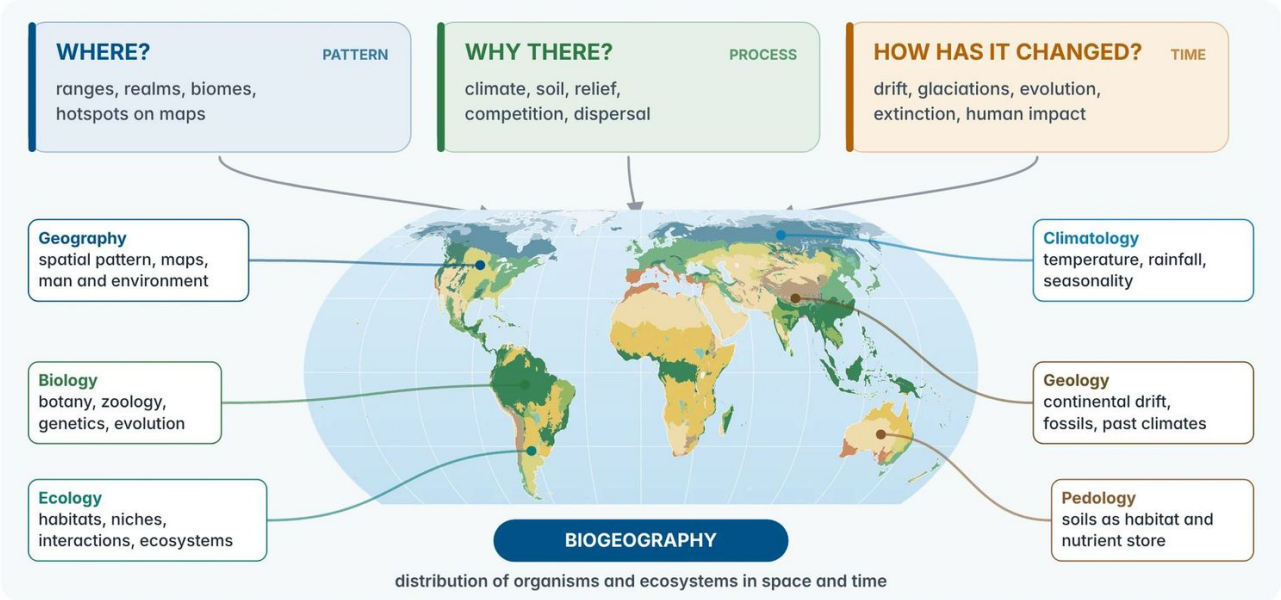
- A fuller modern statement makes biogeography the study of **spatial diversity of organisms** and their **distribution patterns**, together with species origin, geographical and ecological variation, dispersal (diffusion) of species and processes such as extinction.
- **Taken together**, the definitions converge on **three questions**: ***where*** organisms live, ***why*** they live there, and ***how*** that distribution has changed through time.

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BIOGEOGRAPHY · PLANT GEOGRAPHY

Nature of Biogeography

An interdisciplinary field that asks three questions of the living world: where organisms are, why they are there, and how that has changed.



The biologist asks
- How does an organism work?
- Physiology, form, behaviour
- One species, one individual

The biogeographer asks
- Where do communities occur, and why?
- Spatial and temporal patterns
- Processes and factors behind them

The geographer adds
- Links of abiotic and biotic parts
- Reciprocal man–biosphere relation
- Plant geography more than animal

Schematic. Map: WWF terrestrial biomes (Dinerstein et al. 2017); Natural Earth. lotusarise.com

The biosphere: the field of biogeography

- The **biosphere**, one of the **four domains of the Earth**, is the **life-supporting layer** around the planet: the biologically inhabited soil, air and water. Its study is biogeography.
- It has **three components**, the same as those of an ecosystem viewed at the global scale:
  - **abiotic (physical)**: the lithosphere (land and soil), the atmosphere (air) and the hydrosphere (water);
  - **energy**, chiefly solar radiation;
  - **biotic (organic)**: plants, animals including humans, and micro-organisms.
- **Its extent:**
  - The layer is commonly taken as **about 30 km thick**. Its upper limit is set by falling oxygen, moisture, temperature and air pressure; its lower limit by the availability of oxygen and light.
  - Most organisms live in a **thin film** from the lowest few hundred metres of air down to the soil and the sunlit upper ocean. On land the floor is the depth of the deepest roots and burrowers; in the sea, life reaches the deepest trenches.

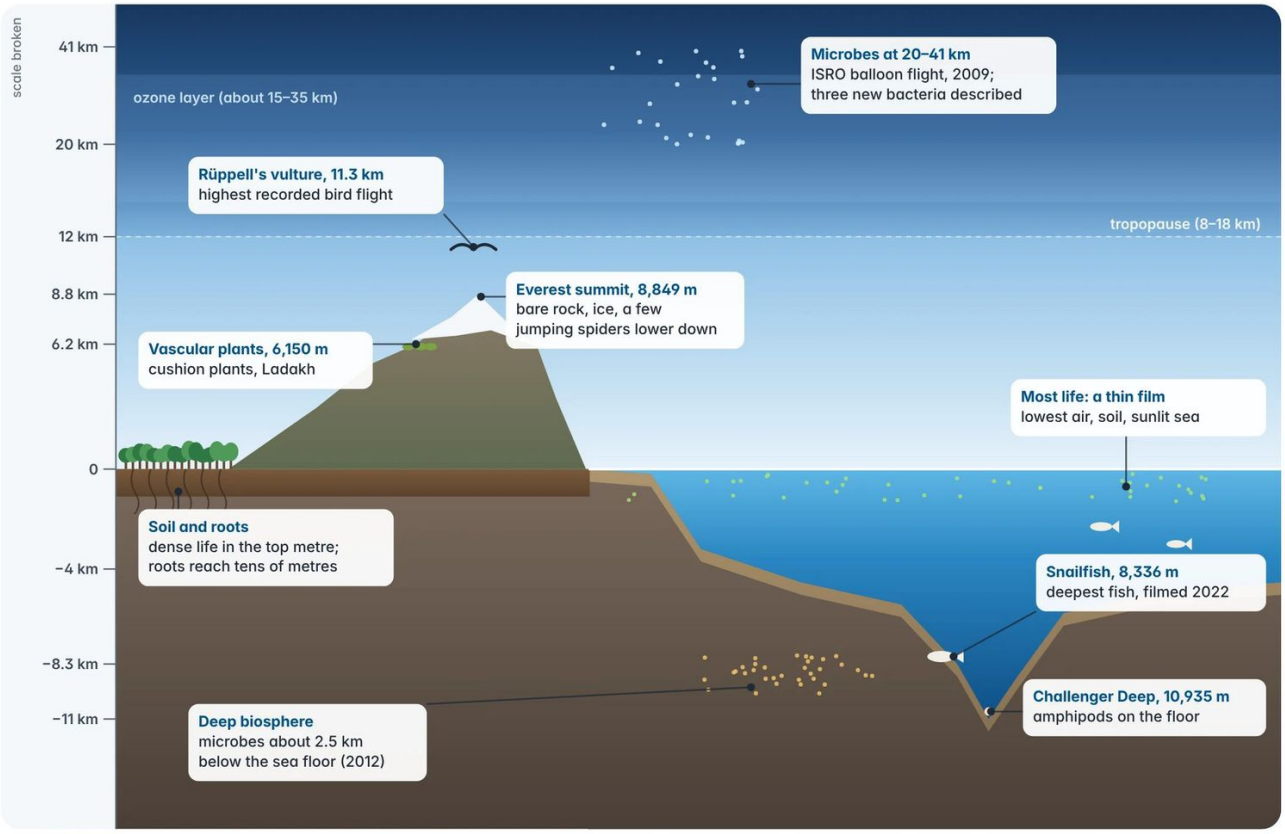
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- **Modern records stretch both limits:**
  - An Indian **ISRO balloon flight (2009)** collected bacteria at **20–41 km** in the stratosphere and described three new species, among them *Bacillus isronensis*.
  - Vascular plants grow up to about **6,150 m** on Mount Shukule II in Ladakh, the highest known.
  - A snailfish filmed in 2022 at **8,336 m** off Japan is the deepest fish on record; amphipods live on the floor of the Challenger Deep (about 10,935 m).
  - Ocean drilling (2012) found microbes about **2.5 km below the sea floor** off Japan, a deep biosphere without sunlight.
- **Sub-systems:** the **terrestrial biome system** (plant, animal and soil sub-systems) and the **aquatic biome system** (plant, animal and nutrient sub-systems), each linked by cyclic pathways of energy and matter, as the **principles of ecology** describe.
- **Modifiers** alter the biosphere directly or through climate: **physical** (temperature change, fire, mining, construction), **chemical** (changed composition of air, water and soil) and **biological** (cropping patterns, population change, manipulation of species and genes).

BIOGEOGRAPHY · PLANT GEOGRAPHY

Extent of the Biosphere

Life fills a layer about 30 km thick, but most of it crowds into a thin film where air, soil and sunlit water meet.



Abiotic component
- Lithosphere: land and soil
- Atmosphere: air
- Hydrosphere: water

Energy component
- Solar radiation drives photosynthesis
- Flows through food chains
- Lost as heat at each step

Biotic component
- Plants: producers (autotrophs)
- Animals including man: consumers
- Micro-organisms: decomposers

Schematic; vertical scale broken and not uniform. Records: ISRO (2009), Dolezal et al. (2016), Jamieson et al. (2023), IODP Expedition 337.

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Nature of biogeography

- **Interdisciplinary.** Botany, zoology, genetics, geology, climatology, pedology and geomorphology all work parts of the same field; none owns it exclusively.
- **The geographer's approach** differs from the biologist's:
  - the biologist studies the physiology, form, behaviour and function of **individual organisms**;
  - the geographer studies the **distribution of communities in space and time**, and the processes and factors behind it;
  - the geographer adds two more emphases: the **interrelationship of abiotic and biotic components**, and the **reciprocal relationship between man and the biosphere**.
- **Spatial and temporal**, at every scale from a habitat to the globe and from a season to hundreds of millions of years.

- **Holistic**: organisms are its core, but the abiotic land, air and water of their habitats are studied too.

Plant geography and animal geography

- The two classical divisions are **plant geography (phytogeography)** and **animal geography (zoogeography)**.
  - **Plant geography** studies the classification of plants, their spatial distribution, origin and development, dispersal, extinction and functions.
  - **Zoogeography** studies the classification, evolutionary history and spatial distribution of animals.
- **In geography, plant geography receives more attention.** Plants are easier to map and more closely tied to the physical environment:

BASIS	PLANTS	ANIMALS
Mobility	Static; grouped in fixed communities	Mobile; ranges shift by season and day
Nutrition	Autotrophs, the primary producers	Heterotrophs (consumers)
Share of biomass (2018 census)	About 80% of living carbon (450 of 550 gigatonnes)	Under 1%
Tie to environment	Directly controlled by climate and soil, and modify both	Depend on vegetation and on other animals
Ease of study	Visible, countable vegetation cover	Many are tiny, secretive, or variable in behaviour

Core concepts in biogeography

- **Species distribution** is the **spatial and temporal pattern of where a species occurs**: the central subject matter of the discipline.
- **Endemism** means **restriction of a species to a particular area**, often an island, an isolated mountain range or a unique ecosystem, as with the lemurs of Madagascar and the Nilgiri tahr of the Western Ghats.
  - **Palaeoendemics** are ancient species surviving in a relict area, the "living fossils".
  - **Neoendemics** are recently evolved species with a small range, often the product of adaptive radiation.
- **Habitat** is the **natural environment of an organism**, made of biotic (plants, animals, microbes) and abiotic (climate, soil, water, terrain) components.
- **Biomes** are **large-scale ecological communities** (forests, deserts, grasslands, tundra) defined by characteristic climate and vegetation.
  - They are the largest recognisable terrestrial ecological units, often called the "major life zones".

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Theories and models

Wallace's Line and Wallacea

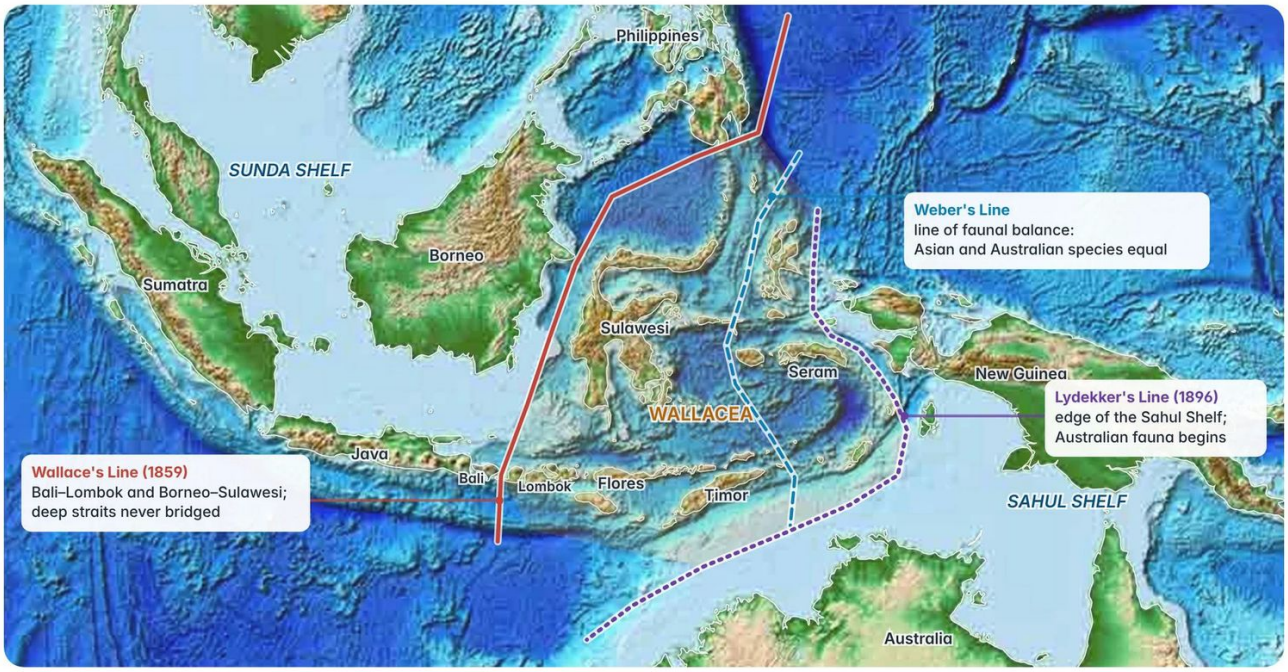
- **Alfred Russel Wallace** first described a **faunal boundary** through the Malay Archipelago in **1859**. It runs between **Bali and Lombok** and between **Borneo and Sulawesi**, and separates Asian (Oriental) fauna from Australian fauna.
  - Bali and Lombok are only about 35 km apart, yet the deep Lombok Strait stayed open even when glacial low sea levels joined the western islands to Asia. A **narrow but deep strait** can thus be an effective dispersal barrier.
  - **Thomas Henry Huxley** named it Wallace's Line in 1868.
- Later biologists refined rather than replaced it:
  - **Weber's Line**, after **Max Weber** of the Siboga Expedition, runs farther east. It marks the line of **faunal balance**, where Asian and Australian species are about equal; many zoogeographers treat it as the truer transition.
  - **Lydekker's Line**, drawn by **Richard Lydekker (1896)** along the edge of the Sahul Shelf, marks where distinctly Australian fauna begins.
- **Wallacea** is the belt of islands **between Wallace's and Lydekker's lines** of the **faunal realms**, mainly Sulawesi, Lombok, Flores, Timor and the Moluccas. It is neither fully Asian nor fully Australian, and is among the **most distinctive, high-endemism regions on Earth**: the Komodo dragon, anoa, babirusa and maleo live there.

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BIOGEOGRAPHY · ANIMAL GEOGRAPHY

Wallace's, Weber's and Lydekker's Lines

Deep straits between the Asian and Australian continental shelves form a transition zone, Wallacea, rather than a single sharp boundary.



Sundaland (west)

- Shelf joined to Asia at glacial low sea levels
- Placental mammals: tiger, rhinoceros, orang-utan
- Macaques, gibbons, woodpeckers

Wallacea (between)

- Islands never joined to either continent
- Mixed fauna, very high endemism
- Komodo dragon, anoa, babirusa, maleo

Sahul (east)

- Australia and New Guinea, joined by the shelf
- Marsupials and monotremes
- Kangaroos, cassowary, birds of paradise

Lines approximate, after Alfred Russel Wallace (1859), Max Weber and Richard Lydekker (1896). Relief: NOAA ETOPO1. **lotusarise.com**

Biogeographic realms

- **Biogeographic realms** are major world regions, each with a **distinctive assemblage of plants and animals** shaped by long isolation and continental drift. **Philip Lutley Sclater (1858)** proposed six from the distribution of birds; **Wallace (1876)** extended them to all animals:

REALM	EXTENT	CHARACTERISTIC FAUNA
Nearctic	North America to the Mexican highlands, Greenland	Bison, moose, beaver, pronghorn
Palaearctic	Europe, Asia north of the Himalaya, North Africa	Wolf, red deer, lynx, wild boar; the largest realm by area

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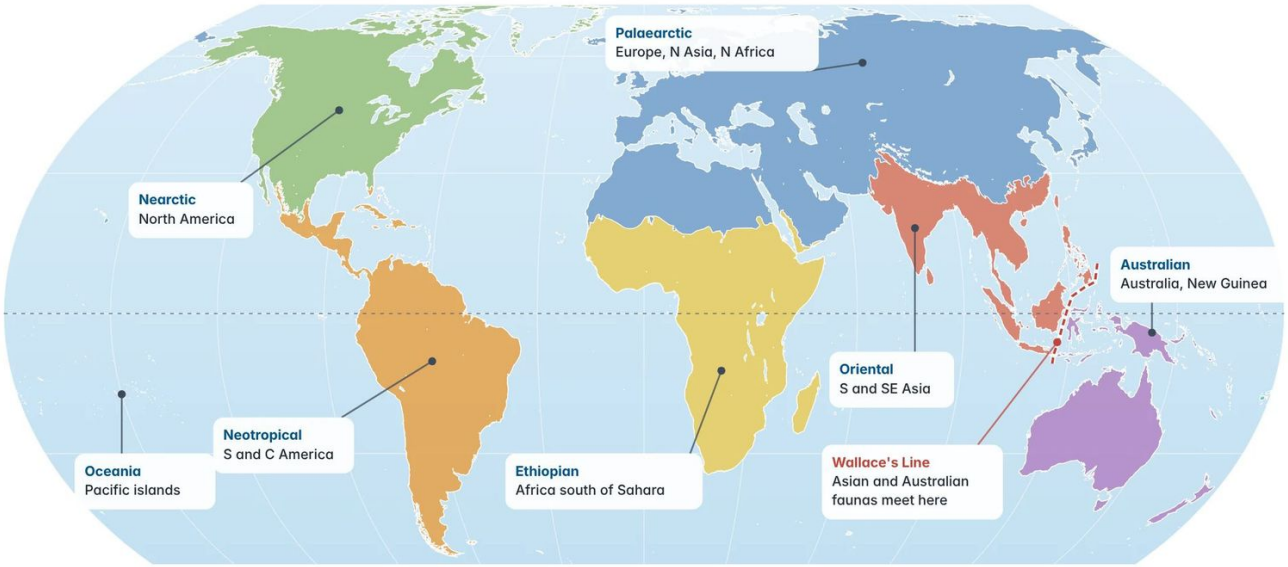
REALM	EXTENT	CHARACTERISTIC FAUNA
Neotropical	South and Central America, from southern Mexico	Jaguar, sloths, capybara, hummingbirds; the richest in species
Ethiopian (Afrotropical)	Africa south of the Sahara, Madagascar	Elephant, lion, zebra, giraffe, gorilla; lemurs in Madagascar
Oriental (Indomalayan)	Indian subcontinent, South-East Asia west of Wallacea	Tiger, Asian elephant, gibbons, rhinoceros
Australian (Australasian)	Australia, New Guinea, New Zealand	Kangaroo, koala, platypus, cassowary

- Realm boundaries are **zones, not sharp lines**, as Wallacea shows. Modern schemes of **biogeographic realms and regions** add Oceania and Antarctica: eight realms for the WWF (2001), eleven for Ben Holt and colleagues (2013).

BIOGEOGRAPHY · ANIMAL GEOGRAPHY

Biogeographic Realms of the World

Each realm holds a distinctive assemblage of plants and animals; the six classical realms map closely onto the modern WWF scheme.



Six classical realms

- Philip Lutley Sclater (1858), from birds
- Alfred Russel Wallace (1876), all animals
- Shaped by isolation and continental drift

Boundaries are zones

- Wallacea mixes Asian and Australian fauna
- Sahara and Himalaya are broad transitions
- WWF puts Wallacea in Australasia

Modern schemes

- WWF (2001): 8 realms, 867 ecoregions
- Holt et al. (2013): 11 realms, 20 regions
- Oceania and Antarctica added

Realm boundaries: WWF (Olson et al. 2001; Dinerstein et al. 2017). Map data: Natural Earth. Wallace's Line approximate. lotusarise.com

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Island biogeography theory

- **Robert MacArthur and Edward O. Wilson (1963, 1967)** explained species richness on an island as a **balance of two rates**:
  - an **immigration rate**, which falls with distance from the mainland source pool;
  - an **extinction rate**, which falls as island area increases, because larger islands hold larger, more stable populations.
- Where the two curves cross gives the **equilibrium number of species** an island can be expected to hold.
- The idea is often summarised through the **species–area relationship**, $S = cA^z$, where S is the number of species, A the area, and c and z are constants.
- It is a load-bearing idea of conservation planning. Reserves surrounded by farmland behave like islands, hence the long **SLOSS debate**: is conservation better served by a Single Large or Several Small reserves?

Factors influencing biogeography

- **Geological processes**, **plate tectonics** and **continental drift**, have reshaped continents and islands over geological time and drive distribution in two ways:
  - **Vicariance**: a once-continuous population is split by a new barrier, such as a rift or a widening ocean.
  - **Dispersal**: species cross an existing barrier by active or passive movement, on wind or ocean currents or rafting on debris.
  - Darwin and Wallace both favoured dispersal. The two are now seen as **complementary**: vicariance explains deep, ancient splits between lineages on separate continents; dispersal explains recent, one-off colonisations, such as an oceanic island gaining its first reptile.
  - **An Indian example:** the purple frog (*Nasikabatrachus sahyadrensis*) of the Western Ghats, described in 2003, has its closest relatives in the Seychelles, a relic of their union in Gondwana.
- **Climate**, through temperature, precipitation and seasonality, **sets the outer limits** of where a species can survive.
  - Steady warmth and humidity help explain the richness of tropical rainforests; deserts and polar regions support fewer, more specialised species.
  - **Pleistocene glaciations** pushed species into refugia, from which they later spread.
- **Evolution**, through speciation, adaptive radiation and extinction, continuously reworks these patterns, acting together with climatic and geological change.
- **Ecological interactions**, such as predation, competition and mutualism, shape populations at a finer grain, sometimes excluding a species from a habitat that would otherwise suit it.
- **Human activity**, through land-use change, introduced species and climate change, is now one of the **factors influencing the distribution of plants and animals** in its own right.

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Methods in biogeography

METHOD	WHAT IT DOES	EXAMPLE
Field surveys	Direct observation and recording of organisms in their habitats; the foundation of the discipline	Plot and transect surveys of forests
Museum, herbarium and fossil records	Show past and present ranges; fossils and pollen (palynology) record distributions through time	Pollen cores tracing post-glacial forest spread
Remote sensing and GIS	Track environmental change and its effect on ranges, at scales no field team could cover	Satellite mapping of forest loss
Genetic analysis (phylogeography)	Reads variation among populations to reconstruct migration and divergence: a molecular record of where a lineage has been	Dating the split of Gondwanan lineages
Modelling (species distribution models)	Turns the other methods' data into testable forecasts of range shifts, for example under climate change	Projected upslope shift of Himalayan species

- **Biodiversity informatics** now pools these records. The Global Biodiversity Information Facility (GBIF), set up in 2001, passed **3 billion occurrence records** in 2024. **Environmental DNA (eDNA)**, traces of DNA in water or soil, now detects species without seeing them.

Applications of biogeography

- **Conservation biology:** biogeography identifies **biodiversity hotspots** and designs protected-area networks, such as India's **biosphere reserves**, with real ecological logic rather than convenience.
- **Restoration ecology:** it guides the choice of ecologically appropriate native species when a degraded habitat is rebuilt.
- **Invasive species management:** dispersal and niche models let managers predict and get ahead of the spread of non-native species.
  - In India, *Lantana camara* covered about **154,000 km²**, over 40% of the forest in the tiger range, by 2020, and a further 300,000 km² was modelled as at risk. Nearly 60% of its occurrences lay outside the climate of its native Central America.
- **Agriculture and genetic resources:** the search for the **centres of origin of crops**, begun by **Alphonse de Candolle** and **Nikolai Vavilov**, rests on biogeography.

Current challenges and future directions

- **Climate change** is already **shifting species ranges** and biome boundaries. Biogeography's main contribution is **anticipation**: modelling the shifts before they arrive rather than only recording them afterwards.
- **Habitat loss** through deforestation, urbanisation and land-use change keeps **fragmenting ranges** and cutting the connections between habitats.

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- The resulting **biodiversity loss** makes understanding why species are disappearing a precondition for any conservation response.

02 Scope of Biogeography: Sub-fields

- Biogeography has grown a **family of sub-disciplines**, each asking where organisms live and why through a different lens:

SUB-FIELD	FOCUS	EXAMPLE
Phytogeography	Distribution of plants and vegetation	Floristic kingdoms; altitudinal vegetation belts of the Himalaya
Zoogeography	Distribution of animals	Faunal realms; the Nearctic fauna
Ecological biogeography	Present-day distribution across habitats; niches, community interactions and environmental controls	Why the Thar has xerophytes and the Western Ghats evergreen forest
Historical biogeography	How tectonics, past glaciations, speciation and extinction shaped today's patterns; links Earth history with the history of life	Gondwanan relics in peninsular India
Palaeobiogeography	Distributions of past geological periods, from fossils	*Glossopteris* flora across the southern continents
Island biogeography	Species–area relations, isolation and the high endemism of islands; their vulnerability to invasive species	Galápagos finches, Hawaiian honeycreepers, Andaman and Nicobar endemics
Regional biogeography	Division of the world into realms, regions and ecoregions on climate, vegetation and species composition	Palaearctic, Afrotropical, Neotropical, Nearctic, Australasian and Antarctic realms
Evolutionary biogeography and phylogeography	Adaptive radiation and the genetic and geographic history of lineages	Darwin's Galápagos finches
Macroecology	Large-scale statistical patterns of richness, range size and body size	The latitudinal diversity gradient
Conservation biogeography	Applying biogeographic principles to protect biodiversity: hotspots, reserves, corridors	Western Ghats–Sri Lanka, Himalaya and Indo-Burma hotspots

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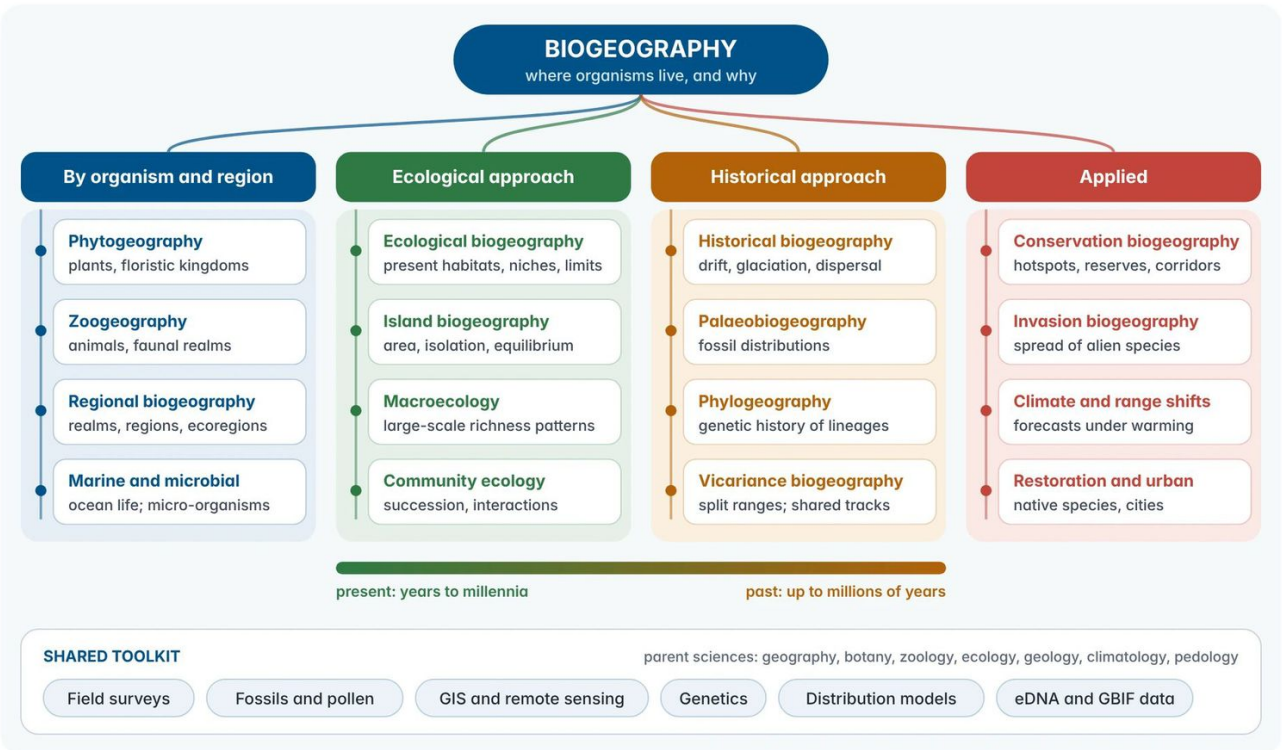
SUB-FIELD	FOCUS	EXAMPLE
Applied biogeography	Restoration ecology, urban biogeography, sustainable agriculture, forestry and land-use planning	How cities reshape species distributions
Marine and microbial biogeography	Distribution of ocean life and of micro-organisms	Coral Triangle diversity

- **Theoretical and methodological approaches** (distribution models, GIS, genetic and statistical methods) are the technical backbone of every sub-field.
- **Interdisciplinary connections** run to climate science (range-shift data), geology and palaeontology (the fossil record), **soil science**, and to sociology and anthropology, which show how human activity reshapes ranges and conservation outcomes.
- **Future directions:** global change and distributions, **biodiversity informatics** such as GBIF, and **connectivity-based conservation**. Biogeography thus bridges the past, present and future of life on Earth.

BIOGEOGRAPHY · BIODIVERSITY

Branches of Biogeography

A map of the discipline: two classical divisions by organism, two approaches by time scale, and a growing set of applied fields.



Schematic classification; branches overlap in practice.

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03 Historical Development of Biogeography

- The discipline's history moves through **four broad stages**: **descriptive natural history**, **evolutionary explanation**, **quantitative theory**, and today's **technology-driven conservation science**.

Ancient observations and the age of exploration

- **Aristotle** (384–322 BCE) studied animal dispersion and adaptation to different settings in his *History of Animals*, the earliest groundwork for linking organisms to environments.
- **Theophrastus** (about 371–287 BCE), the "father of botany", described plant distribution and climatic adaptation in his *Enquiry into Plants*.
- **Pliny the Elder** (23–79 CE) compiled in his *Natural History* one of the first systematic accounts of species across regions.
- **Voyages of the 15th–18th centuries** (Columbus, Magellan, Cook) reported new species and ranges. **Johann Reinhold Forster**, on Cook's second voyage (1772–75), noted that plant diversity falls from the tropics toward the poles.

Early modern biogeography

- **Carl Linnaeus** (1707–1778) created **binomial nomenclature**, the taxonomic scaffolding needed to compare distributions systematically.
  - He explained distribution by dispersal from a single mountain on which all species first lived.
- **Georges-Louis Leclerc, Comte de Buffon** (1707–1788), in his *Histoire naturelle*, argued that environment shapes distribution and adaptation.
  - **Buffon's Law (1761):** regions with **similar climates but long isolated** carry different species, as with the mammals of the Old and New World tropics.

The nineteenth century: foundations

- **Alexander von Humboldt** (1769–1859) explored the Americas (1799–1804) and, with **Aimé Bonpland**, wrote the *Essay on the Geography of Plants* (1805–07).
  - Its profile of Chimborazo linked **climate and altitude to plant zonation**; Humboldt is regarded as the **father of plant geography**, and his *Kosmos* (1845–62) treated nature as one connected whole.
- **Augustin Pyramus de Candolle** (1820) separated **stations** (local habitats, explained by present environment) from **habitations** (regions, explained by history). This is the origin of the ecological and historical approaches; he also stressed competition, "nature's war", between plants.
- **Philip Lutley Sclater (1858)** divided the world into **six zoological regions** from the distribution of birds.
- **Charles Darwin** (1809–1882), in *On the Origin of Species* (1859), devoted two chapters to geographical distribution and gave biogeography its **evolutionary engine**.
  - His Galápagos observations (1835) remain the classic demonstration of adaptive radiation and speciation.

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- **Joseph Dalton Hooker** (1817–1911) advanced plant geography through his southern-hemisphere floras and his work on the flora of India.
  - With **Thomas Thomson** he divided India into botanical provinces in *Flora Indica* (1855). His *Flora of British India* (1872–97) followed.
- **Alfred Russel Wallace** (1823–1913), co-discoverer of natural selection, identified **Wallace's Line** (1859).
  - His *The Geographical Distribution of Animals* (1876) and *Island Life* (1880) founded **zoogeography**.
- **Adolf Engler** (1879–82) divided the world into **floristic kingdoms** from the history of plant lineages.
- **Ecological plant geography** took shape with August Grisebach (1872), Eugenius Warming (1895) and Andreas Schimper (1898), who explained vegetation by climate, soil and plant physiology.
- **Clinton Hart Merriam** recognised **life zones**, altitudinal belts of plants and animals, on the San Francisco Peaks of Arizona (1889–90). In 1894 he tied range limits to temperature.

The twentieth century: ecology, drift and quantitative theory

- **Ecology joins in:**
  - **Frederic Clements (1916)** set out succession toward a climatic climax, and **Henry Gleason (1926)** countered with the individualistic view;
  - **Arthur Tansley (1935)** coined the **ecosystem**.
- **Alfred Wegener** proposed **continental drift** (1912, 1915). Rejected at first, it was vindicated by plate tectonics in the 1960s, which gave historical biogeography its physical basis.
- **Ronald Good (1947)** produced a classic floristic regionalisation of the world, and **Philip Darlington (1957)** a synthesis of animal distribution.
- **Léon Croizat (1958)** founded **panbiogeography**, mapping shared distribution "tracks". With **Willi Hennig's cladistics** it led to **vicariance biogeography** in the 1970s–80s.
- **Robert MacArthur** (1930–1972) and **Edward O. Wilson** (1929–2021) published *The Theory of Island Biogeography* (1967).
  - Its quantitative model linking island size and distance to species richness revolutionised biogeography and conservation planning.
  - **Daniel Simberloff and Wilson (1969)** tested it by defaunating small mangrove islands in the Florida Keys and watching them recolonise.
- **Miklos Udvardy (1975)** mapped the biogeographic provinces of the world for UNESCO's Man and the Biosphere programme.

Contemporary biogeography

- **New sub-fields:**
  - **phylogeography**, named by **John Avise (1987)**;
  - **macroecology**, by **James Brown and Brian Maurer (1989)**;
  - **conservation biogeography**, defined by **Robert J. Whittaker and colleagues (2005)**.
- **New maps:** the WWF's **867 terrestrial ecoregions in 8 realms** (2001), and an updated scheme of **11 realms** built from the evolutionary relationships of vertebrates (2013).

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- **GIS, remote sensing and molecular biology** now handle datasets earlier naturalists could not have imagined, while climate change and conservation have driven **species distribution models** and the mapping of hotspots worldwide.
- **Development in India:**
  - the **Botanical Survey of India (1890)** and **Zoological Survey of India (1916)** inventory the country's flora and fauna;
  - *Ecology and Biogeography in India* (1974), edited by **M. S. Mani**, was the first national synthesis;
  - **W. A. Rodgers and H. S. Panwar (1988)** divided India into **ten biogeographic zones**, revised in 2002.
- **Present-day biogeography** combines ecological, evolutionary and climatic data, with **global change research** running through it: tracking how climate change, land use and pollution reshape distributions, the natural continuation of a discipline that began with Aristotle watching where animals turned up.

STAGE	PERIOD	KEY FIGURES	CONTRIBUTION
Descriptive natural history	Antiquity to the 18th century	Aristotle, Theophrastus, Pliny, Linnaeus, Buffon	Records of where species live; naming; Buffon's Law
Foundations and evolution	19th century	Humboldt, de Candolle, Sclater, Darwin, Hooker, Wallace, Merriam	Plant zonation, faunal regions, evolution, life zones
Ecology, drift and theory	1900s–1980s	Clements, Tansley, Wegener, Good, Croizat, MacArthur and Wilson	Succession, ecosystem, vicariance, island equilibrium
Technology and conservation	1980s to present	Avise, Brown, Whittaker; GBIF	Phylogeography, macroecology, distribution models, conservation biogeography

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BIOGEOGRAPHY · BIODIVERSITY

Development of Biogeography

From Greek natural history to genomics: each stage added a new kind of explanation for where life is found.



1 · Descriptive
- Where species live
- Naming and classifying

2 · Evolutionary
- Regions, realms, life zones
- Darwin and Wallace explain them

3 · Quantitative theory
- Drift, succession, vicariance
- Island equilibrium

4 · Technology and conservation
- Genomics, GIS, big data
- Hotspots, distribution models

Selected milestones; dates are of key works or proposals.

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Previous Year Questions

No direct PYQ has been asked on this sub-topic yet.

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UNIT 03 | 6 CHAPTERS

Distribution of Plants and Animals

Factors influencing world distribution of plants and animals.

CHAPTERS

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GEOGRAPHY OPTIONAL | PAPER I · BIOGEOGRAPHY

Biotic Regions (or) Biomes of the World

PYQ RADAR **8** questions Last asked **2026** 2026 · 2017 · 2016 · 2014 · 2013 · 2011 · 2009 · 1996

CONTENTS

01	The Biome Concept	02	Theoretical Frameworks of Biome Classification
03	A. Terrestrial Biomes	04	B. Aquatic Biomes
05	Global Disruptions and Biome Shifts	06	Previous Year Questions

- The Earth is not a uniform expanse of rock, water and soil but a mosaic of distinct regions defined by their physical conditions and living inhabitants. The largest of these living regions are **biomes** (Greek *bios*, life): **macro-scale bioclimatic landscapes or biotic areas**.
  - Formally, a biome is a **major world community classified chiefly by its dominant vegetation** and marked by the special adaptations of its organisms to that environment: tropical rainforest, savanna, desert, steppe, taiga or tundra.
- Biomes exist because **climate sorts life forms**. Wherever temperature and moisture are alike, plants of similar form (evergreen broadleaf trees, tussock grasses, cushion plants) evolve, even on continents that share no species.
- Biomes are not fixed. Their boundaries moved with the ice ages and are **shifting again under present warming and land conversion**.

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01 The Biome Concept

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Meaning and definition

- A biome is a **broad-scale collection of flora and fauna** that differs in detail from one ecosystem to the next but shares common characteristics across its extent.
  - Its ecosystems receive **similar nutrients and energy**, so similar kinds of plants and animals occur throughout, even though individual ecosystems differ in scale, structure and function.
- **Origin of the term:** Frederic Clements introduced "biome" in **1916**, in his address to the first meeting of the Ecological Society of America, for the whole biotic community.
  - Clements and **Victor Shelford** (*Bio-Ecology*, 1939) tied it to the **climax** idea: a biome is the plant and animal community of formation rank, in equilibrium with a regional climate.
- **Formation and biome:** a **plant formation** is a vegetation unit (rainforest, steppe) recognised by its **life forms**. It becomes a biome when **plants, animals and soils are studied together**.
  - Some ecologists exclude soils, which evolve far more slowly than biota; others limit biomes to land, because marine units are hard to delimit.
  - **Green plants dominate** every biome physically, since their biomass dwarfs that of animals, so biomes are named after their vegetation.
- **Modern consensus:** a biome is a **large-scale ecosystem**, at least sub-continental, defined by climate, dominant plant life form and the functional traits of its organisms.

Biome, ecosystem, ecoregion and realm

- A biome must **not be confused with an ecosystem**. An ecosystem is the **local interaction** of living (biotic) communities with their non-living (abiotic) environment; a biome is a **broad geographical class** containing many interrelated ecosystems that share one macroclimate.
  - One tropical rainforest biome holds freshwater river ecosystems, canopy ecosystems and forest-floor decomposer networks.
- **Similar biomes recur in widely separated regions** wherever the controls are alike: Mediterranean scrub in California, Chile, the Cape, south-west Australia and the Mediterranean basin.
  - Their species differ but their **life forms converge**. A biome is defined by **form and climate**; a **biogeographic realm** by **shared evolutionary history**.

UNIT	BASIS	SCALE	EXAMPLE
Ecosystem	Local interactions of biota and environment	Pond to forest stand	A sal forest patch in Chhattisgarh
Ecoregion	Distinct assemblage of species within a biome and realm	Thousands to lakhs of km^2	Malabar Coast moist forests

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UNIT	BASIS	SCALE	EXAMPLE
Biome	Climate and dominant life form	Sub-continental to global	Tropical and subtropical moist broadleaf forests
Realm	Shared evolutionary history of lineages	Continental	Indomalayan realm

What shapes a biome

- The same **factors that govern the distribution of plants and animals**, namely climate, soil, relief, other organisms and history, shape biomes at the largest scale. The architecture of a biome is set by:
  - **Plant structure:** whether trees, shrubs or grasses dominate.
  - **Leaf phenology and form: broadleaf or needleleaf**, **evergreen or deciduous**, soft or hard (sclerophyllous).
  - **Spatial configuration:** the density and spacing of plants, from closed-canopy forest through open woodland to scattered savanna trees.
  - **Macroclimate:** latitude, solar radiation, relative humidity, weather systems and regional topography.
- The expansion or contraction of a biome is **not a function of temperature alone**: precipitation and its seasonality, humidity, wind direction and atmospheric pressure all move its edges.
- **Soil, landforms and water** also control biomes, through the lithosphere, hydrosphere and cryosphere. Waterlogged, saline or very sandy ground carries **azonal vegetation** (swamps, mangroves, heath) unlike the climatic type around it.
- **Disturbance and history: fire and grazing** keep many savannas and grasslands open where the climate could carry forest; **continental drift** isolated floras; people have cleared, burned and herded for millennia.
- **Ecotones:** biomes meet along transition belts (forest–savanna, forest–tundra), where species of both mix and an **edge effect** raises diversity.

02 Theoretical Frameworks of Biome Classification

- The classification of biomes is not static; it depends on whether a scheme prefers a few broad classes or many sub-classes.
- **Broad consensus systems** recognise five or six foundational biomes: **forest, grassland, freshwater, marine, desert and tundra.** Deeper ecological work uses more rigorous models.

Three orders of biomes

- A classical hierarchy, built on the close link between world climates and vegetation, groups land biomes in three orders:

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ORDER	BASIS	BIOMES
First	Climatic zone	Tundra; Temperate; Tropical
Second	Dominant vegetation	Tundra: arctic, alpine. Temperate: boreal (taiga), temperate deciduous forest, temperate grassland, Mediterranean, warm temperate. Tropical: tropical forest, savanna, desert
Third	Regional variants	Taiga: North American, Asiatic, mountain forest. Temperate grassland: Russian steppe, prairie, pampa, Australian grassland. Tropical forest: evergreen, semi-evergreen, deciduous, semi-deciduous, montane, swamp. Savanna: savanna forest, savanna grassland. Desert: arid, semi-arid

The Whittaker biome diagram

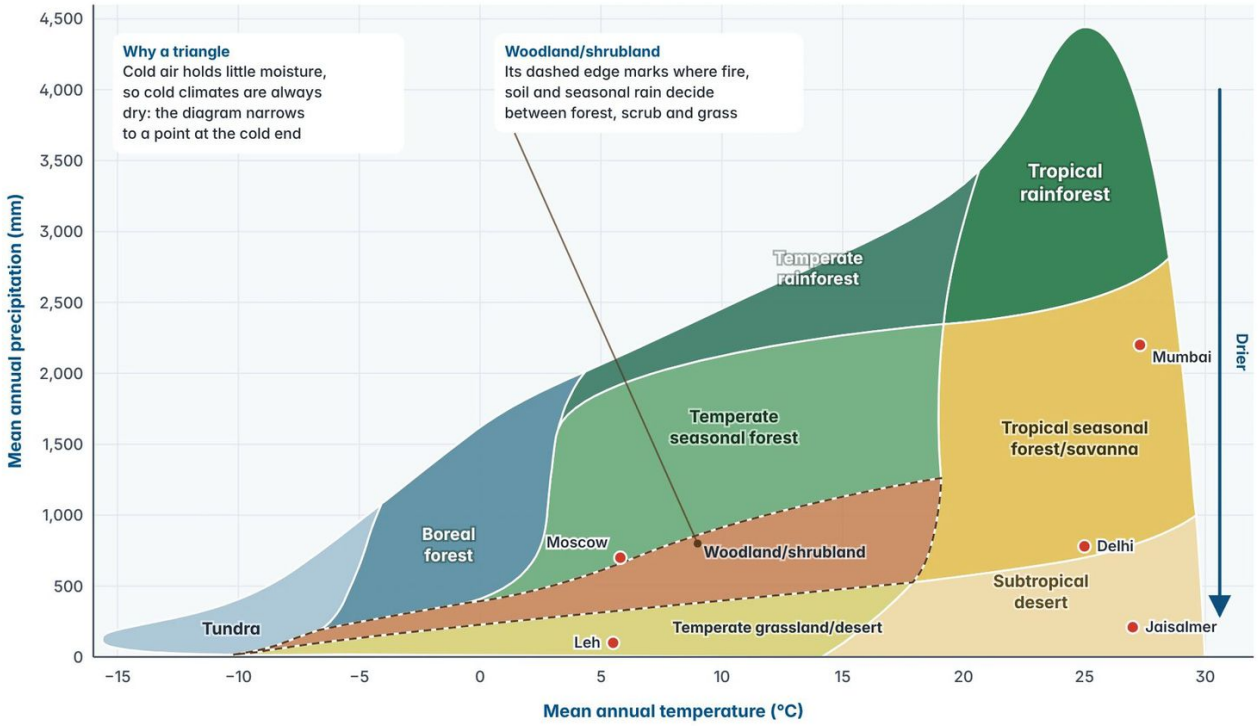
- **Robert Whittaker** (1970, 1975) charted land biomes against two independent climatic variables: **mean annual temperature (MAT)** on the horizontal axis and **mean annual precipitation (MAP)** on the vertical axis. Vegetation types fall into predictable fields.
- **Shape of the diagram:**
  - It is roughly a **triangle**: very wet climates exist only where it is warm, because **cold air holds little moisture**. Cold climates occupy a narrow precipitation range, warm climates the full range.
  - **Tundra** occupies the cold, dry corner (MAT below about −5 °C), **boreal forest** about −5 to +5 °C; temperate forests, grasslands and woodlands fill the middle.
  - Along the warm edge, falling rainfall turns **rainforest into seasonal forest and savanna, then desert**: the whole moisture gradient in one column.
  - **Woodland and shrubland** occupy a broad central band where **soil, fire and the seasonality of rain** decide between forest, scrub and grassland; Whittaker drew it with a dashed boundary for that reason.
- **Limit:** annual means hide **seasonality**. A Mediterranean climate and a summer-rain grassland can share the same MAT and MAP.

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BIOGEOGRAPHY · BIOMES

Whittaker's Biome Diagram

Nine land biomes plotted by mean annual temperature and mean annual precipitation: warmth sets the range of rainfall, and rainfall sets the vegetation.



Reading it

- Temperature sorts biomes from tundra to tropics
- Rainfall sorts them from forest to desert
- The warm edge holds rainforest, savanna and desert

Indian stations

- Mumbai sits in seasonal forest/savanna
- Delhi near the savanna–desert edge
- Jaisalmer is subtropical desert; Leh cold desert

Limits

- Uses annual means only
- Ignores rain seasonality and fire
- Same means can carry different biomes

Biome boundaries after Robert Whittaker (1975), digitised. Station values are approximate long-term means. Colours follow the WWF biome palette used across these notes.

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Heinrich Walter's zonobiomes

- In contrast to Whittaker's annual averages, **Heinrich Walter** evaluated the **seasonality** of temperature and precipitation, recorded on his **climate diagrams** (with Helmut Lieth, 1960s).
  - He mapped **nine zonobiomes (ZB I–IX)**, each with its own zonal soil and vegetation. **Cold stress and drought stress**, not annual totals, are the real gatekeepers of plant form.
  - Two regions with identical annual rainfall are separated if one has rain all year and the other a long summer drought.
- **Departures from the zonal type: orobiomes** (altitudinal belts of mountains), **pedobiomes** (vegetation of unusual soils: saline, sandy, waterlogged) and **zonoecotones** (broad transitions such as forest-steppe).

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ZONOBIOME	CLIMATE	ZONAL VEGETATION	ZONAL SOIL
ZB I Equatorial	Humid all year	Tropical evergreen rainforest	Ferralsols (latosols)
ZB II Tropical	Summer rain, winter drought	Deciduous forest, savanna	Red earths, vertisols
ZB III Subtropical arid	Hot desert	Desert vegetation	Desert soils (aridisols)
ZB IV Mediterranean	Winter rain, summer drought	Sclerophyllous woodland and scrub	Mediterranean brown and red soils
ZB V Warm temperate	Humid, mild winters	Temperate evergreen forest	Red and yellow podzolic soils
ZB VI Nemoral (typical temperate)	Short cold winter	Deciduous broadleaf forest	Brown earths, grey forest soils
ZB VII Continental arid	Cold winter, dry	Steppe to cold desert	Chernozems to sierozems
ZB VIII Boreal	Cold temperate, short summer	Coniferous forest (taiga)	Podzols
ZB IX Polar	Arctic and antarctic	Tundra	Tundra (gley) soils with permafrost

Other schemes

- **Holdridge life zones (Leslie Holdridge, 1947):** a triangular grid of biotemperature, annual precipitation and the ratio of potential evapotranspiration to rainfall, giving dozens of life zones repeated by latitude and altitude.
- **Köppen: Wladimir Köppen** drew his climate boundaries partly from vegetation limits, so the **Köppen classification** and the **climatic regions of the world** match the biomes closely: Af with rainforest, Aw with savanna, BW with desert, Cs with Mediterranean scrub, Dfc with taiga, ET with tundra.

The WWF scheme: 14 terrestrial biomes PYQ 2011

- The **WWF map** (**David Olson and others, 2001**; updated by **Eric Dinerstein and others, 2017**) divides the land into **846 ecoregions**, grouped into **14 biomes** and **8 biogeographic realms**: the standard base for global conservation planning.
- It separates forests by temperature and leaf type and grasslands by temperature and flooding, and treats **mangroves and montane grasslands** as biomes of their own.

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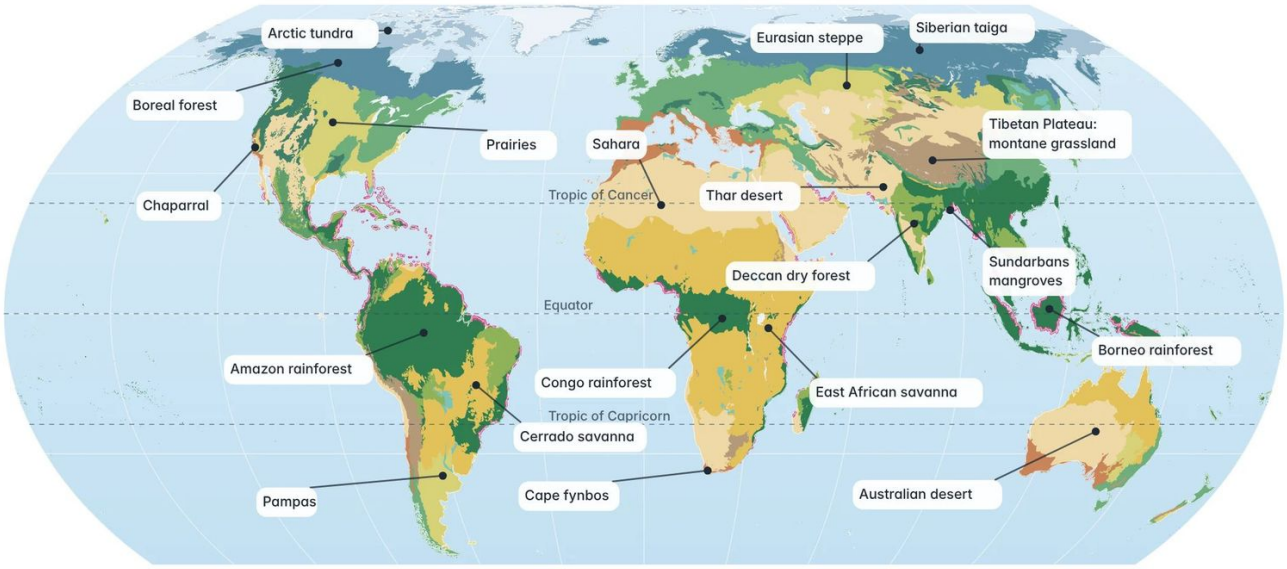
WWF BIOME	SHARE OF ICE-FREE LAND (APPROX.)	TYPICAL REGIONS
Deserts and xeric shrublands	20%	Sahara, Arabia, Thar, Australia, Atacama, Gobi
Tropical and subtropical grasslands, savannas and shrublands	16%	Sudan–Guinea and East African savannas, Cerrado, northern Australia
Tropical and subtropical moist broadleaf forests	15%	Amazon, Congo, Borneo, Western Ghats, North-east India
Boreal forests/taiga	12%	Canada, Alaska, Scandinavia, Siberia
Temperate broadleaf and mixed forests	9%	Eastern USA, Europe, eastern China, Himalaya
Temperate grasslands, savannas and shrublands	8%	Prairies, steppes, pampas, veld
Tundra	6%	Arctic coasts and islands
Montane grasslands and shrublands	4%	Tibetan Plateau, Andean páramo and puna, East African highlands
Tropical and subtropical dry broadleaf forests	3%	Central India, Deccan, Mexico, Madagascar
Temperate conifer forests	3%	Pacific North-west, Himalayan conifer belts
Mediterranean forests, woodlands and scrub	2.5%	Mediterranean basin, California, Chile, Cape, south-west Australia
Flooded grasslands and savannas	1%	Sudd, Pantanal, Okavango, Rann of Kachchh
Tropical and subtropical coniferous forests	0.5%	Mexico, Central America, Caribbean, Himalayan chir pine belt
Mangroves	0.2%	Sundarbans, Indonesia, Brazil, Nigeria

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BIOGEOGRAPHY · BIOMES

Terrestrial Biomes of the World

The 14 WWF biomes, built from 846 ecoregions: zonal belts of forest, grassland and desert, broken by mountains and coasts.



- Tropical moist broadleaf forest
- Tropical dry broadleaf forest
- Tropical coniferous forest
- Tropical grassland and savanna
- Flooded grassland and savanna
- Desert and xeric shrubland
- Mediterranean woodland and scrub
- Temperate grassland (steppe)
- Temperate broadleaf and mixed forest
- Temperate conifer forest
- Boreal forest (taiga)
- Tundra
- Montane grassland and shrubland
- Mangroves

Largest biomes

- Deserts and xeric shrublands: about a fifth of ice-free land
- Tropical savannas, then tropical moist forests
- Boreal forest: the largest forest belt

Pattern

- Belts follow latitude and rainfall
- West coasts: deserts at 15°–30°, Mediterranean at 30°–40°
- Continental interiors: steppe and cold desert

India

- About ten WWF biomes
- Moist and dry broadleaf forests cover most of it
- Thar and the Deccan thorn scrub are desert and xeric shrubland

Biomes: WWF (Olson et al. 2001; Dinerstein et al. 2017). Map data: Natural Earth. Antarctica lies south of the map edge. lotusarise.com

Productivity of biomes

- **Net primary productivity (NPP)**, the organic matter plants add after their own respiration, falls from **warm, wet biomes to cold or dry ones**, tracking the Whittaker gradient.

BIOME	AREA (MILLION KM²)	MEAN NPP (G DRY MATTER/ M²/YEAR)	TOTAL NPP (BILLION TONNES/YEAR)
Tropical rainforest	17.0	2,200	37.4
Tropical seasonal forest	7.5	1,600	12.0
Temperate deciduous forest	7.0	1,200	8.4

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BIOME	AREA (MILLION KM²)	MEAN NPP (G DRY MATTER/ M²/YEAR)	TOTAL NPP (BILLION TONNES/YEAR)
Boreal forest	12.0	800	9.6
Savanna	15.0	900	13.5
Mediterranean woodland and scrub	8.5	700	6.0
Temperate grassland	9.0	600	5.4
Tundra and alpine	8.0	140	1.1
Desert and semi-desert scrub	18.0	90	1.6
Extreme desert, rock, sand and ice	24.0	3	0.07
Open ocean	332.0	125	41.5

- In this classic estimate by **Robert Whittaker and Gene Likens (1975)**, tropical rainforests produce about **a third of all land NPP** from roughly a ninth of the land. Deserts, tundra and the open ocean are the **biological deserts** at the low end.

03 A. Terrestrial Biomes

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1. Forest Biomes

- Forests are large areas dominated by trees. By climate and kind of tree they are grouped into **tropical rainforests, tropical deciduous (monsoon) forests, temperate deciduous forests and boreal (northern coniferous) forests**.
  - Tropical forests hold about 45% of the world's forest area and boreal forests about 27% (FAO, 2020).

Tropical rainforest biome

- **Location:** low-altitude areas near the equator, mostly **10°N–10°S**: the Amazon basin, the Congo basin and West Africa, and the Indo-Malayan region and New Guinea.
  - It reaches farther on rain-fed windward coasts: Veracruz in Mexico (about 19°N), eastern Madagascar and Brazil's Atlantic Forest (towards 30°S).
  - Although these areas are physically isolated, their forests show **great similarity of structure and function**. It is called the **optimum biome**, as neither heat nor moisture ever limits growth.

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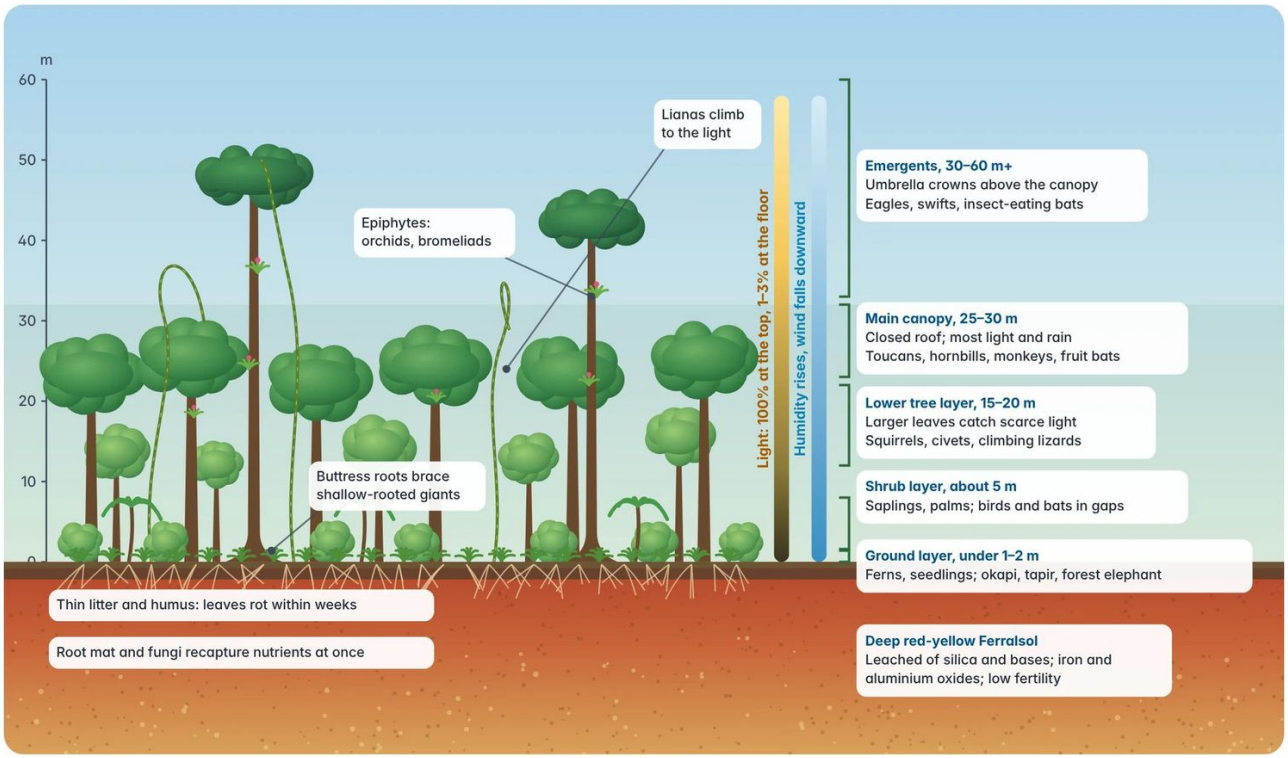
- **Climate (Köppen Af):**
  - Monthly means of **25–28 °C**, an **annual range of only 1–3 °C** and a daily range of 5–10 °C, larger than the annual one.
  - **Rainfall above 2,000 mm**, every month wet, mostly as **convectional afternoon downpours**. Humidity is high and the growing season continuous.
- **Soils: Ferralsols (oxisols, latosols)**, deep and intensely weathered by **laterisation**; silica is leached, leaving **iron and aluminium oxides** and nutrient-poor kaolinite clay.
  - The **humus layer is thin**, not rich: litter decays within weeks, and almost all nutrients sit **in the living biomass**. **Nutrient cycling is rapid and tight**, with root mats and mycorrhizal fungi recapturing nutrients from the litter.
  - If the canopy is removed, the soil **soon becomes infertile**, and exposed laterite can harden into crust.
- **Vegetation:**
  - A **broad-leaved evergreen forest** of dense growth and **extreme diversity**: a hectare in western Amazonia can hold about 300 tree species, against a few dozen in a temperate forest.
  - **All green plants strive to reach the light**: they grow very tall, climb, or live as **epiphytes** (plants growing on other plants without drawing food from them).
  - **Tree features:** tall straight trunks, **buttress roots**, thin bark, dark leathery leaves with thick cuticles against strong sunlight, and **drip tips** that shed water quickly; many flower on the trunk (**cauliflory**).
  - **Lianas** (woody climbers up to 200 m long) bind the canopy into a web; rainforests hold about 90% of all climbing species. **Epiphytes** include orchids, bromeliads, ferns and mosses; **hemi-epiphytes** such as strangler figs send roots down to the soil.
  - **Vertical stratification:** competition for light builds **five strata**:
    - **Emergents** of 30–60 m or more, with umbrella crowns; the tallest known tropical tree, a yellow meranti in Sabah, Borneo, is about 100 m;
    - the **main canopy** at 25–30 m, a nearly continuous layer that intercepts most light and rain;
    - a **lower tree layer** at 15–20 m, with larger leaves to catch scarce light;
    - a broken **shrub layer** of about 5 m, with saplings;
    - a sparse **ground layer** of herbs and ferns, since **only about 1–3% of sunlight reaches the floor**.
  - Downward through the strata, light and wind fall and **humidity rises**. Seedlings wait in the dark until a fallen tree opens a **light gap**.

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BIOGEOGRAPHY · BIOMES

Stratification of a Tropical Rainforest

Competition for light stacks the forest into five layers, each with its own microclimate and animal community, over a deep but poor soil.



Light and microclimate
- Light falls to 1–3% at the floor
- Wind drops, humidity nears saturation
- Seedlings wait for a light gap

Soil and nutrients
- Nutrients stored in living biomass
- Rapid, tight cycling via roots and fungi
- Cleared land loses fertility fast

India
- Western Ghats, North-east, Andamans
- Rainfall above about 2,500 mm
- Lion-tailed macaque, hoolock gibbon, hornbills

Schematic; heights are typical values and vary between forests. Vegetation and soil not to the same vertical scale. lotusarise.com

- **Fauna:**
  - Rich and largely **arboreal**: monkeys, apes, sloths, flying squirrels, snakes, tree frogs, birds and countless insects live in the trees, where the bulk of the foliage is. Climbing aids include claws, adhesive pads and prehensile tails; flying squirrels, lizards and frogs glide.
  - Food is available all year, so animals **rarely migrate**, and the forest is **active day and night**.
  - **Animal strata** follow the plant strata:

ANIMAL COMMUNITY	TYPICAL MEMBERS
Above the canopy	Fast-flying insect-eating birds and bats (swifts, falconets)
Main canopy	Fruit-eating birds and bats, monkeys, squirrels (toucans, hornbills, parakeets)

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ANIMAL COMMUNITY	TYPICAL MEMBERS
Middle zone, flying	Birds and insectivorous bats
Middle zone, climbing	Squirrels, civets, monkeys, lizards, moving along lianas between strata
Large ground animals	Forest elephants, okapi, tapirs, gorillas, pigs, mouse deer, cassowaries
Small ground animals	Pheasants, junglefowl, rodents, and hidden (cryptozoic) animals in the litter

- Ground animals are **smaller than their open-country relatives**: the forest elephant is smaller than the savanna elephant. Snails, centipedes, millipedes and many insects work the forest floor.
- **Ecological significance:**
  - The **most diverse and productive** land ecosystem, with mean NPP of about 2,200 g/m²/year.
  - **Gene pool:** on only about **7% of the land surface** today it holds an estimated half or more of all land species, the source of many foods, drugs (quinine, curare, vincristine) and crop relatives.
  - **Carbon and water:** a huge carbon store; evapotranspiration recycles much of the rain, and the Amazon's "**flying rivers**" carry moisture to southern Brazil and the La Plata basin.
  - **Soil protection** on steep, rain-lashed slopes, and the homes of forest peoples: the Yanomami of Amazonia, the Mbuti and Baka of the Congo, the Penan of Borneo.
- **Human use: shifting cultivation** (*jhum* in North-east India, *milpa* in Central America, *ladang* in Indonesia), gathering and hunting, plantations (rubber, oil palm, cocoa), logging, cattle ranching and soya in Amazonia, mining and dams.
- **India: tropical wet evergreen forests** where rainfall exceeds about 2,500 mm, in the Western Ghats (Silent Valley, Agumbe), North-east India (Namdapha, Dihing Patkai) and the Andaman and Nicobar Islands.
  - Typical trees are dipterocarps, rosewood, ebony and *Mesua*; animals include the **lion-tailed macaque**, the **hoolock gibbon** (India's only ape), the Malabar giant squirrel and the great hornbill.
- **Current threats:**
  - Tropical primary forest loss set a record in 2024, then fell **36% to about 4.3 million ha in 2025**, still far above a decade earlier (Global Forest Watch, 2026); fire causes a growing share.
  - About **20% of the Amazon is cleared** and 6% badly degraded. A 2024 study warned that **10–47% of the Amazon** could face compounding drought, heat and clearing by 2050, risking a shift to degraded, savanna-like vegetation.
  - Clearing for cattle, soya, oil palm and timber, with mining and fire, drives **tropical deforestation**. In India, the **Great Nicobar development project** threatens a large block of island rainforest.

Tropical deciduous (monsoon) forest biome

- **Monsoon forest**, also called **dry forest or tropical deciduous forest**, is often open and grades into woodland, with shrubs and grasses in the gaps.
  - Unlike rainforest it is **deciduous**: most trees **shed their leaves in the long dry season**, which comes at the time of low sun and cooler temperatures.

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- **Location:** the wet–dry tropics, mostly 10°–25° N and S: South and South-east Asia (India, Sri Lanka, Bangladesh, Myanmar, Thailand, Cambodia, Laos, Vietnam), East Africa and western Madagascar, northern Australia, Central America, the West Indies and eastern Brazil.
- **Climate (Köppen Am, Aw):**
  - A **long rainy season alternates with a dry, rather cool season**. India has a hot dry summer (March–June, maxima of 38–48 °C), a warm wet season (July–October) and a dry winter (10–27 °C).
  - Rainfall of about **1,000–2,000 mm**, 80% or more in three or four monsoon months. **The length of the dry season matters more than the annual total.**
- **Soils:** red and yellow soils, laterites on wet uplands, and **black soils (vertisols)** on the Deccan basalts; leaf fall gives a seasonal pulse of litter.
- **Vegetation:**
  - Fewer species and lower density than rainforest, so less competition for light. Trees are mostly **12–30 m** tall in **four strata**: two tree layers, an often evergreen shrub layer and a ground layer.
  - Trees have **thick, rough bark** and either large leaves shed in the dry season or small, hard xerophytic leaves; climbers and epiphytes are far fewer.
  - **Moist deciduous forests** (about 1,000–2,000 mm) carry **teak, sal**, *Terminalia*, shisham and bamboo. **Dry deciduous forests** (about 500–1,000 mm) carry teak, tendu, *Anogeissus*, palas and khair, grading into **thorn forest**.
  - The **teak** of the monsoon forests of southern Asia was once abundant, but much was cut and exported to the West for furniture, panelling and decking.
- **Fauna:** fewer species than rainforest because the vertical structure is simpler; breeding and movement follow the **seasonal rhythm** of leaf and grass.
  - Large mammals include elephant, tiger, leopard, gaur, sambar, chital, sloth bear, dhole, and the **Asiatic lion** in the dry teak forests of Gir and the wider Saurashtra landscape, Gujarat (891 lions in the 2025 count).
- **Human use:** the biome carries the **largest human population** and the most domestic animals of any tropical biome: settled farming, **shifting cultivation**, timber (teak, sal) and **minor forest produce** (tendu leaves, mahua, lac, sal seed) for forest-dwelling communities.
- **India:** the **most extensive forest type of India**: sal in the Shiwalik foothills, Chota Nagpur and Odisha; teak in the Western Ghats, Madhya Pradesh and Maharashtra.
- **Current threats:** one of the **most disturbed ecosystems** in the world.
  - **Dry-season fires** (lightning, carelessness, deliberate burning for jhum and fresh grazing), heavy grazing, mining in the coalfields of central India, and encroachment.
  - Clearing has accelerated **rill and gully erosion**, river siltation and floods, and invasive ***Lantana camara*** has overrun much of the understorey.

Temperate deciduous forest biome

- **Location:** forests of broad-leaved deciduous trees once covered most of **western and central Europe, eastern North America and eastern Asia**, with small areas in **Patagonia** and Australia.
  - In **Western Europe** it goes with the **marine west-coast climate**; the dominant trees are oak and ash, with beech in cooler, moister areas. In **Asia** it forms a belt between the boreal forest to the north and the steppe to the south.

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- **Climate (Köppen Cfb, Cfa, Dfa, Dfb):** a **moderate 500–1,500 mm** spread through the year, a **growing season of four to six months** and higher light intensity. The temperature regime lacks extremes, but a **marked cold season** must be endured; the climate is less extreme than the boreal forest's.
- **Soils:** mostly **brown earths (Cambisols)** and grey-brown podzolic soils (Luvisols, Alfisols).
  - Larger amounts of nutrients are used and move faster than in the boreal forest. **Autumn leaf fall returns nutrients in bulk**, and the nutrient-rich litter decays under bacteria and earthworms into mildly acid, crumbly **mull humus**.
- **Vegetation:**
  - Trees **drop their leaves in the cold season**, a physiological drought when soil water is frozen. Common trees are **oak, beech, birch, hickory, walnut, maple, elm, ash** and chestnut.
  - **Four layers:** a canopy of 20–35 m, smaller trees, shrubs and herbs. Herbs such as bluebells flower in spring before the canopy leafs out, and autumn brings **leaf colouring**.
  - Where these forests are cleared by lumbering, **pines readily develop as second-growth forest**.
- **Fauna:** deer (white-tailed, red, roe), black and brown bears, wild boar, wolves (once widespread), foxes, badgers, squirrels and songbirds; many animals **hibernate, store food or migrate** for winter.
- **Human use:** probably **more modified by human activity than any other biome.** Its fertile soils became the farmland, towns and industrial heartland of Europe, the eastern USA and eastern China; primeval fragments survive at **Białowieża** on the Poland–Belarus border.
- **Related forests: temperate rainforests** on cool, wet west coasts (Pacific North-west, southern Chile, New Zealand) and temperate conifer forests in drier or mountain areas.
- **India:** the **Himalayan temperate broadleaf forests** at about 1,500–2,500 m: oaks (banj, moru, kharsu), rhododendron, maple, walnut, horse chestnut and laurels, with the **red panda** and Himalayan black bear. The **Chipko movement (1973)** began in these Garhwal forests.
- **Current threats:** fragmentation, imported pests and diseases (ash dieback, emerald ash borer, chestnut blight), deer overbrowsing and nitrogen deposition.

Boreal forest (taiga) biome

- **Boreal forest** is the **cold-climate needle-leaf forest of high latitudes**, in two great continental belts, **North America and Eurasia**, spanning the land masses from west to east between about **45°N and 70°N.**
  - These belts closely match the **subarctic (boreal-forest) climate.** It is the **largest forest biome**, with no southern-hemisphere counterpart because there is no land at those latitudes.
- **Climate (Köppen Dfc, Dfd):**
  - Low temperatures all year. The **warmest month averages above 10 °C**, which lets trees grow, but winters fall many degrees below freezing, to about −50 °C in north-east Siberia, and **permafrost** often extends into the northern forest.
  - The **growing season lasts only three or four months**, and solar energy is small even then.
  - **Precipitation of 400–700 mm**, mostly snow, whose weight can damage trees.
- **Landscape and soils:**
  - Severe **glacial and periglacial activity** has left subdued relief and abundant **surface water**: lakes, bogs and muskeg.

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  - Needle litter is acid and nutrient-poor; decomposition is mostly **fungal**, since bacteria are slow in the cold, giving acid **mor humus**.
  - The typical soil is the **podzol (spodosol)**, strongly leached and highly acidic, with **peat** in hollows and permafrost soils in the north.
- **Vegetation:**
  - Conifers form **dense canopies** that intercept much light and precipitation, so it is **dark and dry beneath**, with little undergrowth.
  - **Species-poor:** evergreen **spruce, fir and pine** in North America, Europe and western Siberia; **larch** in north-central and eastern Siberia. Larch **sheds its needles in winter**: a **deciduous needle-leaf tree**.
  - **Adaptations:** needle leaves with thick cuticles cut water loss; the **conical shape sheds snow**; evergreenness lets photosynthesis start as soon as spring arrives.
  - Birch, aspen and willow recolonise after fire; toward the tundra the forest opens into **lichen woodland**.
  - Conifers of **low nutrient demand**, low diversity and the harsh climate make the **nutrient cycle slow and impoverished**.
- **Fauna:** moose, woodland caribou, wolf, **lynx and snowshoe hare** (whose numbers cycle about every ten years), brown bear, wolverine, sable, the Amur tiger in the mixed forests of the Russian Far East, crossbills and summer insect swarms that feed migrant birds.
- **Human use: timber, pulp and paper** (Canada, Russia, Sweden, Finland), fur trapping, mining and the Alberta oil sands, hydropower (James Bay) and reindeer herding.
- **India:** no true taiga, but the **Himalayan subalpine forests** at about 2,800–3,800 m (silver fir, spruce, blue pine, Himalayan birch) are its ecological analogue.
- **Current threats: fire** (Canada's 2023 season burned a record **17.2 million ha**, more than double the 1989 record), bark-beetle outbreaks, permafrost thaw and logging of intact forest.
  - The treeline is advancing north while **interior drought** kills trees; unlike the tundra, the boreal forest **remains a carbon sink**.

2. Grassland Biomes

- **Grasslands** are areas **dominated by grasses.** With savannas they cover about **a fifth or more of the land**, in tropical and temperate regions where rainfall is too low or seasonal, or fire and grazing too frequent, for continuous trees. They have well-defined dry and rainy seasons and many local names.

REGION	NAME OF THE GRASSLAND
North America	Prairies
Eurasia	Steppes (puszta in Hungary)
Africa	Savanna; veld in South Africa
South America	Pampas (temperate); llanos, campos and cerrado (tropical)

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REGION	NAME OF THE GRASSLAND
Australia	Downs
New Zealand	Canterbury tussock grassland
India	Grasslands and savannas (Deccan, Banni, Terai, Himalayan alpine meadows)

- **Grasslands contrast with forests:**
  - **Much smaller biomass**, a large share of it **in roots**.
  - Grasses intercept less precipitation than trees, except at peak growth; the grass form aids **stemflow**, and **surface run-off** is greater than from forested slopes.
  - NPP is roughly **half that of an adjacent forest**, but the standing crop is far smaller, so **nutrient reservoirs are limited** and held mostly in roots and soil.
- Two main types are distinguished: **temperate grasslands**, where woody growth is absent or negligible, and **tropical grassland (savanna)**, where scattered trees are much more common.

Savanna biome

- **Meaning:** to climatologists, savanna is the **tropical wet-and-dry climate (Köppen Aw)**; to botanists, a tropical vegetation of **grasses with scattered trees and shrubs**. The biome has a ground cover of partly xeromorphic grasses, a middle layer of sparse shrubs and an upper layer of scattered trees.
- **Location:** about **5°–20° N and S**, flanking the equatorial forests: the llanos of Venezuela and Colombia, the campos and cerrado of Brazil; the Sudan and Guinea savannas, East Africa (Serengeti) and the miombo woodlands of Africa; northern Australia; and India.
- **Climate (Köppen Aw):**
  - **Distinct wet and dry seasons**, high temperatures and abundant sunshine; no month is cooler than about 18–20 °C.
  - Rainfall runs from 250–500 mm on the desert fringe to 1,300–2,000 mm near the rainforest, **80–90% in the wet season**; the dry season lasts four to eight months.
  - Three seasons: a **cool dry season** (days 26–32 °C), a **hot dry season** (32–38 °C) and a **warm wet season**.
  - The **Indian savanna** has the greatest extremes, 45–48 °C in May–June and 5 °C or less in January, with under 1,500 mm in about three months.
- **Soils:** mostly **Ferralsols**. Many have **near-surface lateritic crusts (ferricrete)**, an impermeable layer in which nutrients, especially **phosphates and nitrates**, are markedly lacking. **Termite mounds** recycle nutrients and mix the soil.
- **Vegetation:**
  - **Rain-green:** the brown, withered grasses of the dry season give way rapidly to **tall, lush growth** with the summer rains.
  - **Grasses** are coarse, tufted perennials, mostly under 1 m but up to 3.5 m; **elephant grass** reaches 5 m. Genera include *Hyparrhenia*, *Panicum*, *Pennisetum*, *Andropogon*, *Themeda* and *Imperata*.

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  - **Trees** are 6–12 m tall with **flat-topped (umbrella) crowns**: acacias, the **baobab** (which stores water in its swollen trunk) and dom palm in Africa, eucalyptus in Australia, pines in Honduras.
  - **Adaptations: deep roots (5–20 m)** to groundwater, leaf shedding or leathery leaves in the dry season, **thick fire-resistant bark** and protected buds (**pyrophytes**), and root tubers that store water.
  - Tree cover ranges from about **50% to nil**; the greater diversity of tropical over temperate grasslands comes largely from these woody plants.
  - **Four types: woodland (closed) savanna**, usually in a belt next to the rainforest with an open, park-like look; **tree savanna** (scattered trees over grass); **shrub savanna** (shrubs over grass); and **grass savanna** (grass alone, with bare patches).
- **Origin: is savanna a climatic climax?**
  - **Climate:** too little soil moisture in the long dry season to support full tree cover, so trees stand far apart.
  - **Fire** sweeps most savannas each dry season. The trees are fire-resistant; fire regenerates grass, mineralises litter and **kills seedlings of forest trees**.
  - **Herbivores and people:** browsing elephants and millennia of burning and herding. Much African savanna is a **delicate balance of climate, soils, vegetation, animals and fire**, partly created by people rather than a pure climatic climax.
  - **Soils:** lateritic crusts and nutrient-poor soils exclude trees in places.
  - **Current view:** between about 1,000 and 2,500 mm of rain, **forest and savanna are alternative stable states**, and **fire decides which one holds**. This is why savanna boundaries correlate **poorly with rainfall** and the length of the rainy season, and why, like prairies, savannas show little ecotone development against the rainforest.
- **Fauna:**
  - The **African savanna** has the **world's greatest variety of large grazing mammals**: about 40 species of large herbivores in East Africa, up to 16 grazing together. With them come **predators**: lions, leopards, cheetahs, hyenas, jackals and wild dogs. **Elephants** are the largest animals of the savanna and adjacent woodland.
  - **Grazing succession** limits competition: the **giraffe** browses treetops, the **zebra** crops coarse grass heads, the **wildebeest** grazes medium grass and the **gazelle** short grass.
  - **Seasonal movement:** some species stay put (giraffe, hartebeest); buffalo, zebra, wildebeest, eland and elephant **migrate in the dry season**, as in the Serengeti–Mara migration of over a million wildebeest.
  - **Elsewhere:** kangaroos (about 50 species) and the emu in Australia; rhea, giant anteater and maned wolf in South America.
  - **Termites** are the key decomposers, moving tonnes of soil and plant matter per hectare each year.
- **Productivity:** mean NPP about **900 g/m²/year**, from about 1,500 in woodland savanna to 200 in desert-scrub savanna; where large herds survive, **animal biomass is among the highest** of any ecosystem.
- **Human use: pastoralism** (Maasai, Fulani), ranching, millet, groundnut and cotton farming, **wildlife tourism** (Serengeti, Kruger) and the soya and cattle frontier of the Brazilian cerrado.

- **India:** Indian savannas are mostly **derived**: they arose within and around **deciduous forests** after long clearing, burning and grazing, and are **dominated by shrubs** rather than grasses.
  - They cover the Deccan plateau, **Banni** (Kachchh) and semi-arid fringes; the **Terai and Brahmaputra floodplains** carry tall-grass flooded savannas (Kaziranga, Manas, Dudhwa) with the one-horned rhino.
  - Animals include the **blackbuck, chinkara, Indian wolf, Great Indian Bustard** and lesser florican. The **cheetah**, extinct in India since 1952, was **reintroduced** at Kuno in 2022.
- **Current threats:**
  - **Conversion:** in **2023**, for the first time, Brazil's **cerrado lost more native vegetation than the Amazon**, about 1.1 million ha.
  - **Woody encroachment** (bush thickening) from overgrazing, fire suppression and rising CO_2 across Africa and Australia; poaching and fencing cut migration routes.
  - In India, savannas have long been **misclassified as "wastelands" or degraded forest**; a 2024 remote-sensing study warned that tree planting on them destroys an ancient ecosystem.

Temperate grassland biome

- **Location: continental interiors** in the westerly belt, too far from the sea for enough rain to support trees. Southern-hemisphere grasslands lie on the south-eastern margins of the continents, so their climate is milder.
  - The **Eurasian steppes** are the most extensive, over 3,200 km from the Black Sea across the Russian plain to the Altai, with outliers in **Hungary (puszta)** and **Manchuria**.
  - The **prairies** run from the Rockies foothills east to the deciduous forest. The southern hemisphere has the **pampas** of Argentina and Uruguay, the **veld** of South Africa, the **downs** of the Murray–Darling basin and the **Canterbury grassland** of New Zealand.
- **Climate (Köppen BSk, Dfa, Dfb):**
  - **Continental extremes** in the north: Winnipeg's July exceeds 20 °C and its January falls to about −20 °C, an annual range near **40 °C**, against 10–12 °C in the southern hemisphere.
  - **Precipitation of 250–750 mm**, mostly in early summer; the Eurasian steppe lies under snow for months.
- **Soils:** the **richest farm soils on Earth**. Grass roots decay in place each year, building a **deep, dark, humus-rich A horizon**, while low rainfall leaves a **calcium carbonate layer** at depth.
  - These **pedocals** are chiefly **chernozems** (black earths) and drier **kastanozems** (chestnut soils), **Mollisols** in **soil classification**.
  - Across the Russian steppe, soils change southward with rainfall: degraded chernozems and grey forest soils, true chernozem, chestnut soils, then grey desert soils (**sierozems**).
- **Vegetation:**
  - Perennial **grasses** form the climax, with flowering herbs (**forbs**); trees grow only on steep slopes or near water.
  - **Single-layered:** the canopy is formed by leaves, joined briefly by flowering stalks. Grass flowers lack petals; **wind pollinates them and disperses the seed**.
  - **Roots outweigh shoots:** roots reach 2 m while shoots stand 0.6–1.2 m, and root biomass (about 2,000 g/m²) exceeds shoot biomass (about 1,600 g/m²).

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- **Tall-grass prairie** has tall grasses with forbs. **Steppe, or short-grass prairie**, has sparse clumps of short grasses, grading into **semi-desert** in dry areas and into prairie where rain is higher.
- **Origin:** mostly **climatic** (continental drought), though fire and grazing helped keep them treeless.

REGION	SUB-TYPES AND RAINFALL	DOMINANT GRASSES
Eurasian steppe	Forest-steppe (500–600 mm): oak, lime, elm, maple in Europe; birch, aspen, willow in Siberia. Meadow and grass steppe (400–500 mm) on deep chernozem. Semi-arid steppe (300–350 mm) on chestnut soils	Feather grass (*Stipa*), fescue (*Festuca*); wormwood (*Artemisia*) in the south
North American prairie	Tall-grass (east, about 1,000 mm), mixed (Great Plains), short-grass (west, about 400 mm)	Big bluestem and switch grass (1.5–2.5 m); needle grass; buffalo grass and blue grama (under 60 cm)
Pampas	Humid pampa (east, 900 mm), sub-humid pampa (west, 450 mm)	*Briza*, *Bromus*, *Paspalum*, *Panicum*, *Lolium*; lucerne introduced
South African veld	Plateau at 1,500–2,000 m: Themeda (red grass) veld, sour veld, alpine veld in the Drakensberg	Red grass (*Themeda triandra*), *Aristida*, *Eragrostis*
Australian downs	Tall, short and xerophytic grasslands as rainfall falls inland	Kangaroo grass (*Themeda*), *Poa* tussock, *Danthonia*, *Stipa*; mulga scrub
Canterbury, New Zealand	Short and tall tussock grassland	*Festuca*, *Poa*, *Chionochloa*

- **Climate links:** prairies match the drier parts of the **moist continental climate**, steppes the **semi-arid continental climate**, and the pampa a **moist subtropical climate** with mild winters.
- **Fauna:**
  - Each region is dominated by **a few large grazers**: **bison and pronghorn** in the prairies, **saiga, Przewalski's horse and Mongolian gazelle** in the steppes, guanaco and pampas deer in the pampas, antelopes in the veld, kangaroos in the downs.
  - **Burrowing rodents** abound (prairie dogs, gophers, sousliks, viscacha, mole rats). Jackrabbits and jumping mice leap to see over the grass; grazers are fast, sturdy and herd-living, and many migrate.
  - Predators include wolves, coyotes, foxes, eagles, hawks and rattlesnakes. **Flightless running birds** fill one niche on three continents: rhea, emu and ostrich. New Zealand's giant **moas** were hunted to extinction.
- **Uniqueness of the Eurasian steppe:**
  - The **largest continuous temperate grassland** on Earth, from Hungary to Manchuria, with a classic **north–south zonation** of forest-steppe, grass-steppe and semi-arid steppe matched by soils.
  - **Severe continentality**, with the largest annual temperature ranges of any grassland and long snow cover.

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  - Its own fauna (saiga, Przewalski's horse, Mongolian gazelle, steppe eagle, bobak marmot) and a long **history of horse-borne nomadic pastoralism**, from the Scythians to the Mongols.
  - Much was ploughed for wheat, notably in the Soviet **Virgin Lands campaign (from 1954)**. The **saiga** recovered from a few tens of thousands in 2005 to over 1.9 million in Kazakhstan, and the IUCN moved it from **Critically Endangered to Near Threatened in December 2023**.
- **Human use:** the "**granaries of the world**". **Tall-grass prairie** gives rich land for cultivation; **short-grass prairie** occupies vast semi-arid areas suited to grazing. Wheat and maize dominate the prairies, the Kazakh steppe and the pampas, and the drier fringes became cattle and sheep ranches.
- **India:** no true temperate grassland; the nearest analogue is the **cold Trans-Himalayan steppe of Ladakh (Changthang) and Spiti**, grazed by pashmina goats, yaks, the **kiang** and Tibetan gazelle.
- **Current threats:**
  - The **least protected biome**, with the highest ratio of converted to protected land; only a few per cent of the tall-grass prairie survives.
  - The **bison** fell from tens of millions to under a thousand by 1889 through mass hunting; prairie dogs and their predators declined with ploughing.
  - The **Dust Bowl (1930s)**: ploughing and drought let wind strip the loose soils of western Kansas, Oklahoma and Texas.
  - **Exotic species:** European rabbits and sheep in Australia, and clovers and ryegrass that suppressed native grasses. **Overgrazing and land-use change** still degrade rangelands from Mongolia to the Sahel.

3. Desert Biome

Hot deserts

- The desert is a **highly evolved ecosystem** supporting a multitude of plants and animals built to save and find water. The biome includes **semi-desert and dry desert** in the tropical, subtropical and mid-latitude dry climates; **deserts and xeric shrublands** are the largest WWF biome, about a fifth of the ice-free land.
- **Location:**
  - **Tropical deserts** at about **15°–30° N and S** on the **western sides of continents**, under the subtropical highs and beside **cold currents**: the Sahara, Arabian, **Thar**, Kalahari, Namib, Atacama, Sonoran and Australian deserts.
  - **Mid-latitude (cold-winter) deserts** in continental interiors and rain shadows: the Gobi, Taklamakan, Turkestan, Patagonian and Great Basin deserts.
- **Climate (Köppen BWh, BWk):**
  - **Rainfall below about 250 mm**, highly unreliable and unevenly spread: years of drought broken by a single storm.
  - **Extremes of temperature**, with daily ranges of 20–30 °C. Air temperatures exceed 50 °C in the Sahara and Death Valley, and satellites have measured ground temperatures near 70 °C in Iran's Lut desert.
  - **Potential evaporation far exceeds rainfall**, and strong winds move sand and dust.
- **Soils:** thin, coarse and poor in humus: **Aridisols**, sand (Arenosols), calcrete and gypsum crusts, **saline soils** in basins and grey desert soils (**sierozems**).

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- **Vegetation:**
  - Desert plants vary widely in appearance; the biome includes formation classes transitional from grassland and savanna into true desert.
  - **Semi-desert**, from the tropical to the mid-latitude zone, consists mainly of **sparse xerophytic shrubs**, such as the **sagebrush** of the middle and southern Rockies and the Colorado Plateau.
  - **Dry desert** has plants **widely dispersed**: small, hard-leaved or spiny shrubs, **succulents** (cacti) and hard grasses. Many small annuals appear only after rare, heavy downpours.
  - In the **Mojave and Sonoran deserts** plants are often large, giving the look of woodland: the saguaro cactus and the Joshua tree.
  - **Drought evaders (ephemerals)** finish their life cycle in weeks after rain; **succulents** store water; **drought endurers** have deep roots or dormant stems. American cacti and African euphorbias look alike though unrelated: **convergent evolution**.
- **Plant adaptations to hot, dry conditions:**
  - Mostly **shrubs**, widely spaced.
  - **Leaves absent or reduced** to scales or spines, with thick cuticles and sunken stomata.
  - **Leaves and stems succulent** and water-storing; in some plants even the **stem contains chlorophyll** for photosynthesis.
  - **CAM photosynthesis**, with stomata open only in the cool night.
  - **Root systems well developed**: widespread and shallow to catch showers, or very deep (**phreatophytes**) to tap groundwater, such as *Prosopis* and the khejri of the Thar.
- **Fauna:** desert animals are **insects, reptiles and burrowing rodents**. The desert shrew, fox, kangaroo rat, wood rat, rabbit and armadillo are common mammals of American deserts. The **camel**, the "ship of the desert", travels long distances without drinking for several days; the oryx, addax and gazelles also survive.
- **Animal adaptations:**
  - Animals are **physiologically and behaviourally adapted**: many are fast runners, and most are **nocturnal** to avoid the sun's heat; many burrow or **aestivate**.
  - They conserve water by **excreting concentrated urine**; herbivores such as the kangaroo rat get enough water from the **seeds they eat**.
  - Many have **long legs** to keep the body off the hot ground, and large ears to shed heat (fennec fox).
  - **Lizards** are mostly insectivorous and can live without drinking for several days.
- **Human use: nomadic pastoralism** (Bedouin, Tuareg, and the Raika and Rabari of the Thar), oasis farming, **canal irrigation** (the Indira Gandhi Canal), oil and minerals, tourism and **solar power** (Bhadla Solar Park, Rajasthan).
- **India:** the **Thar** (hot desert) and the **cold desert of Ladakh and Lahaul–Spiti**. The Thar carries khejri, rohida, ber, phog and *sewan* grass, with the chinkara, blackbuck, desert fox, spiny-tailed lizard and **Great Indian Bustard**.
- **Current threats: desertification** on the margins, overgrazing, groundwater depletion, invasive *Prosopis juliflora*, and power lines and solar parks. The Great Indian Bustard survives in about 16% of its Thar habitat; a 2026 survey estimated about **130 birds** there.

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Biological deserts

- A **biological desert** is any area of **extremely low productivity and biomass**, whatever its rainfall, where life is held back by scarcity of **water, heat, light or nutrients**.
- **Types:**
  - **Hot deserts** (water-limited): Sahara, Atacama, Rub' al Khali.
  - **Cold and polar deserts**: the high Arctic, Antarctica (the Dry Valleys are among the driest places on Earth) and the cold desert of Ladakh.
  - **Oceanic deserts** (nutrient-limited): the clear blue **subtropical gyres**, where a strong thermocline keeps nutrients from the sunlit surface.
  - **Human-made deserts:** monoculture plantations (**"green deserts"**) and oxygen-starved **dead zones** in coastal seas such as the Gulf of Mexico and the Baltic.
- **Characteristics:**
  - **Very low NPP**, usually below about 200 g/m²/year, with sparse, patchy cover and much bare ground.
  - **Low species richness** but a high share of **specialists and endemics**.
  - **Short, simple food chains** with few trophic levels and few large animals.
  - **Pulsed productivity:** boom and bust after rare rain or upwelling, with long dormant phases (seed banks, cysts, aestivation).
  - Slow nutrient cycling and **low resilience**: off-road tracks or overgrazing take decades to heal.

4. Mediterranean Biome

- The **Mediterranean (sclerophyll) biome** is named after its **hard-leaved evergreen trees and shrubs**, adapted to **dry summers and wet winters**.
- **Location:** about **30°–40° (to 45°)** on the **western sides of continents**: the lands around the Mediterranean Sea, central and southern California, central Chile, the Cape region of South Africa and south-west and southern Australia.
- **Climate (Köppen Cs):**
  - **Cool, wet winters** (5–10 °C) and **warm, dry summers** (20–27 °C), with abundant sunshine.
  - **About 350–900 mm** of rain, mostly in winter from westerly cyclones. The **seasonal shift of pressure belts** brings subtropical highs and summer drought.
  - Soil moisture peaks in winter and spring, when growth is greatest, and runs out in summer, which **halts growth**.
- **Soils:** reddish **terra rossa** on limestone and brown Mediterranean soils (Luvisols, Cambisols); thin, stony and **easily eroded** after fire or clearing.
- **Vegetation:**
  - **Sclerophyll formations** from mixed evergreen forest near the coast through woodland and dwarf forest to **scrub**.
  - **Adaptations:** small, **stiff, leathery leaves**, thick cuticles, hairs, **sunken stomata** and thick bark; the **mastic tree** closes its stomata through drought. Roots include deep taproots into fractured rock (almond), shallow-and-deep systems (chamise) and bulbs and tubers (geophytes).

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- **Fire adaptations: resprouting** (eucalypts send up stems from burnt stumps), cones that open after fire (**serotiny**) and seeds that germinate after fire or smoke.

REGION	SHRUBLAND NAME	TREES AND FEATURES
Mediterranean basin	**Maquis**, degraded to **garrigue**, then **batha** or phrygana (dwarf shrubs)	Evergreen holm and cork oaks low down, then deciduous oaks, beech, fir and pine; olive, Aleppo pine, cedar; *Arbutus*, *Pistacia* and carob shrubs yield gums, resins, tannins and dyes
California	**Chaparral**; coastal sage scrub	Oaks 6–23 m with thick trunks and flat crowns; chaparral favours poorer, lighter soils
Central Chile	**Matorral**	Close counterpart of chaparral
Cape, South Africa	**Fynbos**	Showy flowering shrubs (*Erica*, proteas, *Freesia*); about 9,000 plant species, most found nowhere else
South-west Australia	**Mallee** scrub; kwongan heath	About 100 eucalypt species, including **karri** (70 m and more) and **jarrah**; forest gives way inland to grassland and mallee

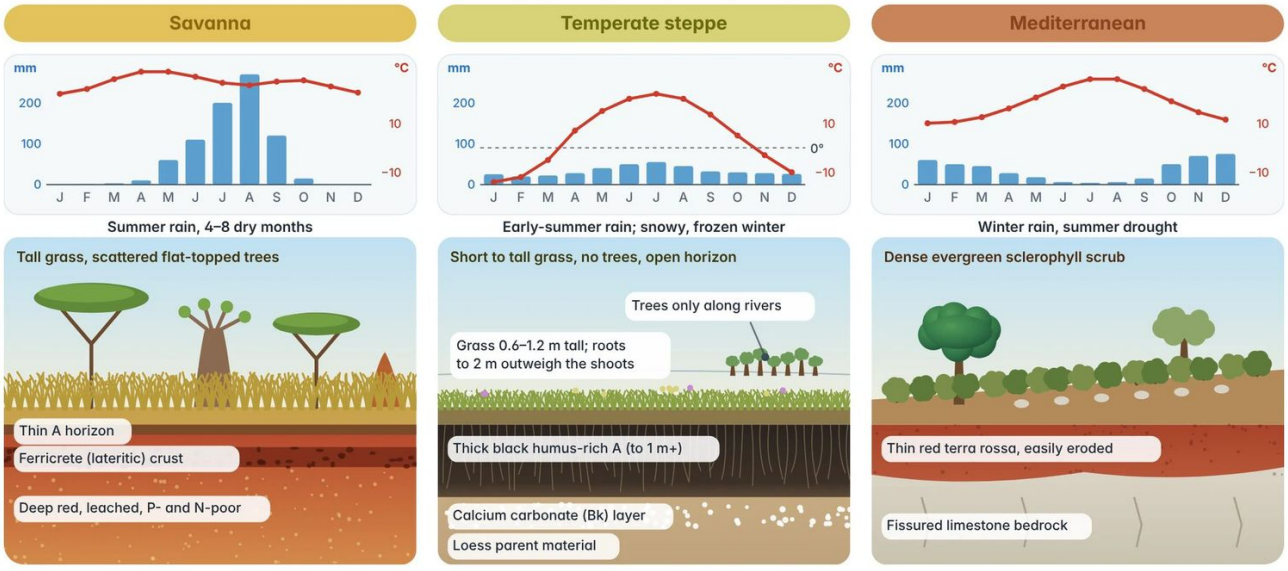
- **Fauna:**
  - **California and Chile:** mule deer, ground squirrels, wood rats, rabbits, coyote (the Chilean fox is its counterpart), lizards, snakes and raptors; the Chilean **guanaco** turned from browsing to grazing. Wolves, mountain lions and grizzly bears became rare under human pressure.
  - **Cape:** clearance and hunting by settlers made the **quagga** (a zebra) extinct and the bontebok rare; duiker and steenbok shelter in fynbos, and hyraxes, baboons and leopards survive in the mountains.
  - **Australia:** western grey kangaroo, wallabies, honeyeaters and wrens. **Mediterranean basin:** the **Iberian lynx**, which recovered enough to move from Endangered to Vulnerable on the IUCN Red List in 2024.
- **Productivity:** mean NPP about **700 g/m²/year**.
- **Biodiversity:** the five Mediterranean regions cover **less than 5% of the land** yet hold roughly **a fifth of the world's vascular plant species**. All five are **biodiversity hotspots**, and the Cape is ranked as a **floristic kingdom** of its own.
- **Human use:** a **cradle of agriculture and civilisation**, with the classic triad of **wheat, olive and vine**, plus citrus, cork and transhumant sheep and goat herding; today also dense coastal cities and mass tourism (Los Angeles, Cape Town, Perth, Athens).
- **India:** no true Mediterranean biome, but two convergent types: the **subtropical dry evergreen forests** of the Shiwalik foothills of Punjab and Jammu (wild olive, *Acacia modesta*), watered partly by **winter western disturbances**; and the **tropical dry evergreen forests** of the **Coromandel coast**, fed by the north-east monsoon.

- **Fire and current threats:**
  - **Fire** is a near-annual event, from lightning and from people who burn after grazing to bring fresh growth.
    - **Benefits:** plants resprout vigorously, some seeds germinate better, ash **mineralises nutrients**, and fire destroys toxic root secretions that slow litter decay and nitrogen fixation.
    - **Harms:** frequent fire alters soil structure and speeds **erosion** in winter storms, raising river silt loads.
  - Fire seasons are growing longer and fiercer: in **January 2025** the Palisades and Eaton fires burned about 15,000 ha of **chaparral-clad hills and suburbs of Los Angeles**.
  - **Urban sprawl, water scarcity** (Cape Town's near "Day Zero" in 2018), invasive species and overgrazing add pressure. The Mediterranean basin is a **climate-change hotspot**, warming and drying faster than the global average.

BIOGEOGRAPHY · BIOMES

Savanna, Steppe and Mediterranean Compared

Three open biomes shaped by drought: the season of rain, the cold of winter and fire decide their vegetation and soils.



Savanna

- 5°–20°; Aw; 500–1,500 mm in summer
- Fire and grazers hold trees apart
- Deccan, Banni and Terai in India

Temperate steppe

- 35°–55° interiors; 250–750 mm
- Roots outweigh shoots; richest soils
- Ladakh–Spiti cold steppe is India's analogue

Mediterranean

- 30°–40° west coasts; 350–900 mm in winter
- Hard leaves, fire-adapted scrub
- Shiwalik and Coromandel dry evergreen forests

Monthly bars (rain) and line (temperature) show typical regimes, approximate; the savanna and Mediterranean curves are northern-hemisphere examples.

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FEATURE	SAVANNA	TEMPERATE GRASSLAND (STEPPE)	MEDITERRANEAN
Latitude and position	5°–20°, between rainforest and desert	35°–55°, continental interiors	30°–40°, west coasts
Rain season	Summer (wet–dry tropics)	Early summer; snowy winter	Winter; summer drought
Temperature	Warm all year	Hot summer, very cold winter	Mild winter, warm summer
Vegetation	Tall grass with scattered trees	Short to tall grasses, treeless	Evergreen sclerophyll scrub and woodland
Soils	Ferralsols, lateritic crusts	Chernozem, chestnut soils	Terra rossa, brown Mediterranean soils
Key animals	Large grazers and predators	Bison, saiga, burrowing rodents	Deer, rodents, reptiles, raptors
Human use	Pastoralism, ranching, parks	Wheat, maize, ranching	Olive, vine, citrus, cities
Indian analogue	Deccan and Terai savannas	Ladakh–Spiti cold steppe	Shiwalik and Coromandel dry evergreen forests

5. Tundra Biome

- **Tundra** (from a Finnish word for a **barren, treeless upland**) is the **treeless vegetation of very cold regions** where conditions are too severe for trees. There are two types, **arctic** and **alpine**.
- **Location:**
  - **Arctic tundra** lies between the polar ice caps and the **northern limit of the boreal forest**: northern Alaska and Canada, coastal Greenland, the arctic seaboard of European Russia and Siberia, and the arctic islands.
  - **Antarctic tundra** is confined to the Antarctic Peninsula and sub-Antarctic islands; Antarctica has only **two native flowering plants**. **Alpine tundra** lies above the treeline on high mountains.
  - **Arctic zones** (by latitude, not altitude): **low arctic tundra** in the south, **middle arctic tundra**, and **high arctic tundra** on the northernmost islands (the Queen Elizabeth Islands), passing into **polar desert**.
- **Climate (Köppen ET):**
  - **Long, severe winters** with polar night and short, cool summers: summer may reach about 15 °C, winter about −57 °C. The **warmest month stays below 10 °C**, which keeps trees out.
  - **Very low precipitation**, below about 250–400 mm, mostly snow, so the tundra is a **cold desert**. Snow lies seven to eight months, swept by **blizzards**.
  - The **growing season is generally under 50–60 days** between spring and autumn frosts, so productivity is low.

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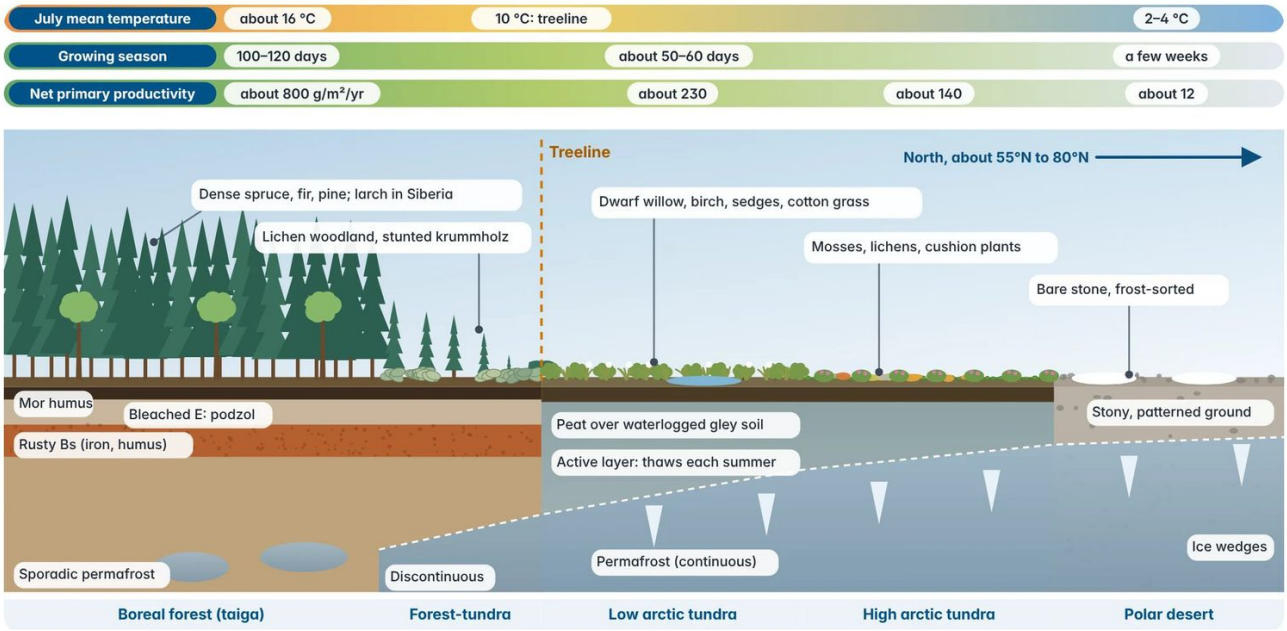
- **Soils: permafrost** (permanently frozen subsoil) underlies arctic tundra; only a thin **active layer** thaws each summer.
  - Meltwater cannot drain, so soils are **waterlogged, gleyed and peaty** (Cryosols); dry stony ground carries only lichens and mosses.
  - Freeze–thaw sorts the ground into polygons, stone circles and solifluction lobes, the **periglacial landforms**.
- **Vegetation:**
  - **Cryophytes**, adapted to cold; only a few per cent of the world's plant species, fewer northward. Typical plants are **cotton grass, sedges, dwarf heaths, dwarf willows and birches, mosses** and **lichens** such as reindeer moss.
  - Most plants are only **5–8 cm** high, hugging the ground, which is warmer than the air, and sheltering under snow. They grow as **cushions** (moss campion), **rosettes** (snow saxifrage), **mats** (mountain avens) and tussocks.
  - **Long-lived and slow-growing:** the **arctic willow (*Salix arctica*)** stays a few centimetres tall but can live **150–300 years**. Thick cuticles and epidermal hairs protect plants from chill.
  - Flowering, pollination, seed ripening and dispersal must fit into about **50 summer days**, so most plants are perennials that form flower buds a year ahead.
- **Fauna:**
  - **Residents** are well insulated: the **musk ox** (dense under-wool and long outer hair, moulted in summer), **arctic fox** (double fur coat, active down to about −50 °C), arctic hare, **lemmings**, ptarmigan, snowy owl, and the polar bear on the coast and sea ice.
    - The ptarmigan, arctic fox and stoat **turn white in winter**. **Large bodies with small ears and tails** reduce heat loss. Lemmings, shrews and voles tunnel under the snow, and lemming numbers **boom and crash** every few years.
  - **Migrants:** caribou and reindeer travel hundreds of kilometres between summer calving grounds on the tundra and winter shelter in the taiga; ducks, geese and swans breed in summer pools; the **arctic tern** winters off Antarctica, enjoying two summers a year.
  - **Insects** (mosquitoes, midges, blackflies) have **short life cycles** completed in the brief summer. Their swarms feed young birds and torment caribou, which take refuge in pools and streams.
- **Productivity:** NPP falls from about 230 g/m²/year in the low arctic to about 140 in the high arctic and 12 in polar desert. Little sunlight, poor soils, permafrost and the short season limit it; wet litter builds **peat**, and food scarcity makes many animals **migratory**.
- **Human use:** the **Inuit** of Greenland, Canada and Alaska, the **Sami** of Scandinavia, the **Nenets** of north-west Siberia, the **Sakha (Yakuts)** of the Lena basin and the **Chukchi and Koryaks** lived as nomads on fish, seals, walrus, caribou and reindeer.
  - Most now live in settled or semi-nomadic communities and herd reindeer; rifles and snowmobiles have replaced harpoons and sledges, enlarging their impact on wildlife.
  - The tundra also hosts **oil, gas and mineral extraction** (Prudhoe Bay, Yamal, Norilsk), and the **Northern Sea Route** is opening to shipping.
- **India: alpine tundra** above about 4,000–4,500 m in the Himalaya and the **cold desert of Ladakh**, with cushion plants, **brahma kamal**, the snow leopard, Himalayan marmot and bharal.

- **Current threats:**
  - The **Arctic is warming nearly four times as fast** as the globe; permafrost temperatures in 2024 were the highest on record at nearly half of Alaska's monitoring sites.
  - NOAA's **Arctic Report Card 2024** found that the **tundra has become a net source of carbon dioxide**, and remains a methane source, as soils thaw and fires grow more frequent.
  - Pipelines, roads, mines and spills (the **Norilsk diesel spill of 2020**) scar fragile ground that heals over decades.

BIOGEOGRAPHY · BIOMES

From Taiga to Tundra

A transect north across the boreal forest, the forest-tundra ecotone and the treeline into tundra and polar desert, above ground and below it.



Why trees stop

- Warmest month below about 10 °C
- Too short a season to grow and ripen wood
- Shallow active layer limits roots

Permafrost

- Sporadic under the southern taiga
- Continuous and shallower northward
- Ice wedges and polygons in the tundra

Changing now

- Treeline and shrubs advancing north
- Thaw releases CO_2 and methane
- Tundra a net carbon source (2024)

Schematic; horizontal distances compressed and vertical scale exaggerated. Productivity values are approximate means. lotusarise.com

6. Mountain Biome PYQ 2013

- The **mountain biome** is a **stack of climates**: on a high mountain, biomes spread over thousands of kilometres of latitude are compressed into a few thousand metres of altitude. Heinrich Walter called these belts **orobiomes**.
  - **Alexander von Humboldt and Aimé Bonpland** mapped them on **Chimborazo** in the Andes (published 1807), the first scientific profile of vegetation zones.

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- **Climate–vegetation relationship:**
  - **Temperature** falls with height at an average **lapse rate** of about **6.5 °C per 1,000 m**. Climbing 1,000 m is roughly like moving 1,000 km or more poleward, so tropical, temperate, boreal and tundra-like belts follow one another upslope.
  - **Precipitation** rises with height through orographic uplift to a **zone of maximum rainfall** on middle slopes, then falls. This band carries the densest forests and **cloud forests** draped in mosses and epiphytes.
  - **Aspect:** in the northern hemisphere, sunny **south-facing (adret)** slopes are warmer and drier than shady **north-facing (ubac)** slopes, so belts sit higher on the sunny side; windward slopes are wetter than leeward ones.
  - **Thin air, intense UV and wind** favour small, hairy, dark-pigmented plants; wind shapes stunted **krummholz** near the treeline.
  - **Treeline:** trees stop where the mean growing-season temperature falls to about **6–7 °C**, so treelines rise from about 1,000 m in southern Scandinavia to **3,500–4,500 m** in the tropics and the eastern Himalaya.
  - **Mass-elevation effect:** large high massifs such as the Tibetan Plateau heat the air above them, so their treelines and snowlines lie higher than on isolated peaks.
  - **Soils** thin out upslope, while **temperature inversions** can place cold-air belts in valleys below warmer slopes.

ZONE	ANDES (TROPICAL)	HIMALAYA (INDIA, APPROX.)
Hot foothill	*Tierra caliente* (below about 1,000 m): rainforest, bananas, cacao	Tropical moist deciduous sal forest, Terai grassland (below 1,000 m)
Warm	*Tierra templada* (1,000–2,000 m): montane forest, coffee	Subtropical chir pine (*Pinus roxburghii*) forest (1,000–2,000 m)
Cool	*Tierra fría* (2,000–3,200 m): cloud forest, maize, wheat, potato	Temperate broadleaf forest of oak, rhododendron and laurels (1,500–2,500 m); conifers: deodar, blue pine, spruce, fir (2,500–3,500 m)
Cold	*Páramo* and *puna* (3,200–4,800 m): grasses, cushion plants, llamas	Subalpine fir, birch and rhododendron to the treeline (about 3,500–4,000 m); alpine scrub and meadows (bugyals) to about 4,800 m
Frozen	*Tierra helada* (above about 4,800 m): rock and ice	Nival zone: snow and ice above about 5,000 m

- **Eastern and western Himalayan forest belts differ:** the wetter east has richer broadleaf and rhododendron forests, higher treelines and the red panda; the drier west has more conifers and dry alpine pastures, and **Ladakh beyond the Great Himalaya is cold desert**.
- **Fauna:** zoned like the plants: snow leopard, ibex, bharal, markhor, Himalayan tahr, musk deer, Himalayan monal, yaks and pikas; in the Andes the llama, alpaca, vicuña and Andean condor.

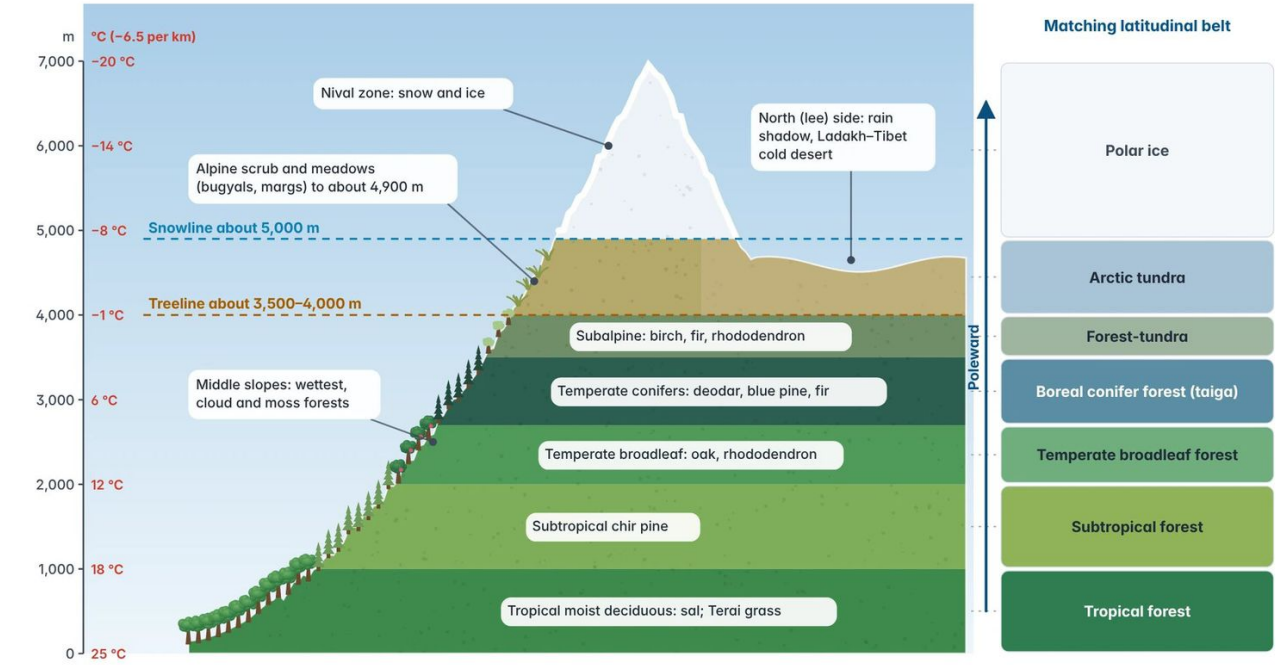
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- **Human use: transhumance** (the Gaddi, Bakarwal and Bhotia move flocks to alpine meadows in summer), terrace farming, apple orchards, medicinal herbs, **hydropower**, pilgrimage and tourism.
- **Current threats: elevation-dependent warming** (mountains warm faster than lowlands), upslope shifts of plants and the treeline, glacier retreat, slopes destabilised by roads and dams (the **Joshimath subsidence, 2023**), invasive weeds and overgrazing of alpine meadows.

BIOGEOGRAPHY · BIOMES

Altitudinal Zonation of a Mountain Biome

On a Himalayan slope, vegetation belts climb from sal forest to snow, repeating in a few kilometres of height the biomes that span the latitudes.



Temperature

- Falls about 6.5 °C per 1,000 m
- 1,000 m up is like 1,000 km or more poleward
- Treeline near a 6–7 °C growing-season mean

Moisture and aspect

- Rain peaks on middle slopes
- Sunny south slopes carry belts higher
- Lee side falls into rain shadow

India

- Wetter east: higher treeline, red panda
- Drier west: more conifers and pastures
- Gaddi and Bhotia move flocks to bugyals

Schematic south-facing Himalayan slope; belt heights approximate and vary from east to west. Temperatures assume a standard lapse rate from 25 °C at sea level.

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Terrestrial biomes at a glance PYQ 2011

BIOME	KÖPPEN	RAINFALL (MM)	SOIL	VEGETATION	INDIAN ANALOGUE
Tropical rainforest	Af	Over 2,000	Ferralsol, thin humus	Evergreen broadleaf, five strata	Western Ghats, North-east, Andamans
Tropical deciduous	Am, Aw	1,000–2,000, seasonal	Red, laterite, black	Teak, sal, bamboo	Central India, Deccan, Shiwaliks
Savanna	Aw	500–1,500	Ferralsol, ferricrete	Grass with scattered trees	Deccan, Banni, Terai
Hot desert	BWh	Under 250	Aridisol, sand, salts	Xerophytes, succulents	Thar
Mediterranean	Cs	350–900, winter	Terra rossa	Sclerophyll scrub	Shiwalik dry evergreen
Temperate grassland	BSk, Dfa	250–750	Chernozem, chestnut	Grasses, no trees	Ladakh–Spiti cold steppe
Temperate deciduous	Cfb, Dfb	500–1,500	Brown earth, mull	Oak, beech, maple	Himalayan oak forests
Boreal (taiga)	Dfc, Dfd	400–700	Podzol, mor	Spruce, fir, pine, larch	Himalayan subalpine fir–birch
Tundra	ET	Under 400	Cryosol, permafrost	Mosses, lichens, sedges, dwarf shrubs	Himalayan alpine zone, Ladakh
Mountain	H (highland)	Varies with height	Thin, immature	Altitudinal belts	Himalaya, Western Ghats sholas

04 B. Aquatic Biomes PYQ 2016 · 2014 · 2013 +2

- An **aquatic ecosystem** is the plant and animal community of a water body. Aquatic biomes are classified by **salinity** into **freshwater** and **marine**, with estuaries and wetlands between them.

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Freshwater ecosystems

- Water on land that is **continuously cycling and low in dissolved salts** is **fresh water**; its study is **limnology**.
  - **Lentic (still) waters:** ponds, lakes, bogs and swamps.
  - **Lotic (running) waters:** springs, mountain brooks, streams and rivers, changing downstream from cold, fast, oxygen-rich headwaters to warm, slow, silty lowland rivers.
- **Physical characteristics:**
  - Low dissolved salts; temperature varies daily and seasonally.
  - Water is **densest at 4 °C**: the surface of **tropical lakes never falls below 4 °C**, that of **temperate lakes swings above and below it**, and that of **polar lakes never rises above it**.
  - In temperate regions the **surface freezes but organisms survive below**, insulated by floating ice.
  - In summer a warm **epilimnion** lies over a cold **hypolimnion**, separated by the **thermocline**; temperate lakes **overturn** in spring and autumn, mixing oxygen and nutrients.
  - **Light** has a great influence; **suspended material** blocks its penetration. Some animals rise to the surface for oxygen, and aquatic plants use dissolved carbon dioxide.
- **Lakes** and **ponds** are inland depressions holding standing water. **Lake Superior** is the largest freshwater lake by area and **Lake Baikal** in Siberia the deepest. In India, **Chilika** (Odisha) is the largest brackish coastal lagoon and **Wular** (Jammu and Kashmir) one of the largest freshwater lakes.
- **Zones of a lake:** the shallow **littoral zone** with rooted plants; the **limnetic zone** of open, lit water beyond it; the dark **profundal zone**; and the **benthic zone** (bottom), where decomposers work.
- **Trophic status: oligotrophic** lakes are deep, clear and nutrient-poor; **eutrophic** lakes are nutrient-rich and prone to algal blooms and oxygen loss when sewage or fertiliser enters.
- **Organisms** float, swim or stay fixed, according to size and habit. Microscopic floaters (algae, diatoms, protozoans, larval forms) are **plankton**; free swimmers are **nekton**; rooted plants, molluscs and other bottom dwellers are **benthos**.
- **Wetlands** are periodically inundated areas that support a flourishing aquatic community, including frogs and other amphibians: **swamps, marshes, bogs and mangroves**.
  - Lying between aquatic and terrestrial ecosystems, they form an **ecotone** (a transitional zone between two ecosystems) and show an **edge effect**.
  - They purify water, store floods, recharge groundwater and store carbon; wetlands of international importance are listed under the **Ramsar Convention (1971)**.

Marine ecosystem

- **Oceans cover about 71%** of the Earth's surface and are habitable throughout. Their living biomass is small next to land plants, but **marine phytoplankton carry out about half of global photosynthesis**.
- In many ways the sea is **more favourable to life than land**: it is more **equable**, oxygen and carbon dioxide are readily available (if unpolluted), and many crustal minerals are dissolved in it. Its main gradients are **temperature, salinity and light**.
- **Salinity** is highest where temperature, and hence evaporation, is highest, in the subtropics. Many marine organisms tolerate only a narrow range, which confines them to certain depths or areas. In the open oceans it ranges only from about **37‰ in the subtropics to 33‰ in polar seas**.

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- **Temperature** varies far less than on land: from about **32 °C** in the warmest seas to **−2 °C** in the coldest, against a land range of about 90 °C. Vertical and horizontal **currents** even out temperature, salinity and dissolved gases and help drive the global energy budget.
- **Light** controls photosynthesis in the sea as on land. Surface light varies with latitude and season, and much is reflected in high latitudes and rough seas, so marine plants are **confined to the euphotic (sunlit) zone**, the upper 100–200 m.
- **Zones:** the **intertidal (littoral)** zone; the **neritic** zone over the continental shelf, to about 200 m; and the **oceanic (pelagic)** zone, divided by depth into epipelagic (to 200 m), mesopelagic (to 1,000 m), bathypelagic (to 4,000 m), abyssopelagic (to 6,000 m) and hadal (trenches). The floor is the **benthic** zone.
- **Marine plants** are far less diverse than land plants: **algae dominate**, and the few flowering plants (seagrasses) grow near shore. Seaweeds are the most visible, but about **99% of marine plant life is microscopic phytoplankton**, one-celled organisms with chlorophyll such as **diatoms and dinoflagellates**.
- **Productivity:** nearshore areas also receive **nutrients from rivers**, so **coastal and estuarine waters** are among the most fertile parts of the sea, as are **upwelling zones** (Peru, Benguela); the open subtropical gyres are biological deserts.
- **Animal life:**
  - The sea is richest at the **higher levels of classification**: almost every major animal group (phylum) occurs in the sea, and several nowhere else. **Insects** are almost absent, with exceptions such as the sea skater.
  - **Maximum diversity** lies in the tidal and nearshore zone and on coral reefs.
  - **Free floaters:** diatoms, algae, dinoflagellates and jellyfish. **Free swimmers:** fish, large crustaceans, squid, turtles, and mammals such as seals, porpoises, dolphins and whales. **Bottom dwellers** are mostly sessile (fixed) or slow: sponges, corals, crabs and starfish.
- **Special marine ecosystems: estuaries** (brackish, nutrient-rich fish nurseries); **mangroves**, salt-tolerant tidal forests with stilt roots and breathing roots (India's **mangrove cover** is about **4,992 km²**, ISFR 2023, led by the Sundarbans); and **coral reefs**, the "rainforests of the sea".
- **Adaptations:**
  - Lightweight animals and plants **float** and move with the currents.
  - Marine organisms tolerate high salt concentrations through **osmoregulation**, the process that keeps a constant osmotic pressure in the body fluids.
  - Swimming animals have **streamlined bodies**, many laterally compressed.
  - **Deep-sea forms** show **bioluminescence** (they emit light) and depend on food sinking from the upper zones; some live on chemosynthetic bacteria at hydrothermal vents.

05 Global Disruptions and Biome Shifts

- The distribution of biomes is **not permanent.** Because biomes are defined by temperature and moisture limits, any shift in global climate moves their boundaries.
  - During the **Pleistocene glaciations** the taiga and tundra spread far south and rainforests shrank into **refugia**; the present pattern is only about 10,000 years old.

- **Present climate change** is driving biome change at an accelerating rate, on top of direct land conversion.

Poleward and upward range shifts

- As temperatures rise, species are moving **toward higher latitudes and higher elevations** to track their climatic niches. Meta-analyses assessed by the **Intergovernmental Panel on Climate Change (IPCC)** show that roughly half of the thousands of land and marine species studied have already **shifted their ranges**.
- **The taiga–tundra shift:** the boreal forest is **advancing northward** into tundra. Warming lengthens its growing season, but **interior drought** raises tree mortality and fuels catastrophic fires, as in Canada in 2023.
- **The mountain squeeze:** montane grasslands and shrublands expand **upward into alpine meadows**, and high-altitude specialists such as the American pika and alpine flora run out of higher ground. Himalayan treelines and alpine plants are moving upslope too.
- **Savanna and forest edges:** repeated drought and fire can push degraded rainforest toward savanna, the feared **Amazon "dieback"**, while CO_2 and fire suppression thicken woody cover in savannas.

Permafrost degradation and Arctic greening

- **Polar amplification** has warmed the Arctic **nearly four times as fast as the global average** since 1979, degrading permafrost widely.
- When permafrost thaws, the ground collapses (**thermokarst**), creating "**drunken forests**" where trees tilt wildly as the soil turns to mud beneath them.
- **Feedback loop:** thawing exposes ancient frozen organic matter to microbes, releasing **carbon dioxide and methane** that accelerate warming; in 2024 the tundra was reported to be a **net carbon source**.
- **Arctic greening:** taller **woody shrubs** colonise the warming soils, permanently altering the tundra's low-growing vegetation; darker shrubs also absorb more sunlight than snow-covered tundra.

Marine biome collapse: coral bleaching

- The marine biome faces the dual threat of **rising ocean temperatures** and **ocean acidification**, caused by seawater absorbing excess carbon dioxide. **Coral reefs** are exceptionally sensitive.
- When water exceeds the local seasonal maximum by even **1–2 °C** for weeks, the bond between **coral polyps** and their symbiotic **zooxanthellae** breaks down; the corals expel the algae, losing their main food source and colour: **coral bleaching**.
  - If the heat persists, corals starve and die, the reef framework collapses, and thousands of associated species, from invertebrates to large fish, lose their habitat.
- The **fourth global bleaching event (2023–2025)** exposed about **84% of the world's reef area** to bleaching-level heat, the most extensive on record.

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Why biomes matter

- Biomes are the **ultimate expression of life's adaptation** to the physical limits of the planet, from rain-soaked equatorial canopies to frozen polar expanses. They **regulate the carbon and water cycles**, purify water and sustain the biodiversity on which society depends.
- **Climate change and land conversion** are breaking these ancient boundaries. Protecting biomes needs climate mitigation together with **large protected landscapes and connected corridors** that give species room to adapt and move.

Previous Year Questions

2026	Explain the vertical zonation of vegetation of the Himalayas.
2017	Describe the characteristics of biological deserts.
2016	Bring out the ecological significance of Tropical Rainforest Biome.
2014	State the uniqueness of the Eurasian Steppe Biome.
2013	Bring out the relationship between climate and vegetation in the Mountain Biome.
2011	Define the term biome. List the terrestrial biomes and describe the characteristics of Savanna biome.
2009	Give a brief account of the principal land biomes and their latitudinal distribution.
1996	Write short note: Man, and the Amazon rainforest.

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23	6	74	435
Chapters	Units	Previous year questions	Pages

IN THE COMPLETE BOOK

01 **Foundations of Biogeography** 3 chapters · from page 6

02 **Soils** 5 chapters · from page 57

03 **Distribution of Plants and Animals** 6 chapters · from page 177

04 **Forests** 2 chapters · from page 300

05 **Wildlife and Gene Pools** 2 chapters · from page 337

06 **Climate Change and Human Impact** 5 chapters · from page 378

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